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Best Available Techniques (BAT) Reference Document for the Production of Pulp, Paper and Board

Industrial Emissions Directive 2010/75/EU
(Integrated Pollution Prevention and Control)

Michael Suhr, Gabriele Klein, Ioanna Kourti, Miguel Rodrigo Gonzalo, Germán Giner Santonja, Serge Roudier, Luis Delgado Sancho

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Abstract

The BAT reference document entitled 'Production of Pulp, Paper and Board' forms part of a series presenting the results of an exchange of information between EU Member States, the industries concerned, non-governmental organisations promoting environmental protection, and the Commission, to draw up, review and, where necessary, update BAT reference documents as required by Article 13(1) of the Directive 2010/75/EU on industrial emissions. This document is published by the European Commission pursuant to Article 13(6) of the Directive. This BREF for the production of pulp, paper and board covers the activities specified in Sections 6.1(a) and 6.1(b) of Annex I to Directive 2010/75/EU, i.e. the integrated and non-integrated production in industrial installations of:

(a) pulp from timber or other fibrous materials;
(b) paper or cardboard with a production capacity exceeding 20 tonnes per day.

In particular, this document covers the following processes and activities:

- chemical pulping:
  (a) kraft (sulphate) pulping process
  (b) sulphite pulping process
- mechanical and chemimechanical pulping
- processing paper for recycling with and without deinking
- papermaking and related processes
- all recovery boilers and lime kilns operated in pulp and paper mills.

Important issues for the implementation of Directive 2010/75/EU in the pulp, paper and board industry are the emissions to air of nitrogen oxides, sulphur oxides, dust, total reduced sulphur and ammonia; emissions to water of organic carbon, suspended solids, nitrogen, phosphorus and adsorbable organically bound halogens. The BREF contains nine chapters. Chapters 1 and 2 provide general information on the pulp, paper and board industry and on the common industrial processes and techniques used within the whole sector. Chapters 3, 4, 5, 6 and 7 correspond to the following specific sectors: kraft (sulphate) pulping process, sulphite pulping process, mechanical and chemimechanical pulping, processing of paper for recycling with and without deinking, and papermaking and related processes. For each sector, these five chapters provide information and data concerning the applied processes and techniques; the environmental performance of installations in terms of current emissions, consumption of raw materials, water and energy, and generation of waste; the techniques to prevent or reduce the environmental impact of installations; and the emerging techniques. In Chapter 8 the BAT conclusions, as defined in Article 3(12) of the Directive, are presented for the pulp, paper and board industry. Chapter 9 is dedicated to concluding remarks and recommendations for future work regarding the sector.

Best Available Techniques (BAT) Reference Document for the Production of Pulp, Paper and Board

Industrial Emissions Directive 2010/75/EU

Integrated Pollution Prevention and control

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This report was produced by the European Integrated Pollution Prevention and Control Bureau (EIPPCB) at the European Commission's Joint Research Centre – Institute for Prospective Technological Studies (IPTS) under the supervision of Serge Roudier (Head of the EIPPCB) and Luis Delgado Sancho (Head of the Sustainable Production and Consumption Unit).

The authors of this BREF were Mr Michael Suhr, Ms Gabriele Klein, Ms Ioanna Kourti, Mr Miguel Rodrigo Gonzalo and Mr Germán Giner Santonja. Mr Michael Parth participated in the reactivation of the Technical Working Group and started the review of the BREF.

This report was drawn up in the framework of the implementation of the Industrial Emissions Directive (2010/75/EU) and is the result of the exchange of information provided for in Article 13 of the Directive.

Major contributors of information were:

- among industry, the Confederation of European Paper Industries (CEPI);
- among environmental NGOs, the European Environmental Bureau (EEB);
- among EU Member States, Austria, Denmark, Finland, France, Germany, Italy, the Netherlands, Poland, Portugal, Spain, Sweden, and the United Kingdom;
- among non-EU EEA Member States, Norway.

The whole EIPPCB team provided contributions and peer reviewing.

This document is one from the series of foreseen documents listed below (at the time of writing not all of the documents have been drafted):

Best Available Techniques Reference Document	**Code**
Ceramic Manufacturing Industry	CER
Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector	CWW
Emissions from Storage	EFS
Energy Efficiency	ENE
Ferrous Metals Processing Industry	FMP
Food, Drink and Milk Industries	FDM
Industrial Cooling Systems	ICS
Intensive Rearing of Poultry and Pigs	IRPP
Iron and Steel Production	IS
Large Combustion Plants	LCP
Large Volume Inorganic Chemicals – Ammonia, Acids and Fertilisers Industries	LVIC-AAF
Large Volume Inorganic Chemicals – Solids and Others industry	LVIC-S
Large Volume Organic Chemical Industry	LVOC
Management of Tailings and Waste-rock in Mining Activities	MTWR
Manufacture of Glass	GLS
Manufacture of Organic Fine Chemicals	OFC
Non-ferrous Metals Industries	NFM
Production of Cement, Lime and Magnesium Oxide	CLM
Production of Chlor-alkali	CAK
Production of Polymers	POL
Production of Pulp, Paper and Board	*PP*
Production of Speciality Inorganic Chemicals	SIC
Refining of Mineral Oil and Gas	REF
Slaughterhouses and Animals By-products Industries	SA
Smitheries and Foundries Industry	SF
Surface Treatment of Metals and Plastics	STM
Surface Treatment Using Organic Solvents	STS
Tanning of Hides and Skins	TAN
Textiles Industry	TXT
Waste Incineration	WI
Waste Treatments Industries	WT
Wood and Wood Products Preservation with Chemicals	WPC
Wood-based Panels Production	WBP
Reference Document	
Economics and Cross-media Effects	ECM
General Principles of Monitoring	MON

Electronic versions of draft and finalised documents are publicly available and can be downloaded from http://eippcb.jrc.ec.europa.eu/.

PREFACE

1. Status of this document

Unless otherwise stated, references to ‘the Directive’ in this document refer to Directive 2010/75/EU of the European Parliament and the Council on industrial emissions (integrated pollution prevention and control) (Recast).

The original best available techniques (BAT) reference document (BREF) on Production of Pulp, Paper and Board was adopted by the European Commission in 2001. This document is the result of a review of that BREF. The review commenced in April 2006.

This BAT reference document for the Production of Pulp, Paper and Board forms part of a series presenting the results of an exchange of information between EU Member States, the industries concerned, non-governmental organisations promoting environmental protection and the Commission, to draw up, review, and where necessary, update BAT reference documents as required by Article 13(1) of the Directive. This document is published by the European Commission pursuant to Article 13(6) of the Directive.

As set out in Article 13(5) of the Directive, the Commission Implementing Decision 2014/687/EU on the BAT conclusions contained in Chapter 8 was adopted on 26 September 2014 and published on 30 September 2014.[1]

2. Participants in the information exchange

As required in Article 13(3) of the Directive, the Commission has established a forum to promote the exchange of information, which is composed of representatives from Member States, the industries concerned and non-governmental organisations promoting environmental protection (Commission Decision of 16 May 2011 establishing a forum for the exchange of information pursuant to Article 13 of the Directive 2010/75/EU on industrial emissions (2011/C 146/03), OJ C 146, 17.05.2011, p. 3).

Forum members have nominated technical experts constituting the technical working group (TWG) that was the main source of information for drafting this document. The work of the TWG was led by the European IPPC Bureau (of the Commission's Joint Research Centre).

3. Structure and contents of this document

Chapter 1, the Sections 2.1 to 2.8 of Chapter 2 and the first sections of Chapters 3 to 7 provide general information on the production of pulp, paper and board and on the industrial processes used within this sector.

The second sections of Chapters 3 to 7 and Section 2.6.2 provide data and information concerning the environmental performance of installations within the sector, and in operation at the time of writing, in terms of current emissions, consumption and nature of raw materials, water consumption, use of energy and the generation of waste.

Section 2.9 and the third sections of Chapters 3 to 7 describe in more detail the techniques to prevent or, where this is not practicable, to reduce the environmental impact of installations in this sector that were considered in determining the BAT. This information includes, where relevant, the environmental performance levels (e.g. emission and consumption levels) that can be achieved by using the techniques, the associated monitoring and the costs and the cross-media issues associated with the techniques.

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[1] OJ L 284, 30.9.2014, p. 76.

Chapter 8 presents the BAT conclusions as defined in Article 3(12) of the Directive.

The fourth sections of Chapters 3 to 7 present information on 'emerging techniques' as defined in Article 3(14) of the Directive.

Concluding remarks and recommendations for future work are presented in Chapter 9.

4. Information sources and the derivation of BAT

This document is based on information collected from a number of sources, in particular through the TWG that was established specifically for the exchange of information under Article 13 of the Directive. The information has been collated and assessed by the European IPPC Bureau (of the Commission's Joint Research Centre) who led the work on determining BAT, guided by the principles of technical expertise, transparency and neutrality. The work of the TWG and all other contributors is gratefully acknowledged.

The BAT conclusions have been established through an iterative process involving the following steps:

- identification of the key environmental issues for the sector (e.g. emissions to water, especially organic load, total suspended solids, etc.; emissions to air from recovery boilers, lime kilns or combustion plants for the production of steam and power; odour and noise nuisance);
- examination of the techniques most relevant to address these key issues;
- identification of the best environmental performance levels, on the basis of the available data in the European Union and worldwide;
- examination of the conditions under which these environmental performance levels were achieved, such as costs, cross-media effects, and the main driving forces involved in the implementation of the techniques;
- selection of the best available techniques (BAT), their associated emission levels (and other environmental performance levels) and the associated monitoring for this sector according to Article 3(10) of, and Annex III to, the Directive.

Expert judgement by the European IPPC Bureau and the TWG has played a key role in each of these steps and the way in which the information is presented here.

Where available, economic data have been given together with the descriptions of the techniques presented in Chapters 3, 4, 5, 6 and 7. These data give a rough indication of the magnitude of the costs and benefits. However, the actual costs and benefits of applying a technique may depend strongly on the specific situation of the installation concerned, which cannot be evaluated fully in this document. In the absence of data concerning costs, conclusions on the economic viability of techniques are drawn from observations on existing installations.

5. Review of BAT reference documents (BREFs)

BAT is a dynamic concept and so the review of BREFs is a continuing process. For example, new measures and techniques may emerge, science and technologies are continuously developing and new or emerging processes are being successfully introduced into the industries. In order to reflect such changes and their consequences for BAT, this document will be periodically reviewed and, if necessary, updated accordingly.

6. Contact information

All comments and suggestions should be made to the European IPPC Bureau at the Institute for Prospective Technological Studies at the following address:

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SCOPE

This BREF concern the activities specified in Sections 6.1.(a) and 6.1.(b) of Annex I to Directive 2010/75/EU, i.e. the integrated and non-integrated production in industrial installations of:

(a) pulp from timber or other fibrous materials;
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In particular, this document covers the following processes and activities:

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  - sulphite pulping process
- mechanical and chemimechanical pulping
- processing of paper for recycling with and without deinking
- papermaking and related processes
- all recovery boilers and lime kilns operated in pulp and paper mills

On-site combustion plants for steam and power generation with a rated thermal input between 5 MW_{th} and 50 MW_{th} are covered in this document. All recovery boilers, without restriction of capacity, and lime kilns in pulp and paper mills are covered.

This document does not address the following activities:

- production of pulp from non-wood fibrous raw material (e.g. yearly plant pulp);
- stationary internal combustion engines;
- combustion plants other than recovery boilers of less than 5 MW_{th} rated thermal input;
- dryers with internal burners for paper machines and coaters.

Other reference documents, which are relevant for the sector covered in this document, are the following:

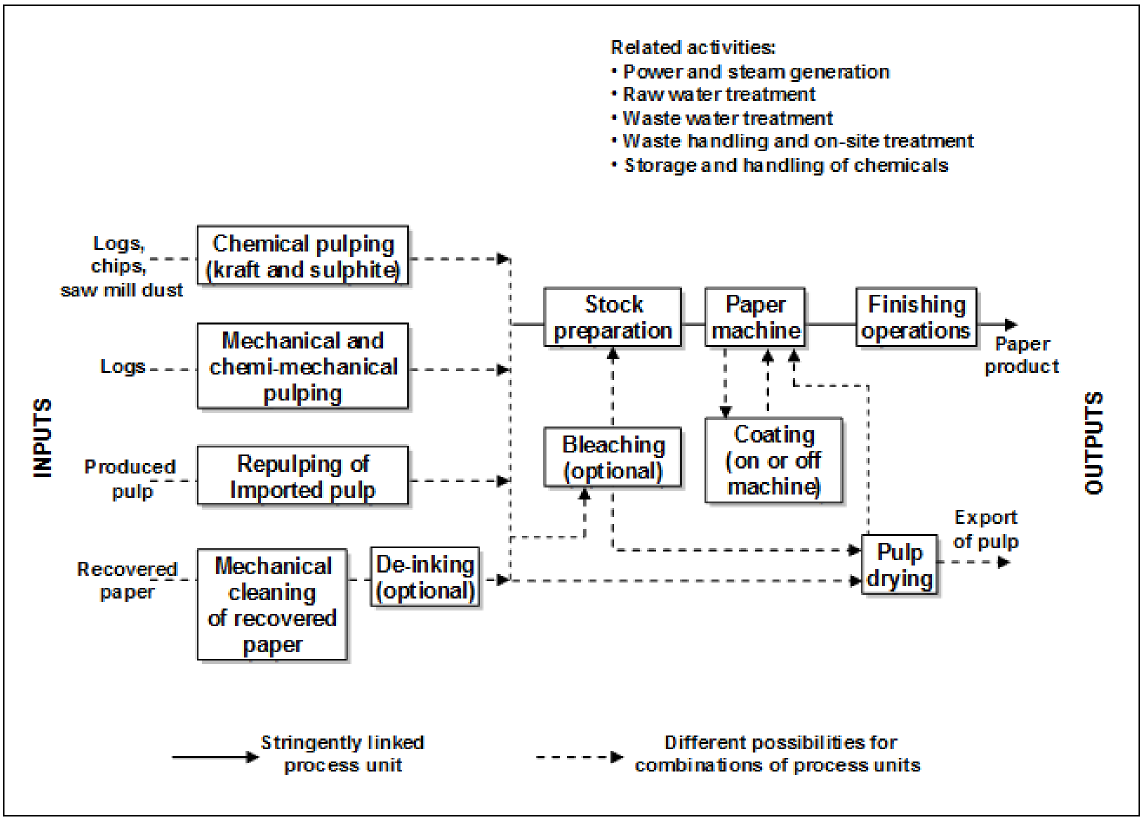
Reference document	Subject
Industrial Cooling Systems (ICS)	Industrial cooling systems, e.g. cooling towers, plate heat exchangers
Economics and Cross-Media Effects (ECM)	Economics and cross-media effects of techniques
Emissions from Storage (EFS)	Emissions from tanks, pipework and stored chemicals
Energy Efficiency (ENE)	General energy efficiency
Large Combustion Plants (LCP)	Generation of steam and electricity in pulp and paper mills by combustion plants with a rated thermal input of ≥50 MWth
General Principles of Monitoring (MON)	Emissions monitoring
Waste Incineration (WI)	On-site incineration and co-incineration of waste
Waste Treatments Industries (WT)	Preparation of waste as fuels

The scope of this BREF does not include matters that only concern safety in the workplace or the safety of products because these matters are not covered by the Directive. They are discussed only where they affect matters within the scope of the Directive.

A paper mill may simply reconstitute pulp made elsewhere or may be integrated with the pulping operations on the same site. That is to say, the activities involved in pulping and processing paper for recycling and those involved in papermaking may be undertaken separately or in combination on the same site. Both pulp mills and paper mills are operated in non-integrated and integrated ways. Mechanical pulping and recycled fibre processing is usually an integrated part of papermaking, but has now also become a stand-alone activity.

This document covers the processes involved in the production of pulp and paper in integrated pulp and paper mills as well as for non-integrated pulp mills (market pulp) and non-integrated paper mills using purchased pulp for paper production.

The main operations covered in this document are illustrated in the figure below.



Upstream processes such as forestry management, production of process chemicals off site and transport of materials used, and downstream activities, e.g. paper converting and printing, are not included in this document. The latter, nevertheless, have an influence on the quality of the paper for recycling and the processes for preparation of used paper products.

There are also a number of environmentally relevant processes and operations which do not specifically relate to the pulp and paper production and so will only be mentioned briefly in this document. These include:

- storage and handling of chemicals
- raw water treatment
- cooling and vacuum systems
- monitoring of emissions.

Production of pulp from non-wood fibrous raw material (e.g. annual plant pulp) is not included, as it is too specific. These installations should be assessed on a case-by-case basis.

1 GENERAL INFORMATION

1.1 Paper consumption in Europe

In developed societies the use of a multitude of paper- and board-based products is an everyday reality for most people. Paper as we know it has been in existence for over two thousand years, and is competing successfully with modern electronic information media, advanced plastic and composite packaging materials. Table 1.1 shows the main functional uses of paper and board.

Table 1.1: Functional uses of paper and board

Functional use	Typical grade	Typical end products	Trends and remarks
To store, collect and distribute information	• Newsprint • Coated and uncoated magazine (SC and LWC paper) • Coated and uncoated wood-free printing and writing	• Newspapers • Journals • Books • Computer printouts • Xerographic copies • Inserts • Illustrations	• Increased use of multicolour printing and copying • Increased recycling as raw material • Increased use of additives
To package for transportation, distribution and protection	• Liner • Sack • Corrugating medium • Folding boxboard • Liquid packaging board • Wrapping	• Bags • Boxes • Wrappings • Containers • Bag-in-bag boxes	• Increased use for distribution of food and liquids • Increasing demand for paper packaging because of online purchasing • General and increased recycling of packaging materials • Increased use of composites
Hygienic uses for: • personal care • cleanliness • disease prevention	Tissue: • dry crepe • wet crepe	• Toilet tissue • Kitchen rolls • Facial tissue • Napkins • Hand towels • Hospital clothing • Wipes	• Use increases with general standard of living • End of the paper chain, i.e. generally non-recyclable • Use of virgin fibre for top-end products
A great variety of uses for speciality paper	• Official papers • Filter paper • Fire-resistant papers	• Notes • Stamps • Air filters • Coffee filters • Baking paper	An ever increasing number of new applications

Source: [1, Finnish BAT Report 1997], modified by EIPPCB.

Further trends not shown above include the following: that more and more functions in many products are combined, such as printing on packages and towels; some packaging grades have seen their grammage decreasing to meet customers' demands (light-weight packaging or corrugated board); some work is being carried out to improve the recyclability of paper, for instance there are working groups on inks and other materials used in printing or paper converting that may have a negative impact on the recyclability of the paper.

The consumption of paper and board is strongly related to standards of living and the economic situation of the user populations and, in the long term, there is a strong correlation between the increase in the consumption of these products and the growth in the gross national product (GNP).

Table 1.2 shows the paper consumption per capita and the total paper consumption by country (calculated values).

Table 1.2: Consumption of paper per capita and by country in 2008

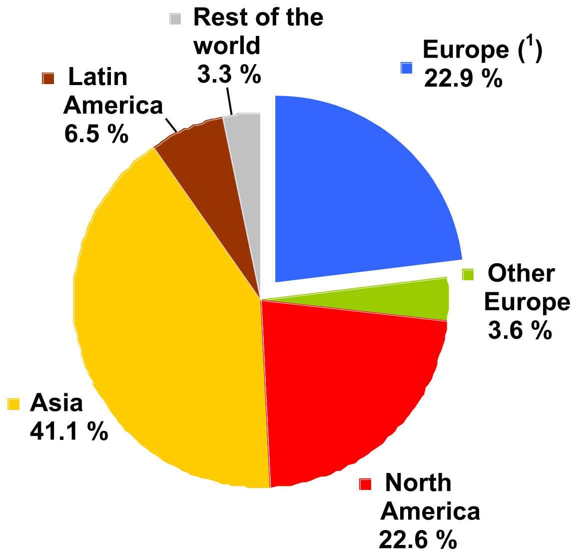
EU Member States	Consumption (1) per capita (in kg)		Consumption (1) by country (in 1 000 t)		Population (in million)	
	1995	**2008**	**1995**	**2008**	**1995**	**2008**
Austria	185	257	1 468	2 140	7.9	8.3
Belgium	256	346	2 589	3 691	10.1	10.7
Bulgaria	30	49	249	376	8.4	7.6
Cyprus	NA	137	NA	108	0.6	0.8
Czech Republic	67	149	693	1 549	10.3	10.4
Denmark	217	225	1 134	1 234	5.2	5.5
Estonia	35	109	50	146	1.4	1.3
Finland	256	291	1 303	1 540	5.1	5.3
France	162	179	9 629	11 462	59.3	64.0
Germany	206	286	16 815	23 525	81.5	82.2
Greece	85	107	902	1 199	10.6	11.2
Hungary	49	90	508	906	10.3	10.0
Ireland	99	113	357	496	3.6	4.4
Italy	160	187	9 108	11 126	56.8	59.6
Latvia	28	83	71	188	2.5	2.3
Lithuania	20	61	74	206	3.6	3.4
Luxembourg	NA	NA	NA	245	0.4	0.5
Malta	70	88	26	36	0.4	0.4
Netherlands	202	246	3 121	4 040	15.4	16.4
Poland	40	115	1 551	4 364	38.6	38.1
Portugal	80	108	803	1 147	10.0	10.6
Romania	15	31	345	663	22.7	21.5
Slovakia	61	93	325	503	5.4	5.4
Slovenia	121	171	240	344	2.0	2.0
Spain	131	160	5 151	7 267	39.3	45.3
Sweden	208	228	1 831	2 089	8.8	9.2
United Kingdom	197	186	11 398	11 401	57.9	61.2
Non-EU Countries						
Norway	174	168	758	794	4.3	4.7
Switzerland	218	218	1 528	1 656	7.0	7.6
USA	332	266	87 409	87 687	263	307
China	22	59	26 499	79 130	1 205	1 339
Indonesia	14	25	2 641	5 916	189	240
Japan	239	242	30 018	30 694	126	127
Brazil	35	45	5 433	8 871	155	199
Egypt	9	21	606	1 751	67	83
Total world	**49**	**58**	**276 231**	**391 325**	**5 637**	**6 772**

(1) Consumption = production + import – export

NB: Where figures are not available 'NA' is indicated.

Source: RISI 2009, [2, CEPI 2009].

The average world consumption per capita in 2008 was 58 kg/capita and totalled around 391.3 million tonnes of paper. The distribution of the paper consumption in the main world regions is shown in Figure 1.1 (data for 'Europe' are reported for the 18 CEPI-associated countries and the 'rest of Europe' separately). Europe consumes around one fourth of the paper in the world.



[1] CEPI associated countries = AT, BE, CH, CZ, DE, ES, FI, FR, HU, IT, NL, NO, PL, PT, RO, SE, SK, UK.

Source: RISI 2009, [2, CEPI 2009]

Figure 1.1: Paper consumption by region in 2007

1.2 Overview of pulp, paper and board manufacturing

The pulp and paper industry supplies an essential product – paper – to over 5 billion people worldwide. Originally, papermaking was a slow and labour-intensive process. Nowadays pulping and papermaking are driven by capital-intensive technical equipment and high-tech and high-speed paper machines that produce rolls of paper at a speed that may reach 2 000 m/min. and with a web width that may exceed eight metres.

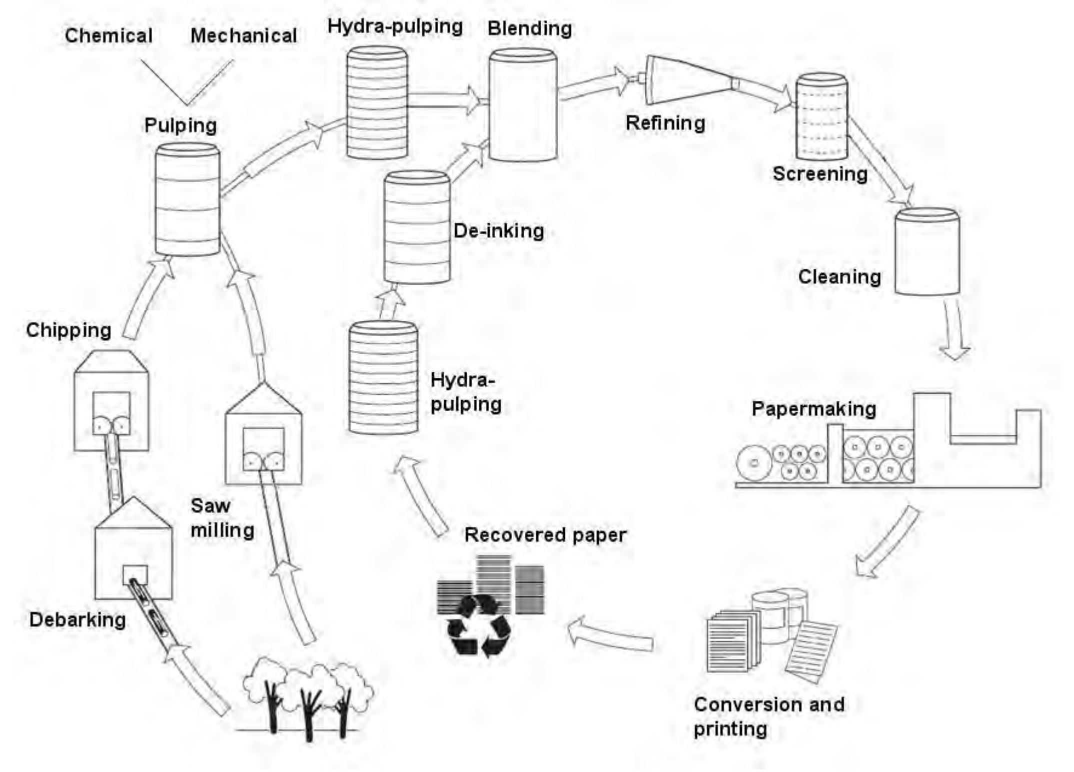
Paper is essentially a sheet of cellulose fibres with a number of added constituents, when necessary, to affect the quality of the sheet and its fitness for the intended end use.

The two terms paper and board (point 6.1 b, Annex I to Directive 2010/75/EU on Industrial Emissions (IED) generally refer to the weight of the product sheet (grammage) with paper ranging up to about 160 – 220 g/m^2 and a heavier sheet regarded as board (cartonboard). The grammage above which papers are called board however varies slightly between countries.

The harmonised list for paper and board grades [3, CEPI 2007] makes no reference to the grammage but defines cartonboard as papers and board mainly used in the manufacture of solid cartons. Cartonboards are multi-layered, usually consisting of three or more layers (plies). Cartonboard is also known as solid board, folding boxboard, boxboard or carrier board.

The official definition of the ISO 4046 (2002), 'Paper, board, pulps and related terms', coincides mainly with the definition of the CEPI list: in the generic sense, the term 'paper' may be used to describe both paper and board. The primary distinction between paper and board is normally based upon thickness or grammage, though in some instances the distinction will be based on the characteristics and/or end use. For example, some materials of lower grammage, such as certain grades of folding boxboard and corrugating raw materials, are generally referred to as 'board', while other materials of higher grammage, such as certain grades of blotting paper, felt paper and drawing paper, are generally referred to as 'paper'.

The pulp for papermaking may be produced from virgin fibre by chemical or mechanical means or may be produced by the repulping of paper for recycling (RCF). In Europe, wood is the main original raw material – paper for recycling accounts for about 50 % of the fibres used – but in a few cases straw, hemp, grass, cotton and other cellulose-bearing material can be used. Figure 1.2 shows an overview of the pulping and papermaking process.



Source: CEPI

Figure 1.2: **The papermaking process**

In the papermaking process, wood logs are first debarked and chipped into small pieces. Then water and heat are added, and by mechanical or chemical means, the wood is separated into individual fibres (pulping). After screening, cleaning and sometimes refining, the fibres are mixed with water. Then this pulp slurry is sprayed onto a flat wire screen which moves very quickly through the paper machine. Water drains out, and the fibres bond together. The web of paper is pressed between rolls which squeeze out more water and press it to make a smooth surface. Heated cylinders then dry the paper, and the paper is slit into smaller rolls, and sometimes into sheets.

The precise composition of wood varies according to the type and species but the most important constituents are cellulose, hemicellulose and lignin. Wood naturally contains around 50 % water and the solid fraction is typically about 45 % cellulose, 25 % hemicelluloses and 25 % lignin and 5 % other organic and inorganic materials. In chemical pulping, chemicals are used to dissolve the lignin and free the fibres.

The lignin and many other organic substances are thus put into a solution from which the chemicals and the energy content of the lignin and other organics are recovered. The extent of this recovery is dependent upon the chemical base used and the process configuration. In mechanical pulping processes, mechanical shear forces are used to pull the fibres apart and the majority of the lignin remains with the fibres although there is still dissolution of some organics.

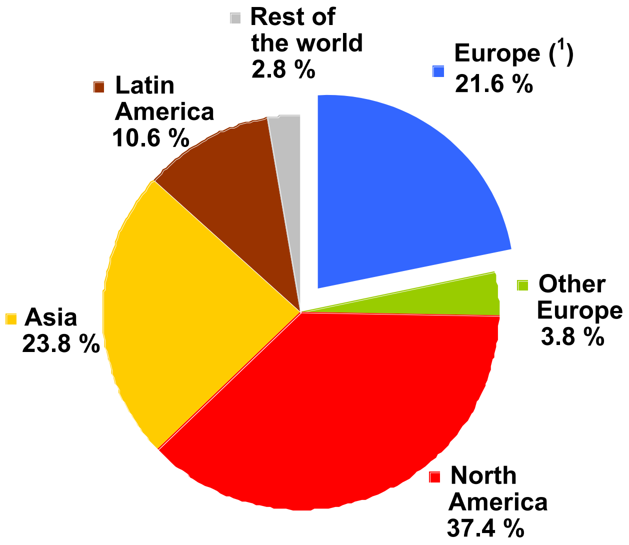
Pulps produced in different ways have different properties, which make them suitable for particular products. Most pulp is produced for the purpose of subsequent manufacture of paper or paperboard. Some is destined for other uses such as thick fibreboard or textile products manufactured from dissolved cellulose (see Section 4.1.1.3).

In Europe, more than 50 % of the fibres from the paper industry come from paper for recycling. Paper produced by the use of paper for recycling as the fibre source involves some cleaning of contaminants prior to use and may involve deinking depending upon the quality of material recycled and the requirements of the end product of the recycling process. The fibres can be reused a number of times depending on the quality of the recycled material and the purpose of the end product. The paper product may also comprise up to 45 % of its weight in fillers, coatings and other non-fibrous substances. Collection and sorting are essential steps, which determine to a great extent the quality of the paper for recycling. Separate collection contributes to high levels of recycling.

There are many different paper grades manufactured by the European papermaking industry. For a reasonable application of the BAT concept, they can be categorised into different groups (see Section 1.5).

1.3 The European pulp industry

Europe plays an important role in the global pulp and paper industry. As shown in Figure 1.3 (data for 'Europe' were only reported for the 18 CEPI-associated countries), it is the second largest producer and the third largest consumer of paper and board, North America being the leader, and Asia being very close to Europe. Its role in pulp production is significant – the annual production of wood pulp in Europe is about 41.8 million tonnes/year, the amount produced representing about 22 % of the world's total pulp production of 192.4 million tonnes.



(1) CEPI associated countries = AT, BE, CH, CZ, DE, ES, FI, FR, HU, IT, NL, NO, PL, PT, RO, SE, SK, UK.

Source: RISI 2009, [2, CEPI 2009]

Figure 1.3: Pulp production by region in 2008

Most of the pulpwood (round wood and chips) used for pulping in Europe is supplied by using domestic resources: in 2008, 79 % or 88.1 million tonnes of pulpwood were supplied from domestic sources and the remaining 21 % or 23.6 million tonnes were imported to European pulp mills that used in total 111.7 million tonnes of pulpwood (*Source*: Eurostat, CEPI).

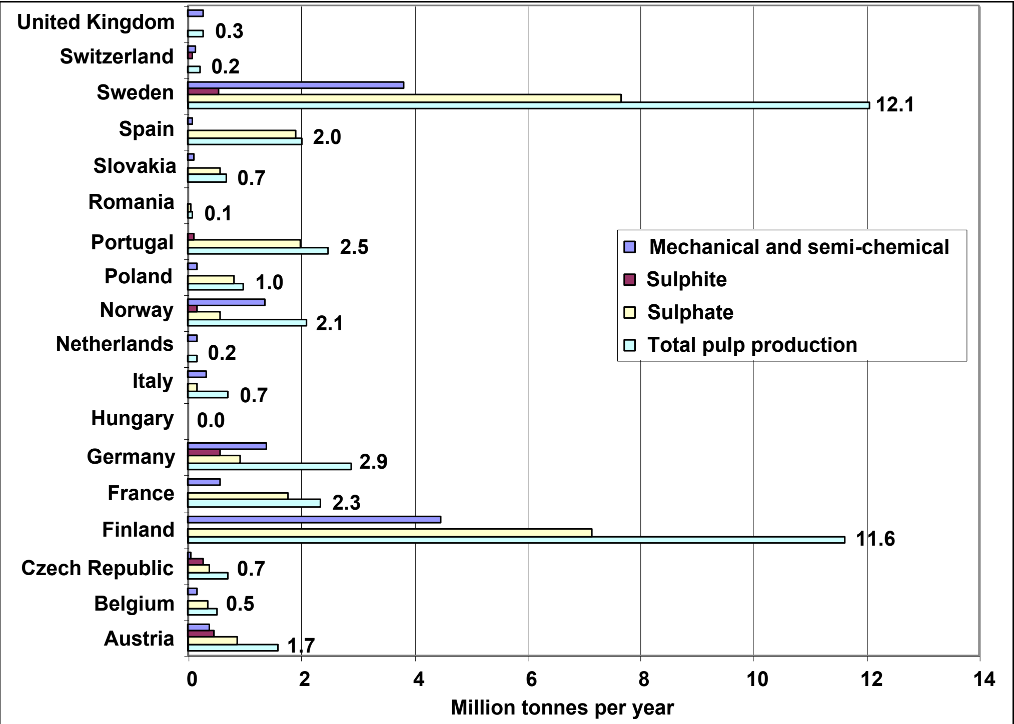
The pulp supply consists of market pulp producers and of companies using the bulk of their pulp output in their own integrated paper production and selling only the remaining part on the open market. In Europe, market pulp is mainly produced by mills in Finland, Sweden, France, Portugal, Spain, Austria, Germany, and Poland. With respect to market pulp, bleached kraft is the dominating grade making up more than three quarters of the whole market pulp production of 13.3 million tonnes. Of that, only 1 million tonnes of sulphite pulp (including dissolving pulp and speciality pulp for chemical applications), and 0.9 million tonnes of mechanical (stone groundwood, TMP) and semi-chemical pulp were delivered to the open paper market.

Finland and Sweden are major producers of softwood and hardwood pulps, with Portugal and Spain also providing significant amounts of hardwood pulp grades to the market. More than 50 % of the sulphate pulp and sulphite pulp manufactured in Europe is used in integrated pulp and paper mills. Table 1.3 shows the total production of the major types of pulps manufactured in Europe and the share of integrated production and market pulp within each pulp grade (data for 2008).

Table 1.3: Total production in 2008 for the major types of pulps manufactured in Europe (CEPI area) and the share of integrated production/market pulp

Types of pulp	Total production (million tonnes)	Integrated (million t/yr)	Integrated (%)	Market pulp (million t/yr)	Market pulp (%)
Mechanical & semi-chemical pulp	13.6	12.17	93.6 %	0.87	6.4 %
• Sulphite	2.2	1.07	53.5 %	1.02	46.5 %
• Sulphate	25.2	13.76	54.6 %	11.4	45.4 %
Total chemical pulp	27.4	14.93	54.5 %	12.47	45.5 %
Total wood pulp for papermaking	40.9	27.61	67.5 %	13.3	32.5 %
Other pulp	0.6	0.55	92.2 %	0.05	7.8 %
Total pulp	41.6	28.21	67.8 %	13.4	32.2 %

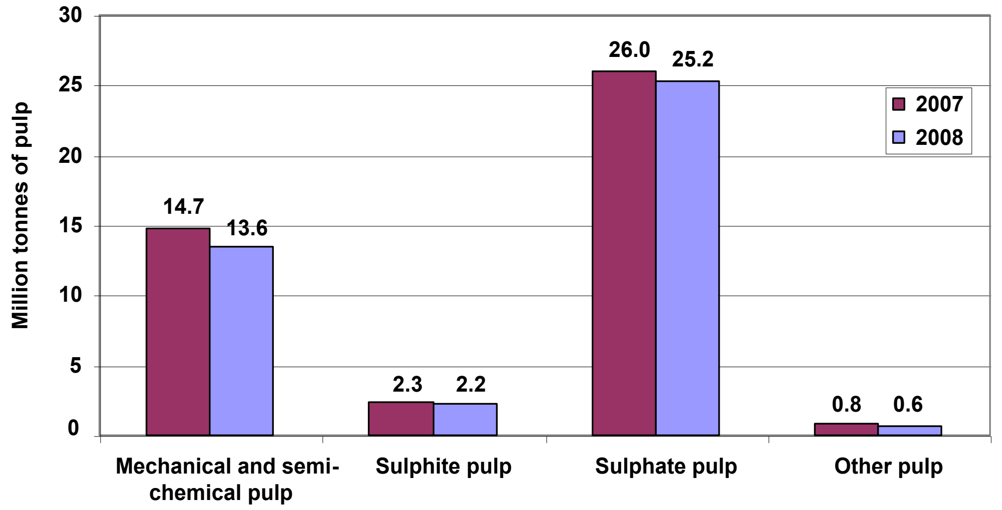
In 2008, some 23.7 million tonnes/year of pulp were produced in Finland and Sweden (together 57 % of the total pulp production of 41.9 million tonnes), whereas Portugal, Spain, Austria, Germany, Norway and France together produced approximately 13.8 million tonnes (33 % of the total production). The four biggest markets for market pulp are Italy, Germany, France and the United Kingdom. Figure 1.4 shows the total pulp production in Europe in 2008 for the three major grades. The total wood pulp production per country is also given. Rounded data in Figure 1.4 and Figure 1.5 cover more than 95 % of production in Europe.



Source: [2, CEPI 2009]

Figure 1.4: Total pulp production by grade in Europe in 2008 (CEPI-associated countries)

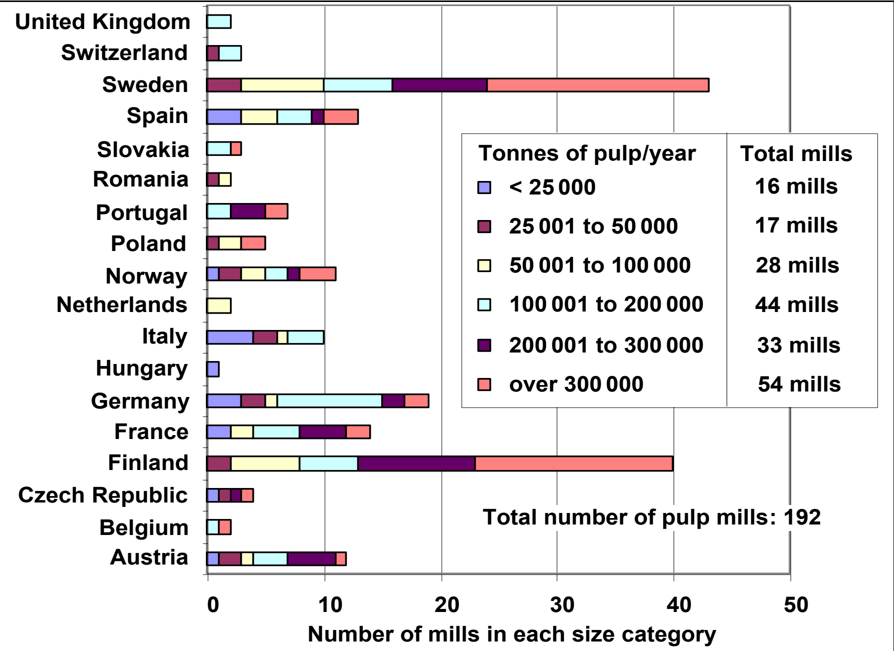
The main grades of wood pulp for papermaking in 2008 across Europe were sulphate pulp (60 % of total pulp production), followed by mechanical and semi-chemical pulp (32 % of total pulp production) and sulphite pulp (5 % of total pulp production). Figure 1.5 shows pulp production data for the major pulp grades across Europe in 2007 and 2008.



Source: [2, CEPI 2009]

Figure 1.5: **Pulp production by grade in Europe (CEPI-associated countries)**

Figure 1.6 shows the geographical distribution of the pulp mills in Europe. The total number of pulp mills includes all mills, including the ones which are not shown in the bar graph.



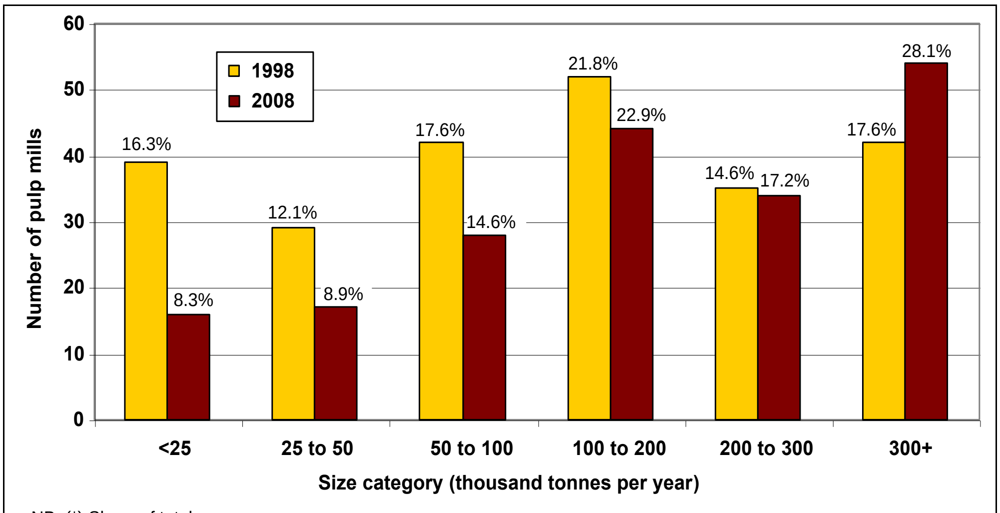
Source: [2, CEPI 2009]

Figure 1.6: **Geographical and size distribution across Europe for pulp mills**

The total number of pulp mills (all grades) in Europe is 192. Relating to pulp grades, most sulphate production (a total of 77 mills) is located in Sweden (21) and Finland (17) with Spain (9), France (8), Portugal (6), Poland (3) and Austria (3) making up the balance. Most sulphite production (a total of 16 mills) is located in Sweden (4), Germany (4) and Austria (3) and with single mills in five other countries.

In Europe, there are 72 mills producing mechanical pulp. They are located mainly in Finland (20), Germany (14), Sweden (9), Norway (7), France (6), Italy (4) and Austria (4). The main producers of semi-chemical pulp (a total of 18 mills) are Sweden (7), Finland (3), Italy (2) and the Netherlands (2) with single mills operating in some other countries.

Sweden and Finland have most of the larger mills with over 300 000 tonnes/year capacity and only a few small mills with a size of less than 25 000 tonnes/year. Figure 1.7 shows the number of pulp mills by volume for the years 1998 and 2008 (note: figures for some countries have been estimated by CEPI). During the ten years, at an average of 1.4 % annual increase in pulp production, the number of pulp mills decreased from 249 to 192. At the same time, the average capacity of the pulp mills in Europe increased from 165 100 tonnes/year in the year 1998 to 239 000 in the year 2008.

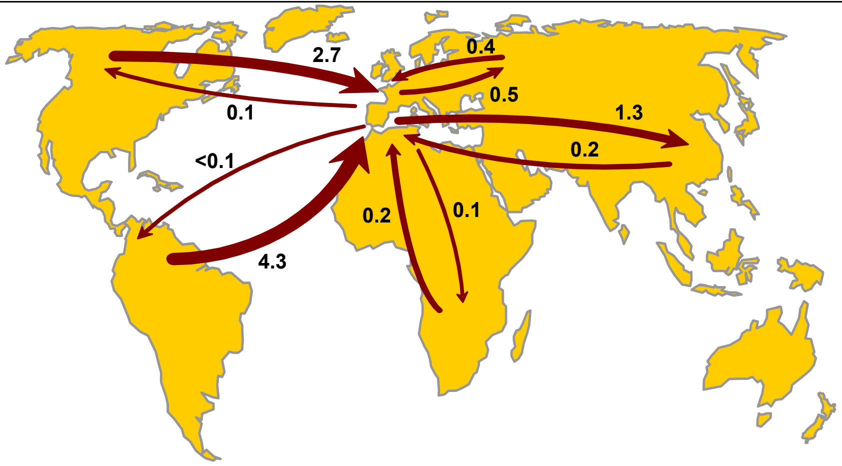


NB: (*) Share of total

Source: [2, CEPI 2009]

Figure 1.7: **Number of pulp mills by volume in Europe in 1998 and 2008 (CEPI-associated European countries)**

With regard to international trade, Figure 1.8 shows the export and import flows of pulp outside the European Union. In 2008 around 2.1 million tonnes of pulp were exported and 7.8 million tonnes were imported, i.e. Europe had a negative pulp trade balance with other regions accounting for 5.7 million tonnes of pulp. The main export region was Asia; major countries from which pulp was imported are North and South America. Between 2000 and 2008, there is a slight trend in increased export of pulp and decreased import of pulp.

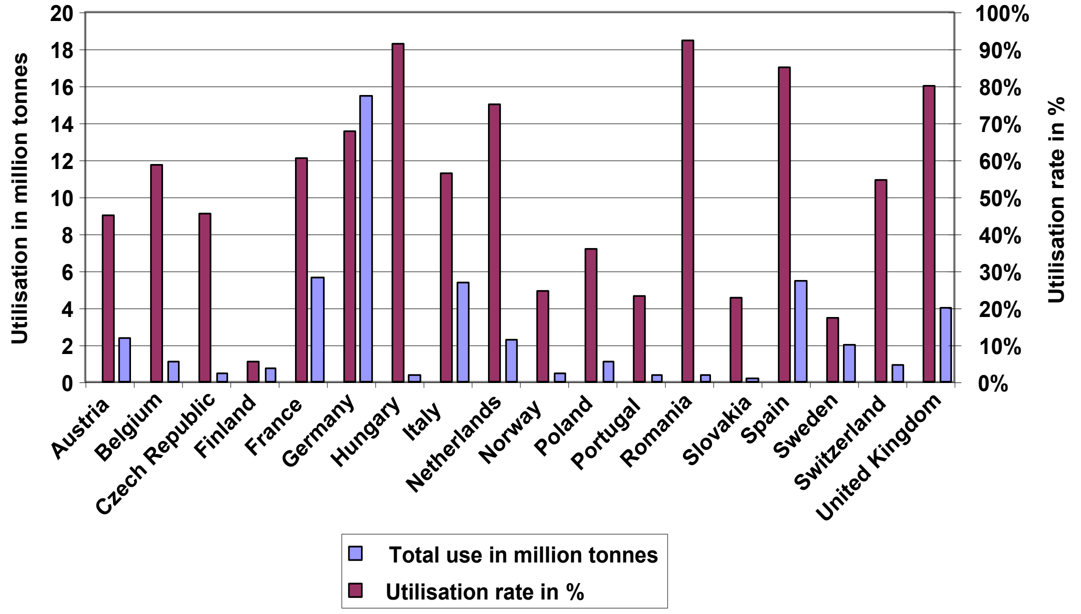


Million tonnes of pulp

Source: [2, CEPI 2009]

Figure 1.8: **Trade flows of pulp to and from CEPI-associated European countries in 2008**

Besides virgin fibres, in 2008 the European paper industry used 48.6 million tonnes of paper for recycling, the same quantity as the total consumption of virgin pulp (48.5 million tonnes/year). These data include the CEPI area only; the contribution of the nine EU non-CEPI countries is limited: 1.3 million tonnes of paper for recycling, i.e. 2.7 % of the CEPI total (*Source*: RISI). The utilisation rate of recycled fibre (the total paper for recycling divided by the total paper and board production) is large in countries with a high population density and a high per capita consumption of paper, such as Hungary, Germany, France, Spain, Netherlands, Italy or United Kingdom as shown in Figure 1.9. About two thirds of the paper for recycling is used for non-deinking purposes (30 million tonnes) and about one third (18 million tonnes) is used for deinked paper grades like newsprint, other graphic papers and hygienic papers.

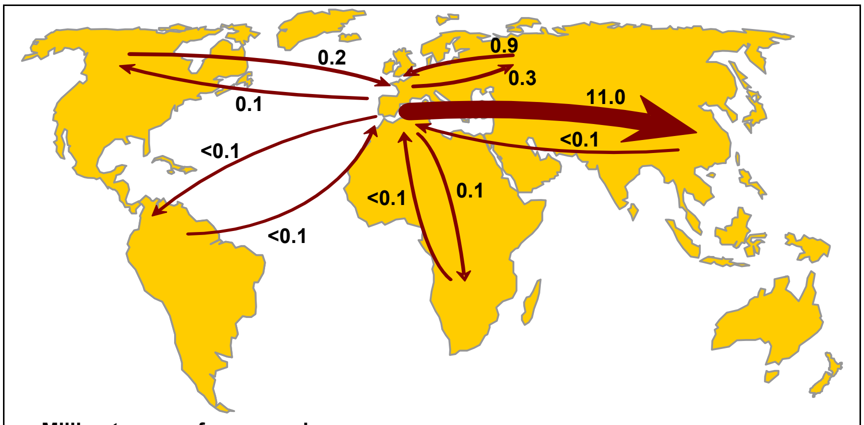


Source: [2, CEPI 2009]

Figure 1.9: Utilisation of paper for recycling of 18 CEPI-associated countries in 2008

In 2008, the average paper for recycling utilisation rate in CEPI-associated countries was 49.1 %. This rate varies between the different paper and board grades, e.g. for newsprint, the paper for recycling utilisation rate is 91.0 %, for graphic papers other than newsprint (higher grades) only 10.3 %, for case materials 91.2 %, for cartonboards 40.7 % and for household and sanitary use 50.1 % [2, CEPI 2009].

Since the year 2000, the demand for paper for recycling has increased, especially in the Asian market. In 2008, 11.0 million tonnes of paper for recycling were exported to Asia (7.9 million tonnes to China, multiplied by four over the last 10 years), the major importing market for paper for recycling. Figure 1.10 shows the trade flows of paper for recycling to and from Europe in 2008.



Million tonnes of recovered paper

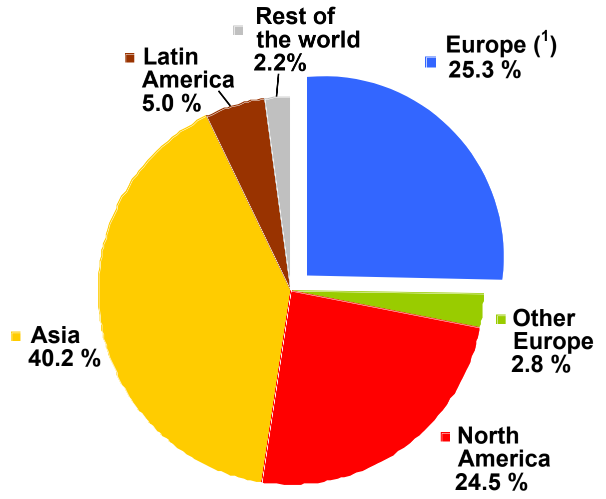
Source: [2, CEPI 2009]

Figure 1.10: Trade flows of paper for recycling to and from Europe in 2008

Paper for recycling has become a global commodity and shortages may occur in the future resulting in increased prices for this important fibre source.

1.4 The European paper industry

In 2008, paper and board production worldwide was 390.9 million tonnes [2, CEPI 2009], the major producers being Asia, North America and Europe (data for 'Europe' were only reported for the 18 CEPI-associated countries). Figure 1.11 shows the production of paper by region in a global context in 2008.



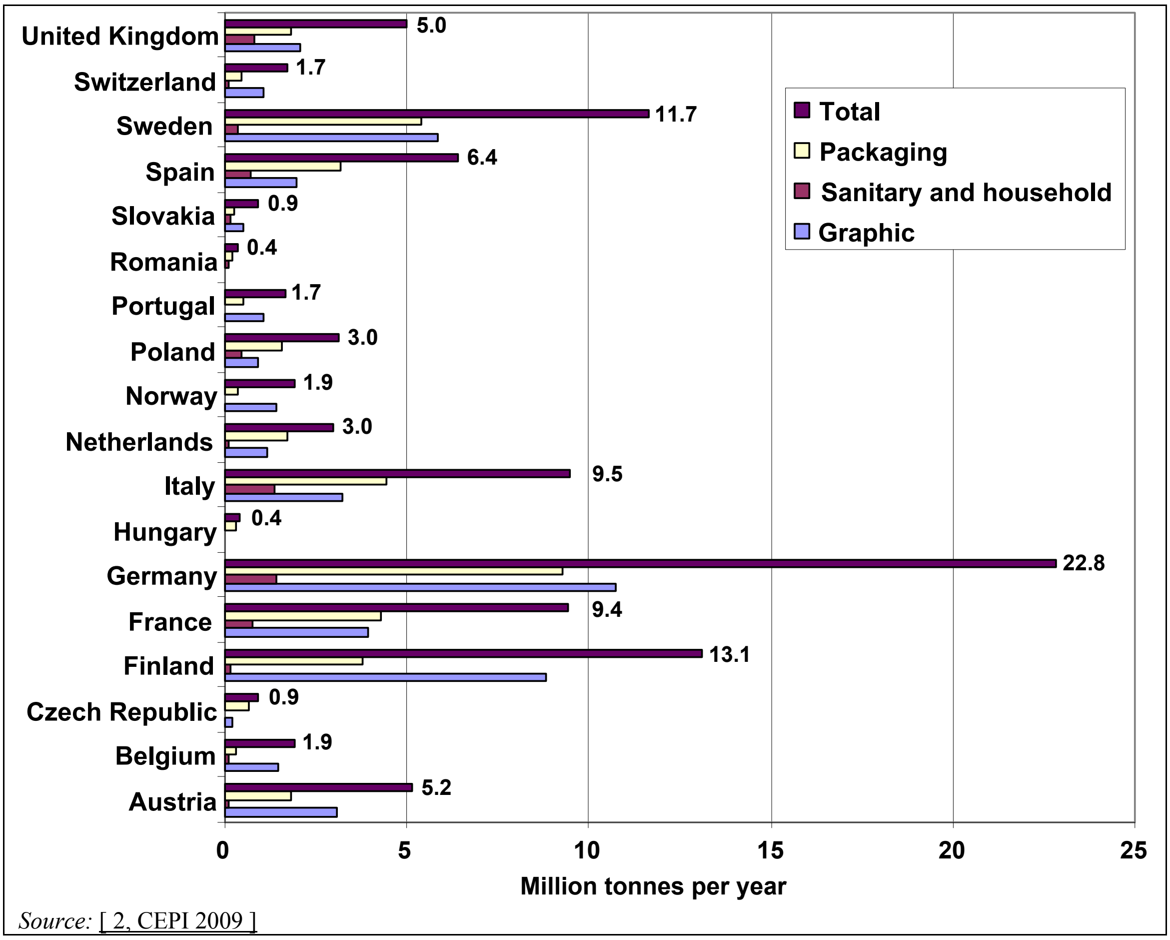
(1) CEPI associated countries = AT, BE, CH, CZ, DE, ES, FI, FR, HU, IT, NL, NO, PL, PT, RO, SE, SK, UK.
Source: RISI 2009, [2, CEPI 2009]

Figure 1.11: Paper production by region in the global context in 2008

In the EU-27, the production of paper and paperboard totalled 98.9 million tonnes in 2008. Since the mid-1990s, the production of the European paper industry has increased at an average yearly pace of 2 – 3 %.

In the year 2008, 48.0 % of total paper production was graphic paper. The biggest groups within this grade, each with around 10 million tonnes per year, are newsprint, coated mechanical graphic paper, and uncoated and coated wood-free graphic paper. A total of 40.7 % was packaging paper and 6.8 % was household and sanitary products, and 4.5 % was other paper products. Of the 47.5 million tonnes of graphic paper production (CEPI area), less than half was coated (19.5 million tonnes/yr).

Section 1.3 shows how paper manufacturing is more widespread across Europe than pulp production. Figure 1.12 distinguishes between graphic papers (newsprint, uncoated mechanical, uncoated wood-free, coated mechanical and wood-free papers), sanitary and household papers (tissue and other hygienic papers) and packaging papers (case materials, folding boxboard, wrapping up to 150 g/m^2 and other papers mainly for packaging).



Source: [2, CEPI 2009]

Figure 1.12: An overview of the distribution of the paper manufacturing industry across Europe for 18 CEPI-associated countries (2008)

In Europe in 2008, the eight leading paper- and board-producing countries were Germany (22.8 %), Finland (13.1 %), Sweden (11.7 %), Italy (9.5 %), France (9.4 %), Spain (6.4 %), Austria (5.2 %) and the UK (5.0 %).

Distinguishing the major grades, the main paper producers of graphic papers were Germany (22.5 %), Finland (18.6 %), Sweden (12.3 %), France (8.3 %), Italy (6.8 %), Austria (6.5 %) and the UK (4.3 %).

Within this grade, newsprint production has traditionally been concentrated in Finland and Sweden. The increased use of recycled fibres by many European producers has caused the location of industry to shift to the large consumer centres, such as Germany, France, the UK and Spain. Due to the nature of newsprint as a commodity paper grade, production units mostly have a relatively large paper machine capacity (about 300 000 tonnes/year on average for a machine).

Printing and writing papers containing wood are mainly produced in Finland and Germany, which together account for approximately a 60 % share of total production. Wood-containing papers are supplied by large-scale integrated mills (250 000 tonnes/year on average for a machine, but one can find bigger or smaller mills and machines).

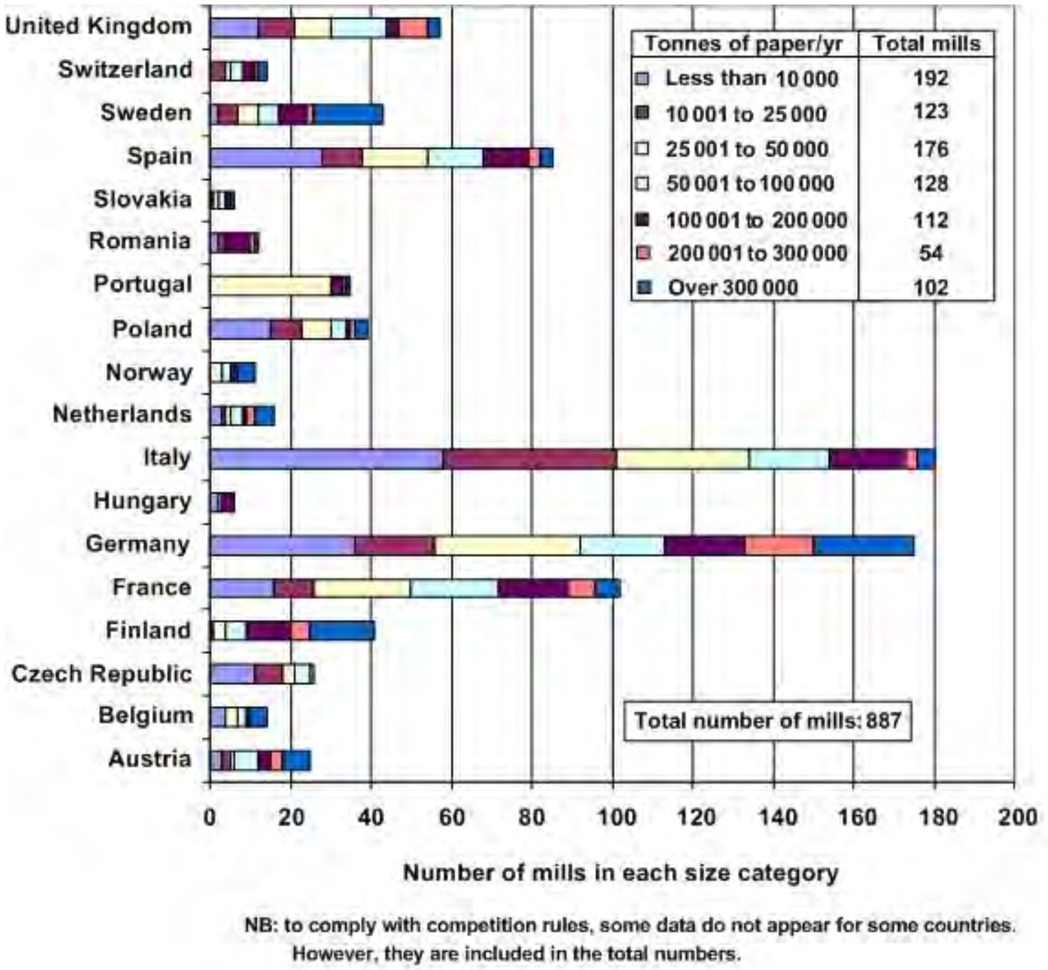
In the manufacturing of wood-free printing and writing papers, Germany, France, Finland, Italy, Sweden, and Austria play the leading role, with a remarkable amount of paper produced in most other European countries. The majority of the market consists of a small number of concentrated producers (150 000 tonnes/year on average for a machine, but one can find bigger or smaller mills and machines).

The major producers of case materials are Germany, France, Spain, Italy and Sweden. They represent around 60 % of total production. Recycled fibre-based production has grown more rapidly than virgin fibre-based production. The typical size of a paper machine is 200 000 – 400 000 tonnes/year.

For the manufacturing of cartonboards, both recovered and virgin fibres are used as raw material. Recycled fibre-based grades are predominantly supplied by Germany, Italy, the Netherlands and France, whereas the virgin fibre-based folding boxboard and liquid packaging board production is concentrated in the Nordic countries. Production capacity consists of rather small mills and machines, the average machine capacity amounting to 33 000 tonnes/year, except for the mills located in Finland and Sweden, which have an average machine capacity of 100 000 – 150 000 tonnes/year.

Tissue production is concentrated in five countries with Germany, Italy, the UK, France and Spain producing over 75 % of the tissue in Europe. Although there are over 60 mills in total producing tissue, four European producers dominate, producing together above 40 %, and two American companies accounting together for 20 % of the total production. There are still many small companies producing 10 000 tonnes/year or less, which are private or family-owned businesses. The average machine size is relatively small, approximately 30 000 – 60 000 tonnes/year.

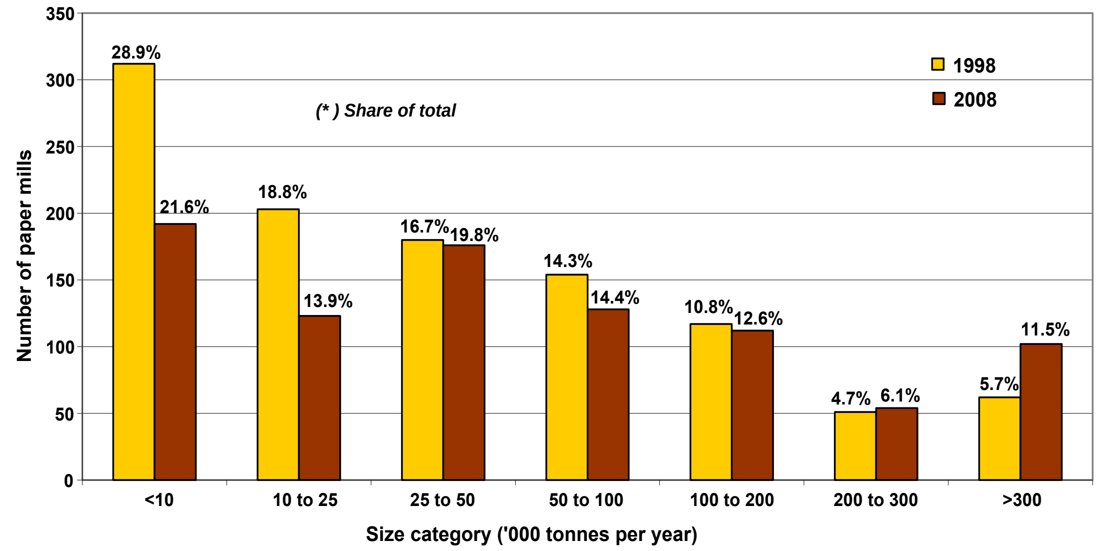
Figure 1.13 shows the number of paper mills within the different size categories across Europe in 2008.



Source: [2, CEPI 2009]

Figure 1.13: Number of paper mills by volume in Europe in 2008

In 2008, the number of paper mills in Europe totalled 887, most of which were located in Italy, Germany, France, Spain and the UK, representing together 599 mills. A total of 102 very large mills are found in the category of > 300 000 tonnes per year and 192 mills in the small category of less than 10 000 tonnes per year. Compared to pulp production, a relatively high number of small- and medium-sized paper manufacturing facilities are in operation: 491 mills with a production capacity below 50 000 tonnes/year or a little more than half of the paper mills. There is a trend to shut down smaller paper mills and build larger production units. Figure 1.14 confirms this trend over the last ten years. In 2008, the average calculated paper machine capacity was around 123 000 tonnes/year.

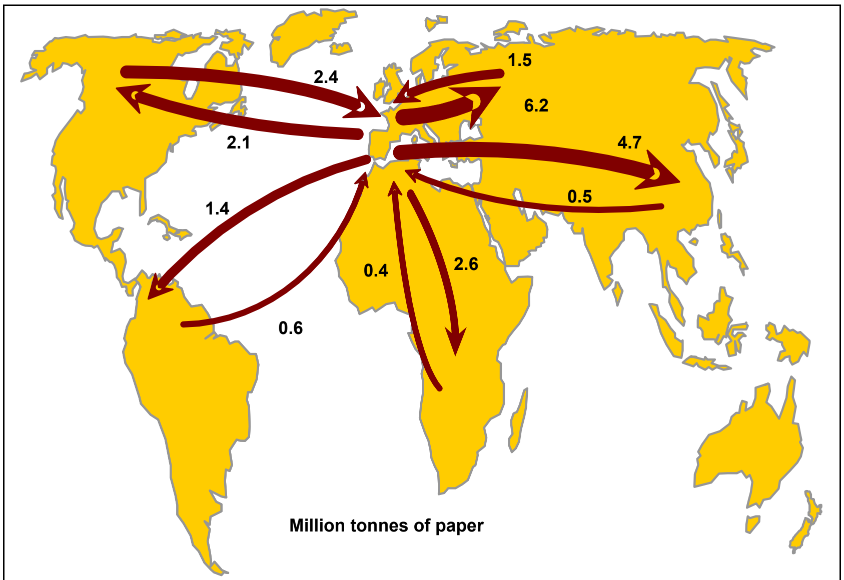


Source: [2, CEPI 2009]

Figure 1.14: Number of paper mills by volume in CEPI-associated countries 1998 and 2008

About one third of pulp produced in Europe is market pulp, i.e. two-thirds of the sites include the integrated production of pulp and paper. Mechanical paper grades, like newsprint, SC and LWC, are usually integrated with mechanical pulp and often use only small amounts of chemical pulp. For paper for recycling manufacturing in particular, the level of integration is very high; nearly all paper for recycling mills include processing paper for recycling, and some of them add some purchased pulp. However, fine paper production in Europe is mainly based on purchased pulp, i.e. it has a high share of the non-integrated industry, whereas in Nordic countries, paper mills have, in many cases, been built adjacent to a pulp mill.

In 2008 total deliveries to other European countries accounted for 45.0 million tonnes, imports within Europe were 45.3 million tonnes. With regard to international trade, Figure 1.15 shows that exports amounted to 17.0 million tonnes to countries outside Europe, imports from countries outside the EU amounted to 5.4 million tonnes. A trend has been observed since the year 2000 towards increasing the export of paper and, for most regions, decreasing the import of paper.



Source: [2, CEPI 2009]

Figure 1.15: **Trade flows of paper to and from Europe in 2008 (95 % of production for CEPI-associated European countries)**

1.5 Classification of pulp and paper mills for the purpose of this document

The often high degree of process integration in the pulp and paper industry implies that the approach to pulp and paper mills must be related not only to describing unit production processes or lines, but also to describing the entire mill. For instance, in order to reduce effluent volumes, water is typically recirculated from the paper mill to the pulp mill which sometimes makes it difficult to distinguish between the two clearly.

It should also be considered that different fibre furnishes and processes (e.g. bleaching) for similar products will give rise to different emissions. Paper products that appear similar (e.g. graphic paper) may be manufactured through different processes and techniques with different associated consumption and emission levels.

For instance, newsprint may be manufactured from stone groundwood pulp (SGW), pressurised groundwood pulp (PGW), thermomechanical pulp (TMP), refiner mechanical pulp (RMP), chemithermomechanical pulp (CTMP), sulphite pulp, bleached softwood kraft pulp (BSKP), and/or deinked pulp (DIP). The brightness of the pulp to be achieved (the extent of bleaching) will also influence the initial emission load. Therefore, when assessing consumption and emission levels, the product-orientated approach (in this case: newsprint) should be supplemented by a process-orientated approach. The major processes that are responsible for different emission levels (e.g. the extent of oxidative bleaching of mechanical pulp) need to be taken into account and available measures for reducing emissions assessed.

Another example that shows that the estimation of emissions from pulp and paper mills should be based on a combination of a product-orientated approach and a process-orientated approach is the manufacturing of tissue paper. For tissue manufacturing too, there is a trend to use a mixture of raw materials as fibre furnishes (e.g. a mixture of different types of virgin fibres and recovered fibres). The choice of a specific fibre furnish has different drivers, such as the costs of fibrous materials, logistical aspects, customer demands and paper quality to be manufactured. There are tissue mills using from 10 % to 100 % recovered fibres. Within a certain range, a higher share of paper for recycling is normally associated with higher loads of organic substances being discharged.

Finally, several of the mills are conglomerates of multiproduct mills (see Section 2.1), making it sometimes difficult to allocate precisely the total discharges of a certain pulp and/or paper product produced when not considering the specific processes involved.

To deal with pulp and paper mills from an environmental point of view in order to determine their emissions, a combined approach should be followed:

- assessing the whole pulp and/or paper mill
- taking into account different products and product qualities manufactured.

As a result of this approach, this document describes in Chapters 3 to 7 the most important types of products manufactured and processes used for pulp, paper and board manufacturing separately for five main classes of mill. The main types of pulp and paper manufacturing are further divided into subcategories.

The structure of the European pulp and paper industry and the composition of this document are shown in Figure 1.16.

The processes and techniques in the pulp and paper industry that are common to all/most mills independent of the type of pulp or paper manufactured are discussed in Chapter 2.

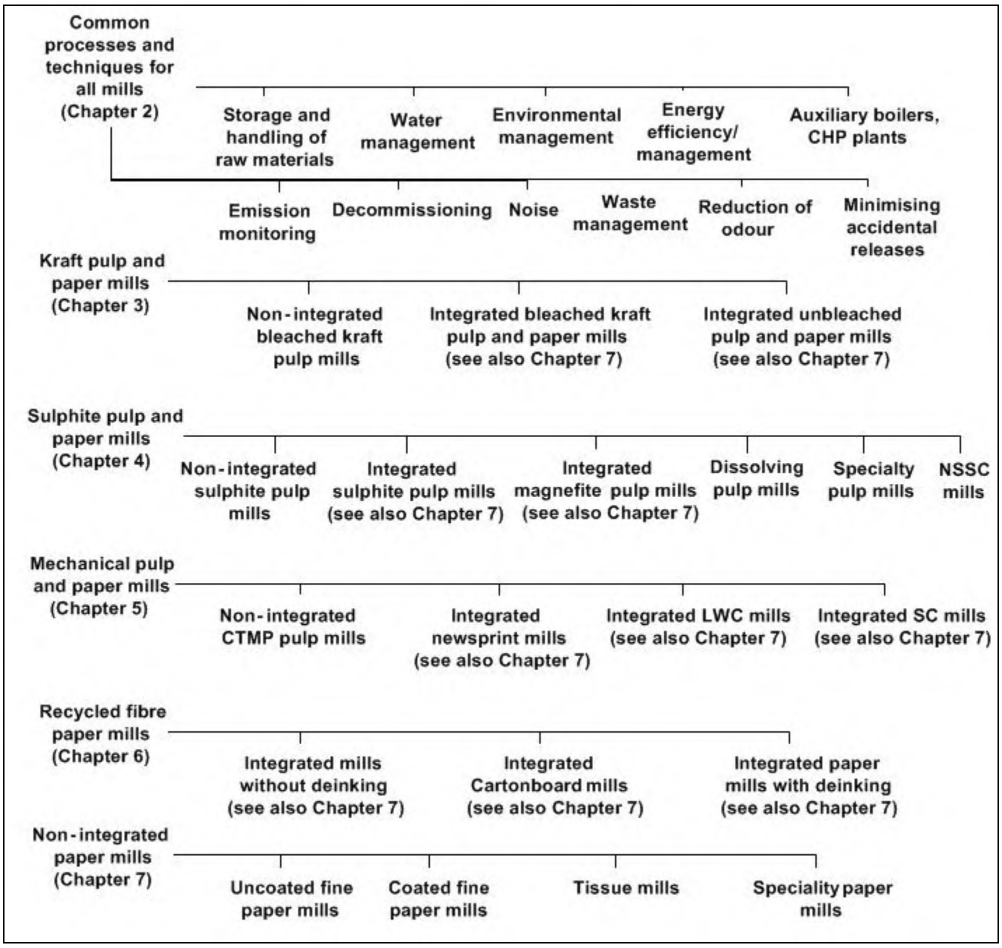


Figure 1.16: **Classification of pulp and paper mills in Europe for this document including the relevant chapters for those mills**

The following five major groups of pulp and paper mills are distinguished:

- kraft pulp mills (Chapter 3)
- sulphite pulp mills (Chapter 4)
- mechanical and chemimechanical pulp and paper mills (Chapter 5)
- mills processing paper for recycling (Chapter 6)
- non-integrated paper mills including speciality paper mills (Chapter 7). This section also covers the papermaking part of integrated kraft, sulphite, CTMP and CMP mills.

The most relevant types of pulp and paper mills within each of these groups are also shown in Figure 1.16. However, because of the variety of raw materials used and processes involved in pulp production and papermaking, this structure will never cover all of the cases, e.g. multiproduct mills may run different pulping lines at the same site (see Section 2.1) and not clearly classify for one of these groups.

For most readers it will not be necessary to consider the whole document but only those chapters or sections that are of interest for the mill in question. For example, market kraft pulp mills are only concerned with Chapter 3; integrated kraft pulp and paper mills should refer to Chapter 3 and Chapter 7 (which discuss papermaking and related activities); relevant information on integrated mills processing paper for recycling can be found in Chapter 6 and 7.

Pulp produced from fibres other than wood represents a small part of the production (CEPI area: 0.6 million tonnes/year; AT, HU, IT, PT, ES) and is too specific to be described in this document properly. These pulps are therefore outside the scope of this document. For them, BAT and BAT-AELs should be determined case by case.

1.6 Economics and employment in the EU pulp and paper industry

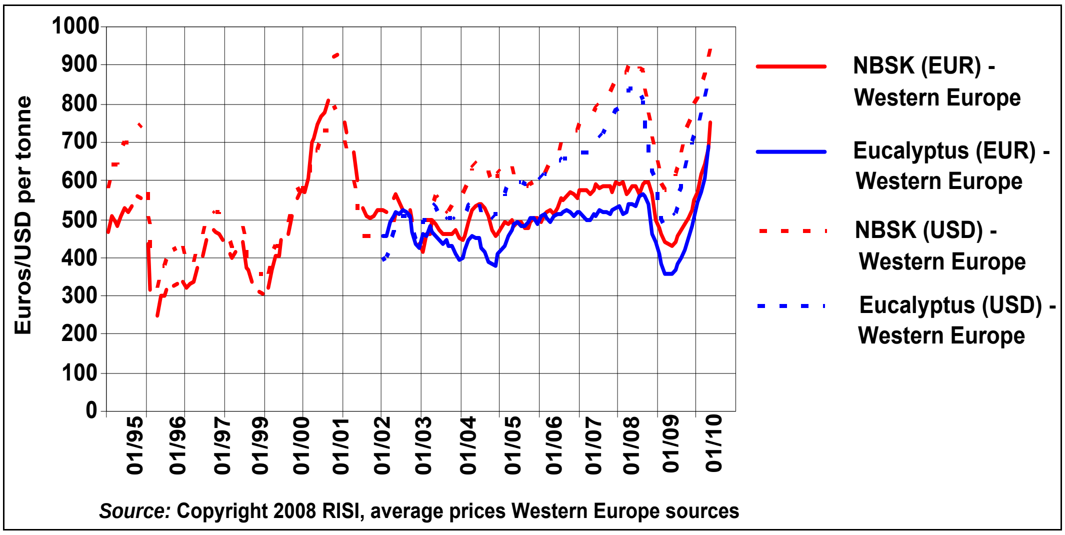
The pulp and paper industry is a capital-intensive one, leading to both long-term and variable investment plans, involving increasing cross-border integration. Since the mid-1990s, the sector has invested an average of 6 – 8 % of total revenue to improve capacity and to develop machinery and other tangible assets to reach higher levels of raw material and energy efficiency, but also to further improve environmental performance. Productivity has also increased relative to other regions.

Pulp and paper industries have been going through a process of consolidation and globalisation, which has not yet reached a more stable status. The concentration process leads to a reduction of companies. As a result of these moves, the structure of the industry is changing markedly. From 1991 to 2008, pulp production increased from 34.0 to 41.9 million tonnes while at the same time the number of pulp mills decreased from 295 mills to 193 mills. For paper production there was a similar trend: From 1991 to 2008 the production increased from 65.9 million tonnes to 98.9 million tonnes while the number of paper mills decreased from 1 292 to 887 mills. The average size of the paper mills increased during the same period from 57 300 to 122 800 tonnes/year [2, CEPI 2009]. Many companies have grown by investing in greater capacity but also by consolidating or closing a large number of small obsolete paper and board mills. Thus, the European paper industry comprises a relatively small number of very large multinational groups at one end of the scale yet a large number of small businesses at the other. The large number of relatively small-sized mills has developed niche strategies on the market.

There has been a significant change in the ownership structure since the early 1990s. Typical features in this development have been the concentration of producers into larger companies and the merging of paper mills and overseas pulp producers into larger companies. Companies from the US, the Republic of South Africa or Indonesia have been integrated into, or have established closer business relationships with European paper and board manufacturers. Likewise, there have been more regional and local integration trends inside some countries like Sweden and Finland. This reflects the global nature of the pulp and paper business today. Besides the major markets of the US, Europe and Japan, Asia and in particular China have become important players on the market. China was in 2011 the largest world producer of paper after the EU-27 (98.9 million tonnes), and the US produced 79.8 million tonnes in 2008. Southeast Asian markets are likely to grow and lead in the world consumption of paper. South America, and in particular Brazil, has also become a leader in the market pulp production. International trade in paper and papermaking fibre (pulp, paper for recycling) will probably continue to be a feature of the industry with growth continuing in all main production regions. The fastest growth will be seen in the paper and paperboard trade as countries with a surplus of fibre add value before exporting.

It is typical of the pulp and paper industry that extreme price variations occur, e.g. the fluctuations of the price of market kraft pulp resulting from business cycles and gross domestic product (GDP) evolution but also from speculation on raw materials and currency exchange rates. Supply/demand imbalances also affect the price variations (e.g. over-capacities and simultaneous temporary demand increases and drops related to stock management) depending on the grade and market considered.

Regarding paper grades, a general trend is that real prices are declining in the long term. The price variation is not the same for all pulp and paper products. The closer a company is to the retail trade and final consumer, the smaller the price fluctuations of the product are. For example, the price of pulp is much more volatile than that of tissue paper. The smaller the transactions and the lower the demand from the customer the smaller the variations tend to be. Figure 1.17 (Copyright: RISI) shows the typical variations of the prices of market pulp on the world stock market for Nordic Bleached Softwood Kraft (NBSK) pulp as well as for eucalyptus pulp – two types of pulp used as a reference on the world market.



Source: Copyright 2008 RISI, average prices Western Europe sources

Figure 1.17: **Typical variation of prices for market pulp**

Paper for recycling prices have also seen dramatic developments in terms of variation of prices over the last three years. Paper for recycling is traded on a global scale and China has a huge impact on availability and prices.

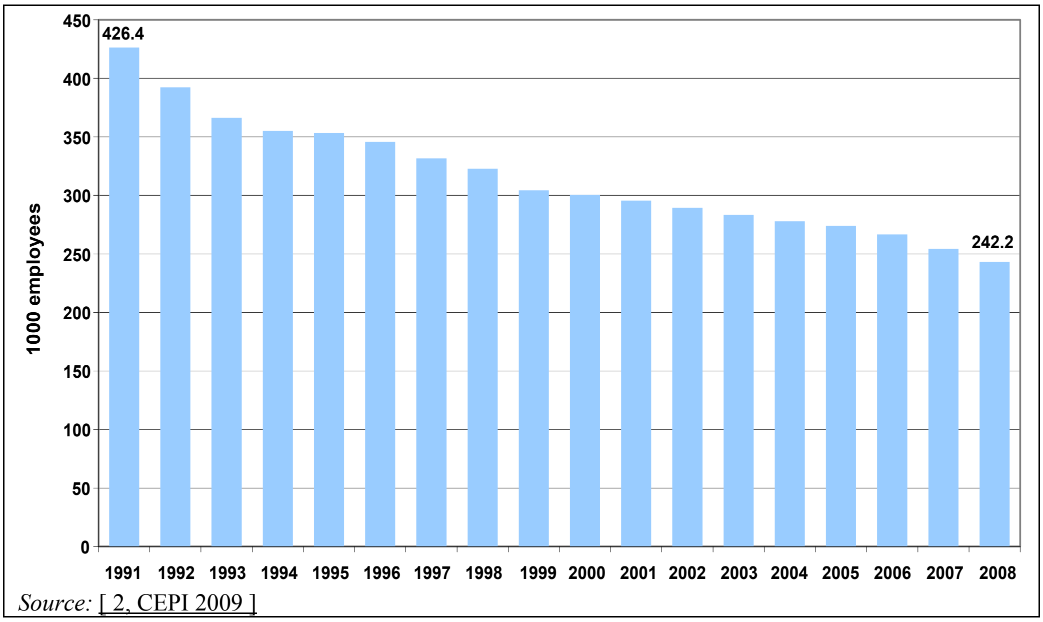
Since 2007, the price of wood stayed firm in Europe, even followed by an increase, especially with regard to pine and birch. The variations have been caused by the competition with wood used for energy generation, supported by public subsidies for the production of renewable energy, especially biomass-based energy. The variations of wood prices have been reinforced by the sharp increase of payments for customs established by Russia for exported wood increasing from EUR 1.5 in 2006 to EUR 15 in 2008. This measure has directly affected Finland but has also led, on a smaller scale, to an increase in prices for pulpwood in the rest of Europe.

Pulp and paper is an energy-intensive industry. On average, 21 % of the production costs come from fuel and electricity consumption [4, CEPI 2009], and as such, improving the energy efficiency of the production process has both competitive and environmental benefits. Higher prices for electricity and gas and an increased awareness of sustainability in the past years have focused the industry on energy efficiency. The increase of energy prices has considerably affected the European paper industry.

The overall demand for paper and board generally shows an upward trend with worldwide paper consumption increasing from 30 million tonnes in 1946 to 214 million tonnes in 1987. The rate of increase since 1987 has slightly reduced and worldwide total paper consumption in 1996 was approximately 280 million tonnes. Between 1991 and 2008, paper consumption in Europe increased at an average pace of 2.1 % per year. In the year 2008, the world consumption reached 391.3 million tonnes. The financial and economic crisis beginning at the end of 2008 has rapidly stopped this trend and initiated a decline in paper consumption for most grades.

Dominating pulp producers are the industrialised countries of the northern hemisphere, i.e. the US, Canada, Sweden, Japan and Finland, but countries in South America such as Brazil and Chile are rapidly developing. In Europe, Finland and Sweden, in particular, largely rely upon the revenue from the exports of pulp and paper grades. This is due to the highly 'native' nature of these products, i.e. very little import is needed in order to support the production. As a consequence of the financial crisis that was followed by a worldwide recession, the world production of pulp decreased by 1.4 % in 2008 and the same development was observed in Europe but with a greater magnitude (-4.6 %). The production of market pulp shows a decrease of 0.1 % in Europe.

In 2008, the sector generated a turnover of EUR 78.3 billion, providing direct employment to 243 300 people in Europe [2, CEPI 2009] and to even more in terms of indirect employment. Arithmetically one person employed manufactures about 172 tonnes of pulp and 407 tonnes of paper per year (only approximated data based on rough assumptions as no data split for pulp and paper is available). This marked the paper industry as a very capital-intensive sector and a highly labour-productive sector. Labour productivity is around 0.50 finished metric tonnes per employee hour which places the European paper industry in the second position just behind Japan [4, CEPI 2009]. Figure 1.18 shows the employment evolution from the manufacture of pulp, paper and paper products in Europe (CEPI-associated countries) since the early 1990s. The trend of externalisation of some tasks such as maintenance and logistics partly explains the decrease.



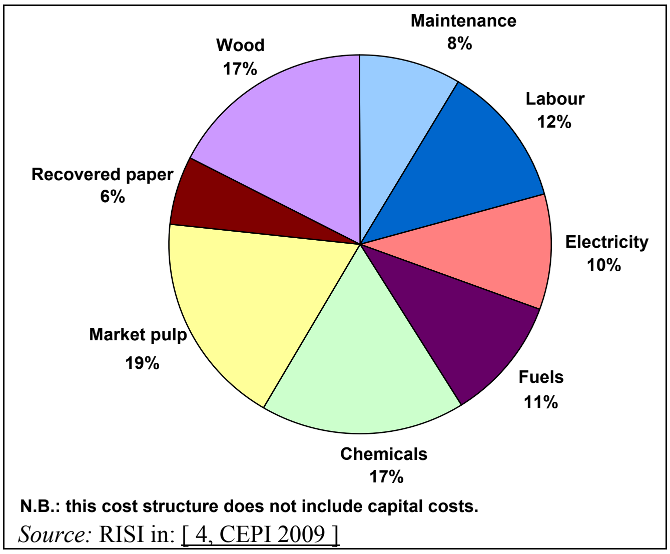
Source: [2, CEPI 2009]

Figure 1.18: Total employment evolution in Europe (CEPI-associated countries) 1991 – 2008

The competitiveness of the pulp and paper sector is closely related to global trends affecting economies such as Russia, China, India and other Asian regions. These have invested substantially in new capacities and are playing an increasing role in reshaping raw material supply and demand. This is particularly true for China, which has welcome around 50 % of the total new capacities over the last five years. The competitiveness is also impacted by currency exchange rate and freight rate swings and market openness (European markets are fully open, contrary to most of the emerging markets which have tariff and non-tariff barriers).

The European paper industry is one of the technological leaders that have maintained their competitiveness with other regions of the world, despite the high production costs. However, increases in the costs of production and raw materials and the emergence of paper industries in parts of Asia and Latin America have presented challenges for the European pulp and paper industry.

Figure 1.19 shows the average cash manufacturing cost structure of the European pulp and paper industry in 2009. The cash manufacturing cost includes some consumables needed to produce ready-to-deliver non-converted products. Capital costs and transport are not included.



N.B.: this cost structure does not include capital costs.

Source: RISI in: [4, CEPI 2009]

Figure 1.19: **Manufacturing cost structure for the European pulp and paper industry in 2009**

In Europe, a relatively large number of small- and medium-sized paper manufacturing facilities are in operation (more than 50 % of the total number of facilities). These mills often face a different challenge in terms of competitiveness to the larger mills. They are often operating in small, sometimes niche markets and have a different level of exposure to international competitors. The extension of the market specific to their kind of products is often more local or limited to very specific customers compared with the larger mills producing bulk grades. Smaller paper mills are subject to the phenomena of 'economies of scale' (a reduction in the average cost per unit resulting from increased production, realised through operational efficiencies and other cost reduction measures).

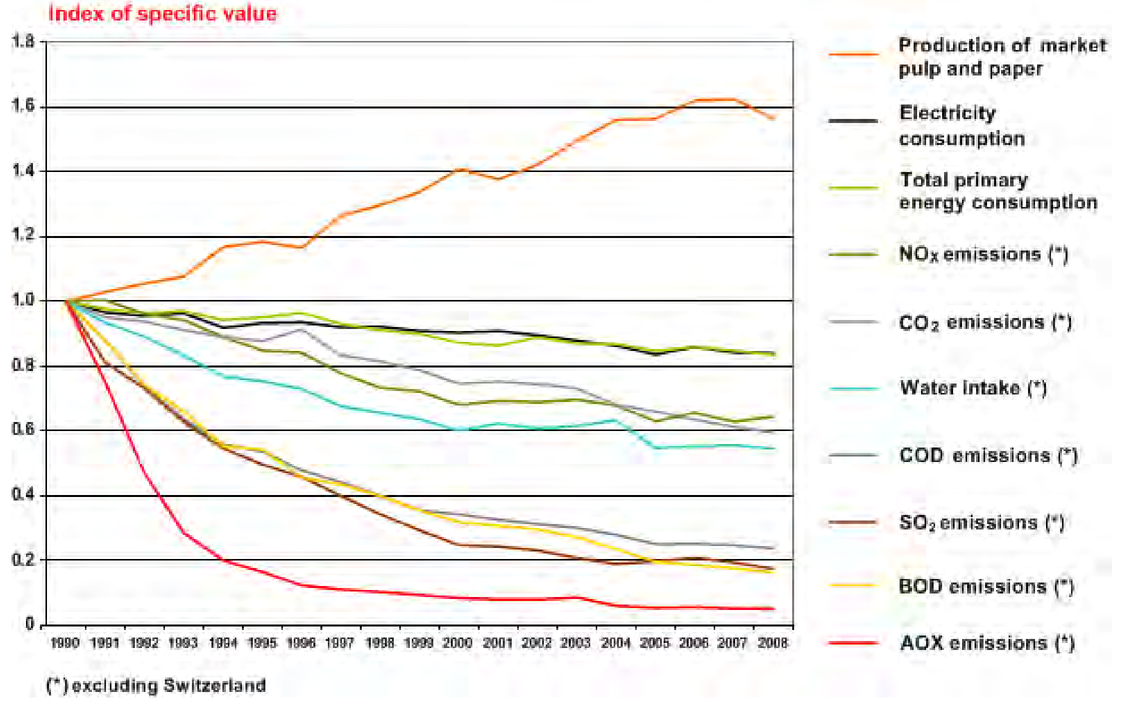
Significant benefits with larger scale operations include the purchasing power to obtain raw material and equipment at a favourable price, the optimisation of transportation, an increased specialisation of management and employees (a high degree of knowledge and specialisation for operating the equipment) needed for adopting production processes and improved marketing capacities. Another factor that could produce benefits based on the scale of production is the structure needed for the process control: plants of larger dimensions can be managed by more sophisticated and more productive equipment (as their higher cost can be amortised more easily) and require fewer employees. Therefore, as the production capacity increases, so does the possibility of taking advantage of specialised controls. The dimension of the plant could influence the level of 'profitability' and 'efficiency' of the paper mill, thanks to the technological economies of scale, which means that as the output increases, real savings of resources are produced [7, Italian TWG 2007]. Companies of larger dimension in the paper sector therefore have the possibility to better manage costs in order to obtain competitive prices and increased profitability that could allow them to be better prepared for further investment in new technologies. The importance of the economy of scale in the paper sector comes from the technologies that are needed. In fact, the paper industry is a typical capital-intensive industry, where the ratio between capital and labour per unit of product is very high and the technologies play an important role. The consolidation of the production processes tends to reward the larger scale operations and also those operations which integrate fibre manufacturing with paper production. Another factor that could produce benefits based on the scale of production is the possibility for larger mills to attract more skilled personnel.

In the paper industry there is a strong tendency for companies to merge which creates economic difficulties for the weakest enterprises, as the packaging sector has experienced, for example. Where merging is less relevant is where there is a possibility of introducing quality differentiation, where small mills can more easily have a share of the market. To increase competitiveness, smaller mills often tend to go in the direction of providing their customers with more specific products and greater flexibility, in many cases ending in niche productions.

1.7 Main environmental issues of the production of pulp and paper

General evolution of consumption and emission levels since 1990

The pulp and paper industry has historically been considered a major consumer of natural resources (wood), energy (fossil fuels but with a substantial share of 'bioenergy', electricity), and water, and has been a significant contributor of pollutant discharges and emissions to the environment. Technological changes, the use of environmental and energy management systems, the increased recycling of paper, the employment of highly trained and committed personnel, investments in environmental measures and continuous improvements allowed for a stepwise reduction in the environmental footprint, and have decreased emissions by 80 – 90 % or more on a product-specific basis (per tonne of product) since about 1980. Figure 1.20 and Figure 1.21 show the relationship between pulp and paper production and consumption and emission levels.



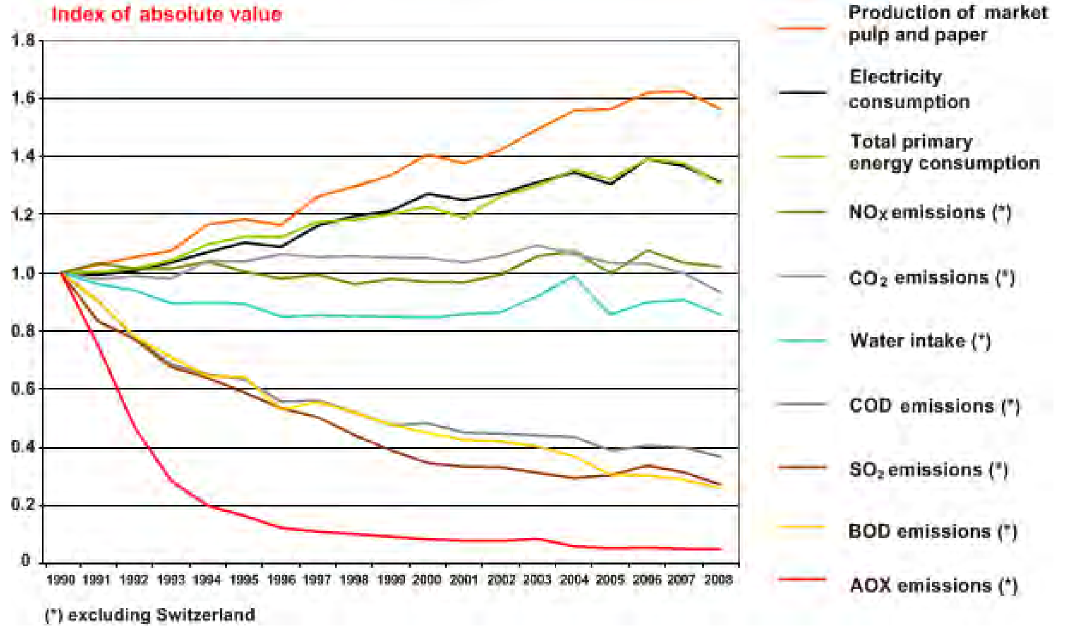
(*) excluding Switzerland

Source: [2, CEPI 2009]

Figure 1.20: Evolution of specific consumption and emissions (kg pollutant/t of product) in the European pulp and paper industry from 1990 to 2008

The index of the product-specific values (see Figure 1.20) shows that energy consumption and emissions per tonne of market pulp and paper have been declining while paper and pulp production has increased by 60 % since 1990. The specific electricity and total primary energy consumption decreased at a slower rate than emissions.

The index of absolute values shown in Figure 1.21 follows a slightly different trend. It shows how pulp and paper production, emissions and consumption levels of European pulp and paper mills have changed between 1990 and 2008 in absolute terms. Primary energy consumption and electricity consumption increases at a similar rate to the increase of production (it is not indicated in the source whether emissions of CO_2, NO_X and SO_2 from the generation of purchased electricity are included in these values); emissions to water and emissions of SO_2 to air have been reduced in spite of continuous growth of production; emissions of NO_X and CO_2 to air and water intake remain approximately stable although production increases.



Source: [2, CEPI 2009]

Figure 1.21: **Evolution of the absolute consumption and emissions in the European pulp and paper industry from 1990 to 2008**

Figure 1.22 gives an aerial view of a rather large integrated site where kraft pulp is produced, part of which is pumped to the adjacent mechanical pulp and paper mill. Activities include energy generation and waste water treatment. The figure shows the extension of a larger site and the general shape of modern installations.

Source: [258, Botnia 2008]

Figure 1.22: **Aerial view of an integrated kraft pulp, mechanical pulp and paper site with a power plant and a waste water treatment plant**

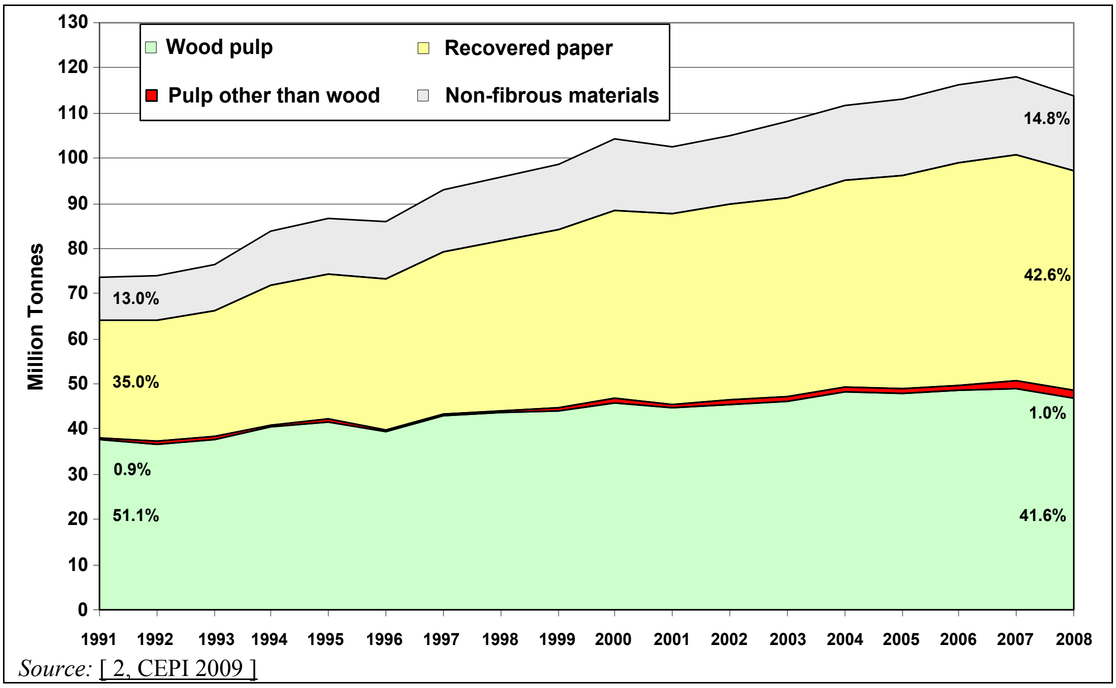
Despite the significant environmental improvements achieved since the early 1990s, the challenge is to continue to make progress to ensure that every part of the production process is environmentally sound. The current environmental challenges of the pulp and paper sector can be summarised below.

Supply of pulpwood, virgin fibre, paper for recycling and non-fibrous materials
In Europe, the raw materials used in papermaking are wood pulp, paper for recycling, non-fibrous materials (e.g. fillers, coatings and chemical additives) and, to a limited extent, other fibrous material (e.g. cotton, linen, bark, hemp, jute, straw and rags). Using wood as the main raw material, the paper industry is based on a renewable resource. In most European countries certification of sustainable forest management has become an important tool to ensure that wood used in products comes from responsibly managed forests, taking equal account of economic, environmental and social impacts. Environmental organisations established the first certification scheme under the Forest Stewardship Council (FSC) banner. Several other schemes followed. Today, the second most prevalent system is the Programme for the Endorsement of Forest Certification (PEFC). While certification was initially created to combat deforestation in the tropics, most certified forests are located in the northern hemisphere, of which nearly 100 million m^3 are in Europe. In total 10 % (approximately 380 million hectares) of the world's forests are certified. Chain of Custody certification makes it possible to trace the raw materials along a chain from the forest to the end product, allowing the manufacturer to label the product as certified. In addition to an increasing demand for certified goods from market players (e.g. publishers, printers), some policy developments have led governments to be increasingly involved in the certification arena, e.g. through FLEGT (the EU adopted Action Plan to combat illegal logging from 2004 entitled 'Forest Law Enforcement, Governance and Trade') and Green Public Procurement.

The increasing competition between wood for bioenergy and for the paper industry presents a new challenge in terms of long-term availability and costs.

Once consumed, most forest-based products start a new life as a valuable secondary raw material or as biofuel. Paper for recycling represented, in 2008, 42.7 % of the total raw materials used and 50 % of the fibres used. Paper for recycling provides an important complementary fibre source for paper production. It reduces the amount of paper in the waste stream, thereby reducing the pressure on landfill capacity and reducing greenhouse gas emissions from paper decaying in landfills. Many European countries have formally adopted their own paper recovery goals and have made substantial efforts to enhance public awareness of paper recovery programmes and their benefits to society and the environment.

The trend of consumption of raw materials for papermaking from 1991 to 2008 is shown in Figure 1.23. In 2008, the European paper industry used 48.6 million tonnes of paper for recycling, decreasing by 2.6 % from the previous year. From 1991, consumption of paper for recycling has grown 89 % (around 23 million tonnes).

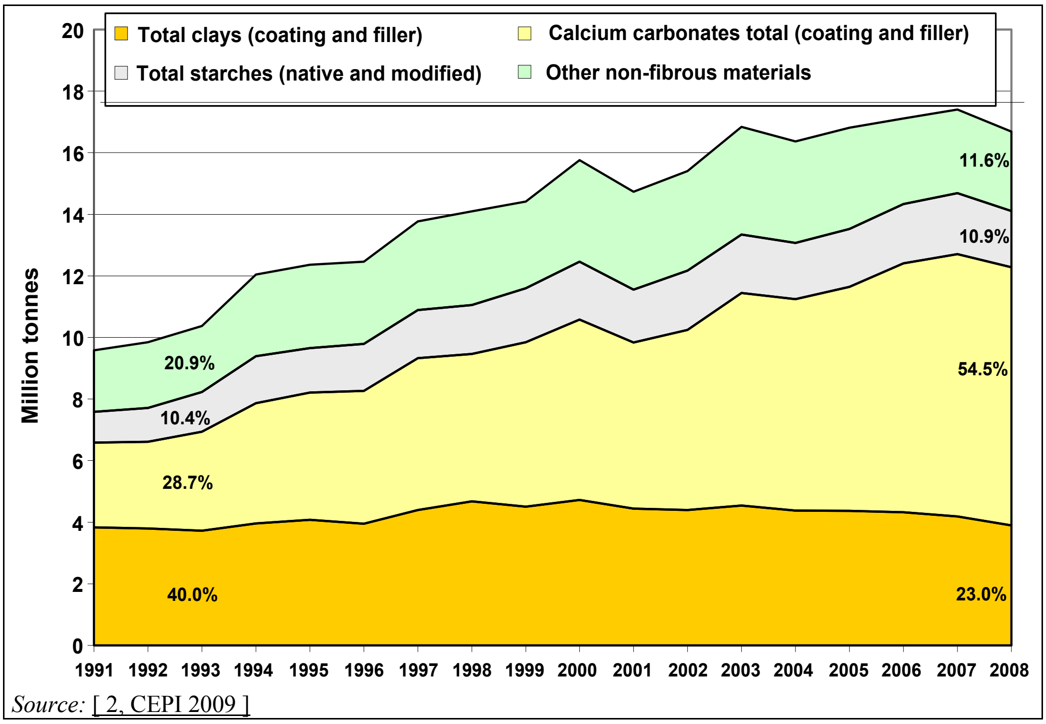


Source: [2, CEPI 2009]

Figure 1.23: Raw materials consumption in papermaking in CEPI-associated countries 1991 – 2008

In 2011, in Europe nearly the same amount of virgin wood pulp and paper for recycling is used. As the recycling of paper for recycling in Europe has reached quite an advanced level, a rather slow increase in recycling can be expected in the coming years. In some Member States, progress can be made in terms of collection and recycling rates. Generally, eco-design, recyclability, sorting and collection are areas where progress can still be achieved.

The non-fibrous materials that are used in larger quantities in papermaking are basically clay, calcium carbonate, starch and other non-fibrous materials (chemical additives). In 2008, 16.7 million tonnes of these materials were used by the European paper industry which represents 14.7 % of the raw materials used in the sector. Figure 1.24 shows the consumption of non-fibrous materials in CEPI countries from 1991 to 2008. The considerable increase in the use of calcium carbonate warrants attention as this trend leads to higher concentrations of $CaCO_3$ in the process waters of processing paper for recycling paper mills (see Section 6.3.5).



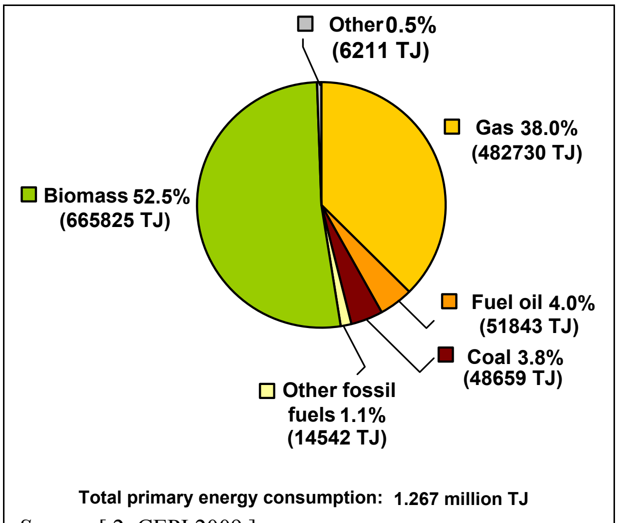
Source: [2, CEPI 2009]

Figure 1.24: Non-fibrous material consumption in CEPI-associated countries 1991 – 2008

Fillers, coatings and starch are often supplied by a few large producers of chemicals. Regarding starch, the producers in Europe use maize, wheat or potato. Clay and calcium carbonate are open-cast mined all over the world and calcium carbonate is partially produced by a precipitation process ($CaO + CO_2$).

Fuel and energy use, CO_2 emissions and climate change

The pulp and paper industry is a very energy-intensive sector. There is a wide range of pulp and paper products and processes, each with different energy requirements. Producing one tonne of paper requires on average around 11.5 GJ of primary energy, depending on the raw materials and fibre furnish used, the paper grade and quality manufactured, and the techniques applied. The energy required for paper production is comparable to that of other energy-intensive products, such as cement or steel. On the other hand, the most important natural resource for paper manufacturing is biomass, mainly wood as the major fibre source, the use of which is assumed to be CO_2 neutral. Today's pulp and paper industry is the largest user and producer of renewable energy sources and relies heavily on biofuels: around 50 % of all primary energy is biomass-based. Figure 1.25 shows the shares of energy carriers in primary energy consumption in the European pulp and paper sector in 2008. 52.5 % is biomass.



Source: [2, CEPI 2009]

Figure 1.25: **Shares of primary energy consumption in the European pulp and paper industry in 2008**

Energy efficiency and reduction of the consumption of fossil fuels is an important issue for the sector and has both competitive and environmental implications. In many European countries, energy efficiency programmes for the sector are under way. However, the total demand of process energy is still high.

Another key aspect in the environmental performance of the sector is the on-site generation of electricity and heat. The pulp and paper industry is one of the largest users of combined heat and power production (CHP) which enables paper mills to save around 30 % of energy when compared with conventional technologies and contribute to a reduction of greenhouse gas (GHG) emissions. In 2007, 95.79 % of the total on-site electricity generation for European pulp and paper mills was produced through CHP or around 50 919 GWh. Table 1.4 shows the electricity consumption in the CEPI-associated countries between 2005 and 2007 and the percentage of electricity produced through CHP compared to total on-site electricity generation.

Table 1.4: **Electricity consumption in CEPI-associated countries 2005 – 2007**

Electricity consumption	**2005**	**2006**	**2007**
Electricity produced on site (GWh)	49 591	50 873	53 157
- amount produced through CHP (%)	*95.55*	*95.96*	*95.79*
Purchased electricity (GWh)	74 926	79 194	76 980
Sold electricity (GWh)	-8 557	-8 893	-9 105
Total electricity consumption (GWh)	**115 838**	**121 192**	**120 742**

NB: CEPI total: AT, BE, CH, CZ, DE, ES, FI, FR, IT, NL, NO, PL, PT, SE, SK, UK, excluding HU.
Source: [2, CEPI 2009], [4, CEPI 2009].

The European pulp and paper industry has a direct emission of about 37 million tonnes of CO_2 per year which accounts for 2 % of the emissions under the EU ETS (European Trading Scheme) and less than 1 % of the EU total emissions (2008 data, *Source:* EU Community Independent Transaction Log (CITL)). About 900 installations are included in the EU ETS system, excluding only about 260 installations [2, CEPI 2009]. The CO_2 emissions are mainly caused by combustion processes: producing the electricity and heat needed for the processes. Indirect emissions are caused by purchased electricity (around 62 % of the total electricity consumption).

Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009, amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community (the EU ETS Directive), contains a range of implementing measures to be adopted by the Commission after agreement by the Member States. As an important measure, the Commission has determined the sectors deemed to be exposed to a significant risk of 'carbon leakage' (i.e. risk of suffering competitive and trading disadvantages due to additional cost burdens caused by the excessive costs of the acquisition of CO_2 allowances). As a result of the consultations, pulp and paper is on the list of energy-intensive industries with a risk of 'carbon leakage' (pulp has a trade intensity above 30 % and paper a trade intensity above 10 % and a CO_2 cost above 5 %).

Water use

Water is one of the main elements for paper manufacturing. It has been an important resource for the paper industry from the beginning and, to date, industry has made a lot of progress to clean and reduce the water used in the paper industry. There has been a development to close up water circuits in pulp and paper mills. And in regions with scarce water resources or a dry climate, further reduction of water use per tonne of product will be essential in order to keep the capital-intensive production sites. Those sites will probably be the first movers that develop new techniques and management methods toward water-saving solutions. Other driving forces for developing techniques using less water will probably be the regional costs of raw and waste water. However, there is a trend not to push too much further for the closure of water circuits in normal pulp and paper mills because of the technical drawbacks often involved such as scaling, increased corrosion, accumulation of salts or non-process elements in process waters, etc. Today there are no kraft mills operating full time that completely recover all bleach plant effluent. One CTMP mill, the sodium-based bleach plant of a sulphite pulp mill and a few producers of corrugating media and Testliner using recycled fibre have realised zero effluents to water.

Under an integrated perspective, the aim is to move towards the most minimal impact pulp and paper manufacturing possible, which means a concept with a broader range of issues and challenges covering minimisation of resource consumption (water, energy, fibres, chemical additives) and emissions, minimising cross-media effects, taking into account economic aspects and working environments. In a few paper mills, an increased reuse of treated process waters by implementing production-integrated advanced waste water treatment systems can be observed. However, water use is not to be seen separately from the other main elements for production which are energy, fibres and chemical additives and proper functioning of all technical devices. Energy consumption, use of chemical additives, runnability of the paper machines and product quality are closely linked to the water used per tonne of pulp or paper and should be assessed in an integrated way.

Emissions to water

The public concern about the potential environmental hazard from the use of chlorine in the bleach plants has brought about a drastic decrease in the use of molecular chlorine as a bleaching chemical since the 1990s. The environmental control authorities in many countries have set severe restrictions on the discharges of chlorinated organics (measured as AOX) into the aquatic environment. A reduction of AOX was achieved by a combination of several measures: in western Europe, the use of molecular chlorine has been completely replaced by chlorine dioxide and the use of chlorine free bleaching chemicals such as molecular oxygen, hydrogen peroxide, ozone or peracetic acid.

Due to the strong reduction of the chloride content of the effluents, a closure of the mill system and recycling of the bleach plant effluent back to the chemical recovery system of the mill has been made possible. The reduction of both chlorinated and non-chlorinated organic substances in the effluents of pulp mills has been achieved to a large extent by in-process measures such as: increased delignification before the bleach plant by modified cooking and additional oxygen stages, spill collection systems, efficient washing, and stripping and reuse of condensates. Another factor contributing to the decreased emissions of AOX and unchlorinated toxic organic compounds into receiving waters was the installation of external treatment plants of different designs.

Water emissions have been targeted and have been improving considerably over time. However, as the water flow especially from larger mills is relatively high, the reduction of the remaining load of poorly biodegradable organic substances including some chemical additives like chelating agents (EDTA, DTPA), the emissions of nutrients (nitrogen and phosphorus) that cause eutrophication in receiving water bodies, and the discharge of suspended solids will continue to remain a challenge for the pulp and paper industry in the future.

Emissions to air

In the past, chemical pulp mills have caused serious emissions of sulphur (acidification) but in recent years, sulphur air emissions have especially been reduced by substantial progress in process technology. Recovery boilers and lime kilns are still important sources of air pollutants such as dust, NO_X, SO_2, CO and H_2S in some cases.

Because of the need for heat and power, most pulp and paper mills operate on-site power plants, auxiliary boilers, steam blocks or combined heat and power plants. These plants contribute significantly to total industrial emissions despite high efficiency combustion and efficient flue-gas cleaning. The key air emissions connected to the combustion of fuels for energy production (NO_X, SO_2, dust) will thus remain an issue for the sector as Directive 2001/81/EC of the European Parliament and of the Council on national emission ceilings for certain atmospheric pollutants (NEC Directive) aims at limiting emissions of acidifying and eutrophying pollutants and ozone precursors. The intention to move towards the long-term objectives of not exceeding critical levels and loads and of effective protection of all people against recognised health risks from air pollution will also demand some additional efforts from a number of mills that still have potential for improvement.

Solid waste

Many companies choose to implement integrated waste management plans that seek to minimise residues to be sent to landfill and to further increase the share of residues that are reused, recycled or recovered (including energy recovery). The goals for the management of residues in the pulp and paper sector include their use as renewable fuels, as soil improvers or as raw materials for other industries or their conversion into added value products for other users. New concepts in the sector aim at a best possible usage and energetic recovery of most residues generated on-site, if possible recycling also the ashes, e.g. in the construction or cement industry or using ash for soil stabilisation. The general target is minimising the amount of waste to be sent to landfills. These solutions aim to achieve waste reduction, resource recovery and energy efficiency at reasonable costs.

Odour and noise

Locally, odour and noise nuisances from pulp or paper mills are expected to remain future priorities for environmental actions in the pulp and paper industry.

Transport

Transportation is a critical theme for the European industry especially because of the closely associated issues of energy, climate change, use of fossil fuels, noise and other traffic-related issues. Transport is an inherent requirement because of the nature of the industry with the raw materials usually located a considerable distance from the end markets.

Road transportation remains the main mode of transport for European pulp and paper distribution and, due to current market demands, this is likely to continue. Alternatives such as rail often do not fulfil the cost and service expectations of the sector. Where available and possible, ship transport can be a cost efficient and environmentally sound alternative. Often companies use a network based on rail, road and water. However, it can be expected that policies to mitigate climate change by internalising external costs and integrating transport into the Emissions Trading Scheme will further increase cost pressures related to the transportation of raw materials and finished products.

2 COMMON PROCESSES AND TECHNIQUES FOR THE WHOLE PULP AND PAPER SECTOR

How to read this chapter

Some processes and techniques in the pulp and paper industry are common to most mills independent of the type of pulp or the paper grade manufactured. They are discussed in this chapter. These processes/operations may play a supporting role to the main production of pulp and paper or may contribute to the environmental performance of the mill and the process-related best available techniques that are described in more detail in Chapter 8. Cross references refer the reader to more detailed aspects discussed in the process-related chapters.

The chapter starts with a discussion of the general concept of how to approach emissions for integrated pulp and paper mills or multiproduct mills (see Section 2.1).

Then, information and data on general processes used within the sector are provided (starting with Section 2.2). These are horizontal matters or activities that do not relate to one specific pulp and paper activity. The logic of the chapter follows the major raw material flows that enter the pulp or paper mills and that are converted into pulp and paper products (fibre sources, chemical additives, water, energy) and discusses the general techniques that can be considered for integrated prevention and reduction of pollution.

The chapter on the common processes and techniques is organised in a similar manner to the other process-related Chapters (3 to 7) of this document: it starts with a description of the applied techniques and indicates the environmental impact of these measures (see Section 2.2 to 2.8).

Consumption and emission levels are presented here only for two cases: (a) regarding energy use, consumption levels are given (Section 2.5.2 and 2.5.4) as far as deemed necessary to understand the general aspects; (b) for steam and power generation in pulp and paper mills consumption and emission levels are given here (Section 2.6.2), following the same approach as the process-specific Chapters 3 to 7.

Then, starting from Section 2.9, the general techniques to consider in the determination of BAT are discussed. Finally, those techniques from Chapter 2 that are considered BAT for the sector as a whole are summarised in Section 8.1 'Best Available Techniques'. These best available techniques are suitable for reducing the overall emissions and will therefore influence the environmental performance of pulp and paper mills.

Chapter 2 should be read in conjunction with the respective Chapters 3 to 7 that are applicable to a given pulp and paper mill in order to get the complete picture of the BAT for a particular installation.

2.1 Integrated and/or multiproduct pulp and paper mills

This section on integrated sites and multiproduct mills explains the special features to be considered for integrated pulp and paper production and advises the reader of this document how a more complex plant that produces various types of pulp and paper at the same site can be approached when estimating its emissions.

For the different areas of pulp and paper production, the product and process-related BAT-AELs are described in Chapter 8.

The BAT-AELs for chemical pulping and also for papermaking are described in Chapter 8 for non-integrated mills. However, in practice there are very often integrated and even multiproduct mills. For such cases, it is important to have an appropriate approach to estimate emissions that combines the contribution from the individual processes involved (pulping and papermaking). Such an approach that proposes a mixed calculation for the waste water discharge is presented in Section 2.1.2. This approach requires a definition of the terms non-integrated, integrated and multiproduct mills.

2.1.1 Definition of non-integrated, integrated and multiproduct mills

Non-integrated mills
A non-integrated installation means either:

- a pulp mill that produces market pulp and does not run a paper machine. Market pulp is pulp manufactured and normally dried at one mill location for sale to paper manufacturers at other locations; or
- a paper mill that simply reconstitutes pulp made elsewhere and manufactures paper.

Integrated mills
Integrated production means that pulp and paper are produced in the same plant. The pulp is not dried before paper manufacture. Integrated mills can however also use some dried pulp acquired elsewhere. The level of integration can vary from a normal integrated mechanical pulp and paper mill to multiproduct integrated mills. There are mainly the following types of integrated mills:

- chemical pulp mills (kraft or sulphite pulp) with papermaking;
- mechanical pulping with papermaking;
- mills processing paper for recycling with papermaking;
- mixture of mechanical pulping and processing paper for recycling with papermaking;
- other mixtures, e.g. chemical pulp and paper for recycling can be used at the same site for the manufacture of a single product. Some additional mechanical pulp may also be produced in some mills;
- multiproduct mills.

Multiproduct mills
The term 'multiproduct mill' refers to a production site where wood-based products of a wide variety are manufactured (sawn goods, chemical pulps, mechanical pulps or pulp from processing paper for recycling, different paper and board grades and wood-derived by-products). An overview of such a multiproduct mill and the major processes and possible combinations are shown in Figure 2.1. The figure also indicates where the different processes are described in this document.

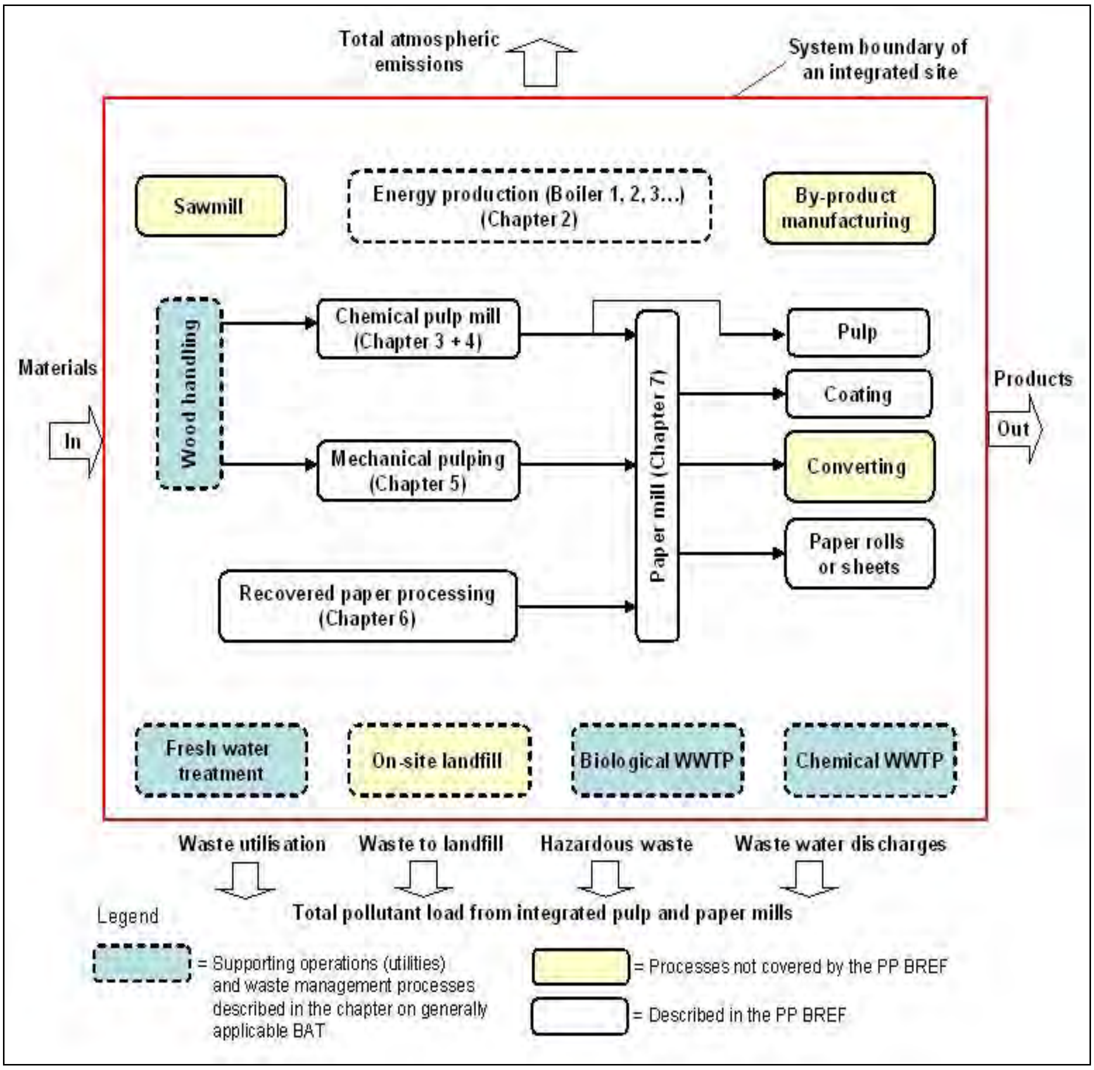


Figure 2.1: **Overview of the different processes in a multiproduct mill and where they are described in this document**

The multiproduct mills may run different pulping lines and may produce paper grades from a mix of raw materials. There are multiproduct mills with and without papermaking. A mill producing e.g. kraft pulp and CTMP but no paper is also a multiproduct mill but not an integrated mill.

For complex integrated pulp and paper mills such as most multiproduct mills, there are basic differences between point source atmospheric emissions and waste water discharges.

Gaseous emissions from point sources are released from selected processes directly to the atmosphere (after having passed air cleaning devices, if applicable) and can be assigned to a specific emission source. Non-point sources such as weak and strong gases from kraft pulp mills are collected from various locations in the mill and are normally burnt and thus converted into a point source. Additionally, uncollected odorous gases are released as diffuse emissions.

Waste waters from different processes of the integrated production are usually mixed and treated together in the biological waste water treatment plant. In large integrated mills that run different production lines/machines, the variation of emissions over time from the mill is smaller than in smaller mills, and a smoother running of the biological treatment plant is achievable (variation of emissions during different reporting periods can be consulted in Section 10.2.1). Normally only one point of discharge is measured. It is not easily possible to distinguish after treatment between the discharges from individual processes to the environment.

In some integrated mills, additional pollution loads may be considered, which however do not contribute large amounts of extra pollutants: (i) some mills run PCC (precipitated calcium carbonate) plants that produce PCC used in papermaking from burnt lime and carbon dioxide. Solid-containing waste water from the PCC plant is directed to the waste water system of the integrated mill, which results in an increase of the initial TSS emissions to the waste water treatment plant; (ii) leachate and condensation water from the drying of timber in the sawmills can be directed to the integrated waste water treatment plant. The oxygen demand load and nutrient load of these waters are minor though; (iii) conversion of by-products from kraft pulp-making, e.g. further processing of turpentine and tall oil in conversion plants situated on the integrated site. The waste water from these often externally-owned companies (e.g. Arizona Chemicals Oy for the Stora Enso Oulu site, Forchem Oy for the UPM/Botnia Rauma site) is directed to the integrated waste water treatment plants.

Atmospheric emissions and waste amounts can be allocated according to the source of the pollutant. The emissions of the auxiliary boilers, the recovery boiler(s) or the lime kiln can be assigned to the technical unit of concern. However, in multiproduct mills the recovery boiler can be fed with fuel from various processes, e.g. kraft process, the NSSC fibre line or other processes. The same applies to the process-related waste fractions. The values of BAT-AELs for these individual technical units/processes are given in Chapter 8 of this document.

2.1.2 Proposed approach to estimate emissions for integrated chemical pulp mills and/or multiproduct mills

As indicated above, in integrated and/or multiproduct mills, there is a common treatment of the waste water from the different production areas. Consequently, the difficulty of estimating emissions for integrated and/or multiproduct mills is limited to waste water.

The technical descriptions of the basic production operations at integrated and/or multiproduct mills can be found in the corresponding chapters of this document, e.g. supporting operations (utilities), processes and techniques common to all mills in Chapter 2; chemical pulping in Chapters 3 and 4; different types of mechanical pulping in Chapter 5; processing paper for recycling in Chapter 6, and papermaking in Chapter 7.

However, in the case of integrated mills with mechanical pulping and processing paper for recycling, the breakdown may not be necessary as mechanical pulping and processing paper for recycling operate almost exclusively in an integrated way. For practical reasons, for these two types of pulping (mechanical pulping and processing paper for recycling), the description of processes, techniques, BAT and the BAT-AELs cover both mechanical pulping/processing paper for recycling and papermaking (only for a detailed description of the processes and techniques of papermaking should readers refer to Chapter 7). If a mill however produces market mechanical pulp or market deinked pulp (DIP), the same emission levels associated with the use of BAT apply to them as for integrated mills. This is because the pollution load generated during papermaking or alternatively during drying of the pulp does not differ significantly.

In the case of parameters like fresh water use, waste water flow, specific emission loads (e.g. kg COD/ADt), total process heat and electrical power consumption, the specific emission/consumption levels for integrated chemical pulp mills and/or multiproduct mills can be calculated using the method given below for specific waste water discharges. This does not apply to normal integrated RCF paper mills and mechanical pulp and paper mills that are not multiproduct mills.

Equation 1 in Section 2.1.3 can be used to calculate the emission load of a multiproduct integrated mill. However, if a multiproduct integrated mill runs processes that are not covered by this document (e.g. a sawmill, see Figure 2.1) but that affect the total emission load (e.g. the waste water load from a sawmill, from conversion of by-products, from PCC production, etc.), these emissions have to be taken into account when estimating the emissions for the entire mill.

The estimation can be verified based on continuous or periodic measurements of atmospheric and water emissions, the weighing of waste fractions and, in the case of resource and energy consumption, using the direct mill production data.

2.1.3 Proposed method for assessing emissions for specific waste water discharges

As mentioned above, waste waters from the processes of the integrated production are usually mixed and emission data after treatment are usually measured at only one point of discharge. In order to consider the individual contribution from pulping and papermaking to the measured total pollution load, a simplification is proposed that gives reasonably accurate results. The proposed method of estimation is based on the principle of additive shares of discharges from sectors/operations of the integrated pulp and paper mill. The estimation method does not apply to common RCF paper mills and mechanical pulp and paper mills (i.e. which are not multiproduct mills). This is because for these mills manufacturing pulp only (DIP, mechanical market pulp), no data were provided and also only a few single mills of this type are operating in Europe. Their pollution load can be approximated by using the consumption and emission levels per tonne of product produced of the integrated sites.

The load of a certain pollutant (pollutant P, e.g. COD) from an integrated chemical pulp mill and/or multiproduct mill can be calculated according to Equation 1:

Equation 1: $$\mathrm{Load_P = (LOAD_{P1} \times PROD_1 + LOAD_{P2} \times PROD_2 + LOAD_{Pn} \times PROD_n)}$$

where

$\mathrm{Load_P}$:	Total emission load of a pollutant P (e.g. COD) from the integrated chemical pulp mill and/or multiproduct mill. The load should be expressed for the same reference period as the corresponding net production (PROD). The unit will be in kg pollutant/day for daily average values or in kg pollutant/year for yearly averages.
$\mathrm{LOAD_{P(1\ to\ n)}}$:	Emission levels of a pollutant (P) for different types of pulp or paper production.
$\mathrm{PROD_{(1\ to\ n)}}$:	Corresponding net production (e.g. ADt/day or ADt/year) of each type of pulp or paper manufactured in the integrated mill determined for the same reference period as the load.

As a result from Equation 1, for an integrated chemical pulp and paper mill and/or multiproduct mill we get the total emission load (e.g. kg COD/day) of a pollutant P (e.g. COD) for a selected reference period (e.g. day, month or year).

When using Equation 1 for the assessment of the total load of an integrated mill, it should be borne in mind that these calculated values do not take into account all the features of integrated processes and are therefore only indicative. In integrated mills, this assessment should be carried out by subprocesses (pulping, papermaking, etc.), which are described in this document.

The same estimations can be carried out for the corresponding flows (m^3/ADt) of the main production processes involved in order to determine the total associated flow (e.g. m^3/day) from an integrated or multiproduct mill (according to Equation 2):

Equation 2: $\sum flow = (flow1 \times PROD_1 + flow2 \times PROD_2 + flown \times PROD_n)$

The abbreviations used in Equation 2 have the same meaning as for the load discussed for Equation 1 however always replacing load with flow. Additional emission sources and emission prevention and control measures may have to be considered case by case.

All reliable estimation methods should consider the properties of the different waste water streams, their biodegradability, the type and removal efficiency of the waste water treatment plant and the production data. However, in many cases the treatment process itself determines the final emissions more than the properties of the incoming waste water, reducing the relevance of the estimated allocation of emission loads. Allocation can therefore be simplified by use of transparent assumptions or the assessment of removal efficiencies of the treatment system for the waste water streams in question.

Some integrated mills have developed their own individual estimation methods for the allocation of the pollution load. These methods are either based on rather rough assumptions and rules or on laboratory or pilot testing with the different waste water fractions as well as on long-term experience in running the waste water treatment plant. In the latter case, test results of the biodegradability of the effluent components, the content and usability of the nutrients for the biomass and total reduction rates in the treatment plant are typically available. With this information and the data on production rates and on the flow and the properties of incoming waste water fractions, the operators can assess the contribution of the different manufacturing processes of the integrated plant to the total emission load measured at the point of discharge.

For further explanation of this issue, the reader is referred to Annex I (see Section 10.1) which discusses two examples of real multiproduct mills and describes how the emissions for specific waste water discharge can be estimated in practice.

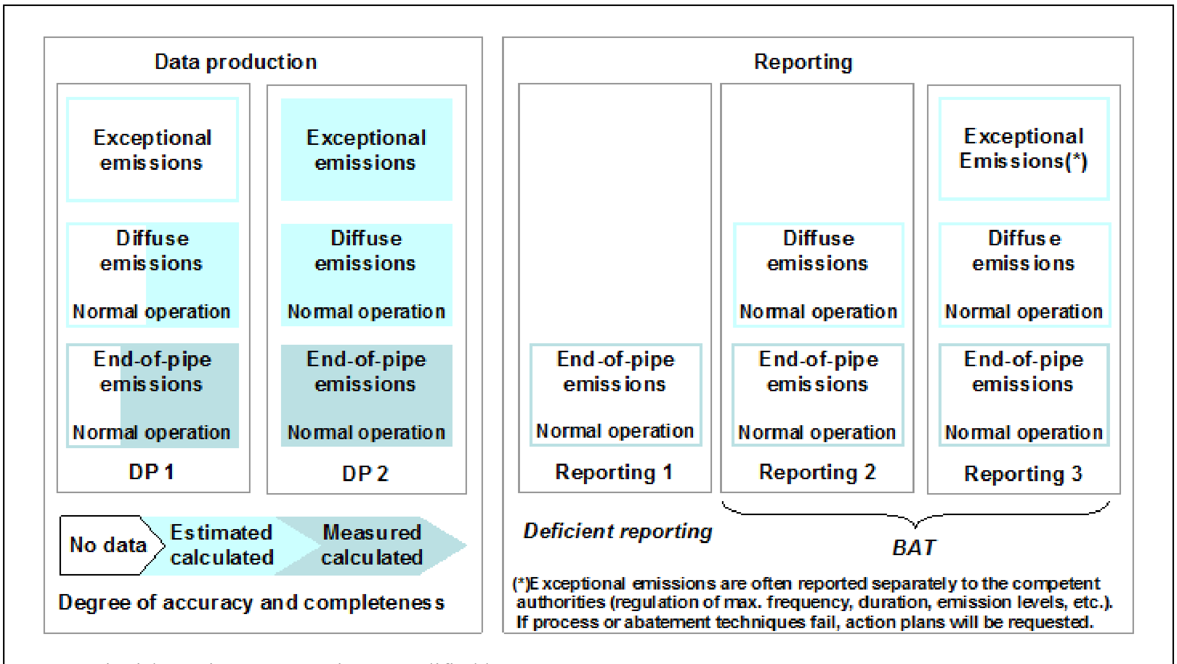
2.2 Monitoring

2.2.1 General aspects of emission monitoring in pulp and paper mills

The way emissions are monitored strongly influences the comparability of produced emission data, which are, among others, used for the determination of BAT-AELs.

The reader should bear in mind that depending on the purpose of monitoring and reporting (such as compliance control or environmental reporting) different reference periods (daily, monthly, yearly averages) are used (see Section 2.2.1.3).

Figure 2.2 shows schematically different forms of data production including the relevant types of emissions to be taken into account during the data production and the reporting of emissions for pulp and paper mills. The degree of accuracy and completeness of different methods for the determination of emissions is also indicated in the figure: emissions that are directly measured and values calculated on the basis of direct measurements are normally the most accurate and complete.



Source: Finnish Environment Institute, modified by EIPPCB

Figure 2.2: Different forms of data production and reporting of emission data from pulp and paper mills

In order to compare total emissions of pulp and paper mills, all relevant emission sources and operational conditions have to be included, i.e. channelled, diffuse and fugitive emissions both under 'normal operating conditions' and under 'other than normal conditions' (includes foreseeable and unforeseeable operational conditions). Exceptional releases during foreseeable conditions are generated e.g. during routine start-up and shutdown periods, during maintenance or due to normal variations in the input or process conditions. Unforeseeable conditions include e.g. unexpected varying input or process conditions or malfunction in the process, the abatement technique or the monitoring devices, or human error.

A more detailed description of these concepts is provided in the Reference Document on General Principles of Monitoring [269, COM 2003].

2.2.1.1 Emission sources covered

Emissions to water
Pulp and paper mills have usually only one point of discharge (see Section 2.2.2.1.1). Waste water discharges from pulp and paper mills are normally collected from all parts of the mill, mixed and sent to an on-site treatment plant. In a few cases, the collected waste water is discharged via sewer. Emissions may include the cooling water (if it is reused as process water) and often consider the process effluents only. Diffuse emissions to water are not relevant if collecting systems are implemented and sewer systems are periodically inspected and maintained.

Emissions to air
For atmospheric emissions, several sources for channelled emissions have to be taken into account (mainly combustion processes). The major types of plants in pulp and paper mills that emit pollutants to the atmosphere are listed in Section 2.6.1, and are further discussed in Section 2.2.2.2.1, Section 2.2.2.2.2 and in more detail in the respective sections of the process-related Chapters 3 to 7 that deal with atmospheric emissions.

For a number of processes, diffuse emissions are also relevant and should be considered. Diffuse emissions can mainly play a relevant role in some chemical pulp mills (see Section 2.2.2.2.6 and Section 3.3.15). Collection, treatment and measurement of diffuse emissions from kraft pulp mills are described in Section 2.2.2.2.6 and Section 3.3.15. In most sulphite mills, almost all ground-level SO_2 and odour-containing gases are collected and incinerated or scrubbed (see Section 4.3.22). When reporting the total sulphur emissions from kraft pulp mills, in all the cases where weak gases are not (almost) completely collected and treated, malodorous gases from the large number of non-point sources should be periodically measured, assessed and reported separately. Odour nuisances give a first indication of diffuse emissions released from the processes.

2.2.1.2 Operating conditions covered

Emissions to water
Normal operating conditions include all activities that regularly occur during normal production days and which may have effects on the water use and the discharge levels, such as maintenance or normal variations in the input or process conditions:

i. For chemical pulp mills, normal operating conditions include spillages from the pulping or recovery line, change of production output, change of wood raw material, change of product quality such as brightness (ISO %), regular routine maintenance and cleaning. For integrated pulp and paper mills, see also iv. 'paper mills' below.
ii. For mechanical pulp mills, normal operating conditions include the change of refining targets and wood raw material used, change of product quality such as brightness (ISO %), regular routine maintenance and cleaning. For integrated pulp and paper mills, see also iv. 'paper mills'.
iii. For RCF mills, normal operating conditions include the change of quality of the paper for recycling used. For paper manufacturing see iv. 'paper mills'.
iv. For paper mills, normal operating conditions include the change of paper grades and qualities, paper breaks, stopping and start-up of the paper machine or other parts of the process due to paper breaks, regular routine maintenance and cleaning of equipment, tanks, pipes, chests and floors.

For emissions to water, differences between 'normal operating conditions' and 'other than normal operating conditions' are in general less significant due to the dilution and equalising effects caused by the great volumes that are collected and mixed in the sewer system on-site, the equalisation tanks before the biological stage, in some cases the use of emergency basins (spillages), and the volume and retention time in the waste water treatment plant itself. The emission levels set in the permit normally cover all types of operating conditions.

Other than normal operating conditions - if they occur - are normally defined in the permit and/or are reported to the competent authorities (number of events, time interval during which exceptional emissions occurred, cause, emission levels measured and actions planned or taken to return to the previous state). Such 'exceptional operating conditions' may include e.g. testing new chemical additives, other new materials or process equipment that may have an impact on the waste water treatment performance.

Emissions to air
'Normal operating conditions' include all activities that occur during normal production days either at regular intervals or occasionally (e.g. paper breaks) and they include in particular procedures which are part of the routine maintenance activities. They also include typical variations in emissions as a result of variations of the input or process conditions.

Even though they often have an effect on the atmospheric emissions, 'normal operating conditions' include:

- change of load conditions for boilers;
- normal variations in the input or process conditions;
- change of product quality or grade;
- paper breaks or other interruptions in other parts of the process;
- routine maintenance and cleaning on a regular basis (e.g. periodic cleaning of filters, scrubbers or other parts of the abatement equipment or measuring systems);
- supervision of the plant and 'external' measurements.

Special arrangements can be drawn up for start-up or shutdown time periods. Such situations that are normally defined in the permit include particular processes during which:

- a waste gas purification facility has to be turned off for safety reasons (danger of deflagration, clogging-up or corrosion);
- a waste gas purification facility is not fully effective because of insufficient waste gas flow rate; or
- waste gas collection and purification is not feasible or not sufficiently feasible as receptacles are charged or emptied.

For recovery boilers of sulphite pulp mills, with regard to the SO_2 emissions in most mills, two different operating conditions have to be distinguished: 'normal operating conditions' and periods of 'acid operation' (flushing and cleaning of the incrustation in the scrubbers and washers). The latter refer to an operational mode where the scrubbers are cleaned preventatively of incrustations of magnesium monosulphite ($MgSO_3$). During the cleaning cycles of the scrubber, the emissions raise as one of the scrubbers or the final washer is not operating and must be compensated for by the residual scrubbers.

2.2.1.3 Data processing

Yearly average emission data should cover all releases, from all operational sources and under all conditions, including end-of-pipe and diffuse emissions during normal operating and also other than normal operating emissions, if they occur. Data are usually based on direct measurements (such as continuous and discontinuous measurements) or indirect monitoring (such as calculations, mass balances and emission factors). The annual load should cover almost 100 % of the total operation time in the case of water (to be noted: the frequency of analysis). In the case of air emissions, 100 % of total operating time is only covered when continuous monitoring systems or specific calculation tools are applied and all diffuse emissions are collected or taken into account (refer to the right-hand column in Figure 2.2).

Representative daily average emission data reflect what is normally achieved over a longer and sustained period of time. All emissions that are measured, whether continuously, periodically or by grab samples, are recorded and reported.

For the purpose of reporting representative achieved emissions or BAT-AELs for short-term reference periods such as daily average emissions, an assessment of the data set is often needed to allow the removal of misleading and non-representative data. In many cases, it makes sense not to consider unusual extreme peak values. If all peak values for reporting of representative achieved daily average emissions or BAT-AELs were included, in some cases this could result in very large, misleading emissions ranges that would not representatively reflect the real environmental performance of a mill since unusually low or high emission values would be overestimated (because they only occur during a very short time interval). Therefore, for reporting representative daily average values, certain exceptional operating conditions and unusual peak values of a very limited number of operation days may be dismissed. Different methods can be used, e.g. statistical approaches (e.g. 95th percentile) or analysing the causes of unusual peak emissions in order to assess individually the representativeness of the data.

For further information on the variation of emissions during different reference periods and the relationships between the different applied reference periods (daily, monthly and yearly mean values), the reader is referred to Section 10.2, Annex II.

2.2.1.4 Presentation of emission data

Emissions to water measured as concentration values should always be completed with the corresponding waste water flow measured at the same time interval as when the sampling took place. Concentration values without knowing the corresponding flow have little value. Reading flow and concentration values simultaneously allows for calculation of the pollutant load discharged to water bodies (or the sewer). Loads can be expressed as kg pollutants/day (or month, or year) or as a product-specific emission load (kg pollutant per tonne of product).

When calculating the emission load for emissions to air, a simultaneous measurement of the concentration, the corresponding average volumetric flow rate (i.e. under the same standard conditions and oxygen content) and the operational time should be carried out and reported in order to derive comparable emission loads. With these emission loads, specific emission factors can be calculated such as e.g. kg NO_X/ADt.

2.2.2 Emission data production in pulp and paper mills

2.2.2.1 Monitoring of waste water discharges

Monitoring the discharge of waste water includes taking representative samples of waste water, analysing, interpreting and reporting them. For the determination of relevant parameters in all Member States, standardised procedures and methods exist for sampling and analysing waste water. The procedures should use the relevant international standards (e.g. European Committee for Standardization (CEN), ISO) or national standards which will ensure the provision of data of an equivalent scientific quality.

The analysis should be performed by accredited laboratories (ISO 17025). The techniques used for monitoring are generally described in the Reference Document on the General Principles of Monitoring [269, COM 2003]. Therefore, only the aspects specifically relevant to pulp and paper mills are discussed below.

The use of standard procedures and methods for the determination of major emission parameters have always to be met for measurements of compliance control. Rapid test methods can also be used. The result of rapid tests should be checked regularly (e.g. monthly) against EN standards or, if EN standards are not available, against other standards which ensure the provision of data of an equivalent scientific quality. These rapid tests are often also used for other company-internal measurements or analysis of certain flows and concentrations in the context of self-monitoring (see next section).

2.2.2.1.1 The sampling points

Sampling at the point of discharge (for parameters set in the permit)
Normally, reported data refer to the point where the effluents are discharged into the receiving water, i.e. after external treatment. In most cases, this is the point at which the waste water leaves the treatment plant and is either merged with the receiving water body (direct discharge) or with waste water flows from other origins (indirect discharge to the sewer). Most pulp and paper mills discharge directly to water bodies and make sure that the effluents are rapidly mixed with the receiving water body, in some cases by the use of special devices such as effluent diffusors.

Sampling in self-monitoring programme
Additionally, many mills take samples from a number of other points in the mill and in the waste water treatment plant as part of their internal process-oriented quality management or self-monitoring programme. These more comprehensive monitoring programmes can ensure that production processes and the associated treatment plant operate at the designed capacity and achieve the targeted performance. Additionally, possible malfunctioning of the waste water treatment plant and each of its technical units can be more easily avoided or detected at an early stage. If malfunctions occur, by analysing the data from self-monitoring the disturbances can quickly be assessed and counteraction can be taken. The application of this type of self-monitoring allows for effectively managing the proper functioning of the waste water treatment plant. For this purpose, many mills take additional samples of the inflows and outflows of each part of the treatment system for the major process parameters.

2.2.2.1.2 Sampling methods and periods and frequency of analysis

Samples are usually collected in a flow-proportional way using continuous automatic samplers. In some cases (sufficient flow stability), time-proportional sampling is also used. Differences between countries and mills in terms of complete and accurate continuous monitoring of the different parameters seem to exist: different sampling periods are used, the frequency of analysis of a given parameter varies and in a few cases, different methods of analysis are used (e.g. tot-N).

The taking of samples for analysis can be carried out using different sampling periods.

- A grab or random sample (RS), which refers to a single sample taken from a waste water flow.
- A mixed or composite sample (MS or CS), which refers to a sample which is taken continuously over a given period, or a sample consisting of several samples taken either continuously or discontinuously over a given period and blended. The most common sampling period in the sector is 24 hours (24-hour mixed sample, 24 MS). In most cases, continuous samples based on the flow are used.
- In some countries, different reference periods are applied: (i) Germany and Poland also use shorter periods (e.g. two-hour mixed sample, 2 MS); (ii) in Italy concentration values are determined by random or three-hour composite samples, while load is calculated from the average of the values of the samples used for concentration measurements; (iii) in Finland, weekly composite samples (WCS) or even monthly composite samples (MCS) are also collected and analysed in some cases.
- In Germany, in some mills a 'qualified random sample' (QS) is taken, which refers to a composite sample of at least five random samples taken over a maximum period of two

hours at intervals of no less than two minutes and blended. A similar sample is taken in Poland (three random samples taken over a maximum period of two hours).

Usually 24-hour mixed samples are taken from Monday to Sunday. At some mills in Finland, Norway and Sweden 24-hour samples are taken from Monday to Friday and one 72-hour sample from Friday to Monday. In the latter case the daily average values are based on the average load for the weekend and the measured flow for each separate day.

Table 2.1 shows examples of the sampling periods for the relevant parameters in pulp and paper mill effluents.

Table 2.1: Examples of sampling periods for the relevant pollutants

Country	**TSS**	**COD**	**BOD$_{7 or 5}$**	**Tot-P**	**Tot-N**	**AOX**	**EDTA**	**Chlorate**
AT(*)	24h CS	24h CS	24h CS	24h CS	24h CS	24h CS		
DE(**)	DCS	DCS	BOD$_5$ DCS	DCS	DCS (1)	DCS	Case by case (2)	Not measured
FI	DCS	DCS	BOD$_7$ WCS or MCS (3) (4)	WCS or MCS (3) (4)	WCS or MCS (3) (4)	WCS or MCS (3) (4)	Not measured	Not measured
NO	DCS	DCS	-	24 MS or MCS (5)	DCS or MCS (5)	DCS	Not measured	Not measured
PL	DCS, QS (6)	DCS, QS (6)	BOD$_5$, DCS, QS (6)	DCS, QS (6)	DCS, QS(6)	DCS	Not measured	Not measured
SE	DCS	DCS	Only mill internal control	WCS	WCS	WCS	WCS	WCS in ECF mills
UK	RS or DCS	RS or DCS	RS or DCS (7)	RS or DCS (7)	RS or DCS (7)	Not measured		
IT (*)	RS, THCS	RS, THCS	RS, THCS	RS, THCS	RS, THCS	RS, THCS	Not measured	
Other countries	No sufficiently qualified data available							

NB: RS = Random sample; THCS = Three-hour composite sample; DCS = Daily (24-hour) composite sample of a corresponding flow; 24h CS = 24-hour composite sample of a corresponding flow, WCS = weekly (once a week) composite sample; MCS = monthly (once a month) composite sample. Samples are taken continuously and in a flow-proportional way.

Austria

(*) Number of measurements per year for self-monitoring and/or compliance monitoring is defined by the competent authority. For large plants, self-monitoring for certain parameters can be up to continuous measurement: compliance monitoring up to 5 times per year.

Germany

(**) For emission control by permitting authorities, the sampling period for the relevant pollutants: COD, BOD, P, N, AOX in Germany is a two-hour composite sample or qualified random sample.

(1) In some cases, data reported as tot-N were determined as inorganic nitrogen. In pulp and paper mill waste water, the share of organically bound nitrogen is typically high and the difference between TN_b and $N_{inorganic}$ is often significant.

(2) EDTA or DTPA (containing organic nitrogen) is only determined separately in some mills.

Finland

(3) A sample is collected in relation to the flow using the collection container in the freezer.

(4) Some mills also analyse these parameters daily.

Norway

(5) Depending on the receiving waters more frequent sampling does occur, normally every fourth week, analysed on weekly composite samples or samples from the last 72 hours.

Poland

(6) In some cases the qualified random sample (QS) is used. It refers to a composite sample of at least three random samples taken over a maximum period of two hours at regular time intervals, and blended.

United Kingdom

(7) Some mills do not monitor BOD$_5$, tot-P and tot-N.

Italy

(*) Number of measurements per year: for self-monitoring, defined by an internal monitoring system; for compliance monitoring, defined by the competent authority. Random samples correspond with the use of rapid tests (e.g. self-monitoring), while three-hour composite samples are linked to compliance monitoring.

The sampling period and the frequency of monitoring are shown to be similar but do vary to a certain extent both between countries and between mills within the same country (see, e.g. the cases of Finland or Germany). This variation should be considered when comparing emission data between mills and countries.

All countries measure suspended solids, organic substances such as COD, the nutrients N and P, and also AOX in most cases. In most countries and mills, COD (or alternatively TOC), TSS, phosphorus and nitrogen (the Dr Lange method is often used for monitoring P and N) are analysed for each of the samples. In other countries and mills, tot-P, tot-N, AOX and chlorate are analysed only for weekly composite samples. For example, in Sweden emissions of chlorate are monitored at ECF kraft pulp mills. Other countries do not measure chlorate at all. EDTA/DTPA are analysed for weekly composite samples in some chemical or mechanical pulp mills, e.g. in Sweden and Germany. EDTA is not a routine parameter and is only monitored when it is used as a chelating agent and not in all cases. Recent permits, e.g. in Germany, include target values for daily loads of EDTA released to water bodies that have to be monitored.

As after biological treatment the biodegradable organic substances are mostly eliminated, these days BOD receives less attention and the parameter BOD is measured only once a week in many mills.

Besides the type of sampling or the sampling period, the frequency of analysis of the major parameters plays an important role when interpreting and comparing emission data. An example of the frequency of analysis is shown in Table 2.2. All samples are shown to be 24-hour composite samples. The frequency of analysis may vary between parameters (P, N, AOX) and between mills in the same country. COD and TSS are analysed daily on a 24-hour composite sample basis, BOD once a week. The rest of the parameters show a relatively wide variety in terms of measurement frequency. This should be borne in mind when e.g. comparing AOX reported as 'yearly average values'.

Table 2.2: Example of the frequency of analysis of the relevant waste water parameters in pulp and paper mills of several countries

Country	TSS	COD	BOD_5	Tot-P	Tot-N	AOX	EDTA	Chlorate
Portugal	24 MS	24 MS	24 MS	24 MS	24 MS	24 MS	Not measured	Not measured
	(1)	(1)	(2)	(2) or (3) or (5)(*)	(2) or (3) or (5)(*)	(3) or (4) or (5) or (6)(*)	NA	NA
Finland	24 MS	24 MS	24 MS or WCS or MCS	24 MS or WCS or MCS	24 MS or WCS or MCS	24 MS or WCS or MCS	Not measured	Not measured
	(1)	(1)	(1) or (2) or (5)	(1) or (2) or (5)	(1) or (2) or (5)	(1) or (2) or (5)	NA	NA
Germany	24 MS, daily	24 MS, daily	BOD_5 weekly of one DCS (8)	Once per week one 24 MS (8)	Once per week one 24 MS (8)	DCS, 4 times per year	Case by case, if applicable	Not measured
Poland	The frequency of analysis is established case by case in the integrated permit. For pulp and paper mills the frequency is usually higher, e.g. once a month. Some larger mills collect 24-hour composite samples every day and analyse the samples daily in their own laboratory for their own control purposes.							
Other countries	No sufficiently qualified data available							

NB:
NA = not available
24 MS = 24-hour mixed sample of a corresponding flow.

Portugal
Source: CELPA Associates, 2009: (1) Analysed daily; (2) Analysed once a week; (3) Two analyses per month; (4) Occasional analysis; (5) Analysed once a month; (6) Analysed every six months.
(*) According to the permits.

Finland
(1) Analysed daily; (2) Analysed once a week; (5) Analysed once a month.

Germany
(8) Many mills also analyse these parameters daily, source: VDP, 2009.

Determining N and P over lengthy intervals does not provide the operator with the necessary information for immediate action in case of inadequate dosage of nutrients or malfunctioning of the biological treatment plant. However, additional self-monitoring is possibly carried out in these mills.

As part of their self-monitoring, in several biological waste water treatment plants on-line measurement of nitrogen and phosphorus for controlling the dosage of the nutrients is used successfully (e.g. DE, FI, SE). The on-line analysis of samples that are taken continuously and flow proportionally allows in these cases for accurate quantification of the nutrient situation in the treatment plant and, in the case of poor performance of the treatment plant or inadequate dosage of nutrients, for taking prompt action.

2.2.2.1.3 Major parameters and analytical methods

All samples are taken unfiltered by accredited laboratories under ISO 17025 or laboratories accepted by the authorities, preferably certified under other ISO standards (e.g. ISO 9001), and are analysed (COD, BOD, TSS). Analytical methods applied are standardised methods and are accepted by the competent authorities of the given countries. It can be expected that the analytical methods are very similar and the results comparable between countries. As evidence for this statement, Table 2.3 shows analytical methods used in three selected European countries. All countries use standardised methods that are based on similar measurement principles.

Table 2.3: Parameters measured and analytical methods used in three example countries

Parameter	Analytical methods used in Finland	Analytical methods used in Germany	Analytical methods used in Portugal
Flow	Flow meter (magnetic or ultrasonic) or level-based flow meter	Flow meter (magnetic or ultrasonic)	Ultrasonic flow meter or BS 3680- Part 4C or Parshall flow meter
TSS	SFS-EN 872: 1.6 µm (GF/A)	DIN EN 872 1.6 µm (GF/A)	SMEWW 2540B, D or EN 872 or SMEWW 250D; 1.5 µm
COD (unsettled, unfiltered sample)	SFS 5504 ISO 15705	DIN EN 38409 or rapid tests that are considered equivalent to standard methods (a list is provided by Dr Lange)	SMEWW 5220B, D or ISO 15705 or ISO 6060:1989; also rapid tests
TOC	Not applied	EN-1484 unfiltered	Not applied
$BOD_{5 \text{ or } 7}$ (unsettled, unfiltered sample)	SFS-EN 1899 and SFS-EN 25813 or SFS-EN 25814	DIN EN 1899-1	SMEWW 5210B, D or SMEWW 2510B or ISO 5815-1
Tot-P	SFS-EN 6878 or SFS-EN 1189 or SFS 3026	Spectrometric, often rapid tests	SMEWW 4500-P, A, B4, C, D, E, H or ISO 6878 or MI Nº133
Tot-N	SFS-EN 11905 or SFS 5505	DIN EN ISO 11732, DIN EN 10304-2, DIN EN ISO 13395, often rapid test (sum of $N_{inorganic}$)	SMEWW 4500 N and 4500NO3 I or ISO 11905-1 or ISO 10048 or MI Nº135
AOX	SFS-EN 1485	EN ISO 9562	EN ISO 9562 or DIN 38409-H14
Conductivity	SFS-EN 27888	DIN-EN 27888	No data
EDTA	Not measured	DIN 38413-3	Not measured
Chlorate	Not measured	Not measured	Not measured
Temperature	No data	On-line	No data
pH	No data	On-line	No data

NB:
SMEWW = Standard methods of examination of water and waste water;
EN = The European Standards (EN) are methods that have been ratified by the European Committee for Standardization (CEN). After ratification European standards apply without changes as national standards (except for e.g. an introductory preface).
In Germany, data reported as tot-N were determined as inorganic nitrogen.
To determine TSS in Europe, different methods and filter types are used: Austria (0.45 µm paper membrane filter), Sweden (1.6 µm filter), Netherlands (7-12 µm filter), Italy (0.45 µm membrane filter), Spain (0.7 µm glass fibre filter), Germany (1.6 µm filter), UK (1.2 µm glass fibre filter), Belgium (7-12 µm filter paper), France (20-25 µm filter paper, some sites 2 µm filter).

Source: Paper Associations of FI, DE, PT

Many mills use rapid tests (e.g. Dr Lange, Hach) in their daily routine. The results of these rapid tests are controlled regularly and results are compared with standardised methods such as EN or ISO methods in order to guarantee comparable and reliable data.

2.2.2.1.4 Interrelationship between measured concentrations and calculated emission loads

On the basis of reliable concentration measurements and flows, emission data can be transformed into specific emission factors or loads. Emission data in both forms are very useful for the regulator and operator. In the pulp and paper sector, it is quite common to express the emission data as a specific emission load (e.g. kg COD/ADt). In some countries however it is more common to set permit values expressed as concentrations (e.g. mg COD/l). Therefore, the document presents both units and discusses below how BAT-AELs expressed as emission loads can be converted into concentration values and vice versa.

If an emission level is determined in the form of concentration levels only, this value for the polluting substances applies at the point where the emissions leave the installation, and any dilution (i.e. adding extra water which is not useful for the process and is not needed for the quality of the product) prior to that point is disregarded when determining those values.

It is recommendable that both concentration and load values always be interpreted considering the corresponding flow thus assessing emission loads to the environment as well as the local impact of a concentrated stream of waste water on the receiving water body. By this means, water-saving measures that keep or reduce the emission load but which may increase the measured concentration values will not be penalised.

The current practice of pulp and paper mills in Europe is to calculate from measured concentrations the load of pollutants that are released to the environment. Most permits refer to maximum load values that are derived from the BAT-AELs for a given pollutant. In permits, the loads are often expressed as daily, monthly or yearly loads (e.g. kg COD/day, tonnes COD/month, tonnes COD/year). These values are derived from technically-based product-specific values expressed as kg pollutant per tonne of end product manufactured (e.g. kg COD/ADt). Environmental quality standards may require additional measures.

In Figure 2.3 the calculation of daily emission loads and product-specific emission loads are explained by use of the relevant equations. An example calculation for a real mill follows for the parameter COD further below. It can be calculated in the same way for all the other parameters of concern and for other reference periods (monthly or yearly time intervals).

The calculation of the daily emission load and the specific loads and flows is based on reliable knowledge of the following data:

- concentration of a given pollutant during a defined time period [e.g. mg/l of a 24-hour composite sample]
- flow determined during the same time interval as the concentration value [e.g. m^3/day]
- net production during one and the same time interval [e.g. ADt/day].

Equation (1) for the daily COD load [kg COD/day]
Concentration (1) [mg/l] × corresponding flow (2) [m^3/day]/1 000

Equation (2) for the specific COD load [kg COD/ADt]
COD load per day [kg COD/day]/daily net production [kg ADt/day]

Equation (3) for the specific flow [m^3/ADt]
Daily flow/daily net production

The same calculation can be carried out for monthly and yearly emission average values. For the monthly specific COD load, the daily COD loads are summed up and divided by the monthly net production; for the yearly specific COD load, the COD loads of all days of the year are summed up and divided by the yearly net production. In the same manner, these values can be established for very short reference periods (e.g. two-hour mixed samples and the two-hour corresponding flow).

(1) Results of the laboratory analysis of the 24-hour composite samples.
(2) The flow is measured by flow meters for a corresponding reference period (day, week, month, year).

Figure 2.3: Example for the conversion of the concentration of a water pollutant of concern (mg/l) into daily emission loads and specific emission loads and flows

A calculation for a real kraft pulp mill exemplifies the interrelationship between measured concentration, and daily emission load and product-specific load for the parameter COD.

The COD concentration of the effluents from the waste water treatment plant of this mill is 397 mg/l (measured in a 24-hour composite sample). The corresponding flow during that day is 44 204 m^3/d (on-line measurement over the corresponding 24 hours). The daily COD load can be calculated according to Equation (1) by multiplying the concentration and flow which gives 17 549 kg COD/day. The net pulp production during that day is 1 840 ADt/day (value of the corresponding day). The product-specific COD load can be calculated according to Equation (2) to be 17 549/1 840 = 9.5 kg COD/ADt. The specific waste water flow according to Equation (3) is 24 m^3/ADt.

In permits of European pulp and paper mills for the calculation of the product-specific load, two different approaches for the corresponding production are applied: 'net production' and 'installed maximum machine capacity'. In order to present comparable and traceable data, in this document, all emission values and BAT-AELs refer exclusively to the net production (air dry) or the 'saleable product' (see Item II below).

I. **The installed maximum machine capacity**

The installed maximum machine capacity is the defined capacity of production of an end product weighed after the production machines and agreed to by the authorities. This value refers to the yearly maximum net production capacity of a pulp mill or the net paper machine(s) production capacity (i.e. paper manufactured after roller, cut and wrapped, broke excluded). The maximum machine capacity is a fixed value (independent of the real amount of production at a given period of time) that does not change until the operator applies for an increase of the production capacity at the permitting authority. The installed maximum machine capacity normally differs from the real production (see Item II below). The result is quite comparable with the saleable product when the mill operates at full capacity. For permit compliance, the specific loads (e.g. kg COD/ADt) are calculated on the basis of the actual flow and the actual concentrations and the production capacity laid down in the permit. For external communication or environmental reporting, these companies additionally often use emission load factors based on the real net production. For this document, the emission data from these mills were provided based on real net production in order to have comparable data.

II. The net production

(i) For paper mills, net production refers to the unpacked, saleable production after the last slitter winder, i.e. before conversion.
For off-line coaters, the net production is after coating.
For tissue mills, net production refers to saleable tonnes off the tissue machine before any rewinding processes and excluding any cores.
(ii) For market pulp mills (non-integrated mills), the net pulp production refers to the tonnage after packing (pulp at 90 % dryness, i.e. 'air dry' - AD).
(iii) For integrated pulp and paper mills, the net pulp production refers to the tonnage after packing (pulp at 90 % dryness, i.e. AD), plus the pulp transferred to the paper mill (pulp calculated at 90 % dryness, i.e. air dry). For the net paper production of the integrated pulp and paper mill, see (i).

Sometimes paper mills refer also to the 'saleable product' which for pulp is the same as the net production explained above; for paper production 'saleable product' refers to the weight of the paper that is sent to the warehouse.

2.2.2.1.5 Special issue that influences the comparability of emission data

In Germany, for many industrial sectors, tot-N is still defined as the sum of inorganic nitrogen, i.e. nitrite-N, nitrate-N and ammonia-N. Organically bound nitrogen is not included in most cases. Normally, the nitrogen values reported from German pulp and paper mills therefore only include part of the total nitrogen bound (TN_b) discharged to the environment; therefore, measured and reported nitrogen emissions from German paper mills tend to be lower compared with mills from countries where TN_b or tot-N is measured and reported - depending on the share of organic nitrogen that a given sample contains.

2.2.2.2 Monitoring of emissions to air

The purpose of emission monitoring is to obtain accurate, representative and comparable figures of the quantity of emitted pollutants (see Section 2.2.1). Results of emission monitoring are used for compliance control, for the purpose of informing the public, for calculating emitted loads and for optimising the emission behaviour (e.g. with respect to NO_X and CO) or the functioning of flue-gas cleaning systems (e.g. concerning SO_2). They are also used to compare the environmental performance of different plants and technologies and to define emission levels associated with the application of BAT.

State-of-the-art for emission monitoring includes the consideration of many aspects. To fulfil the above-mentioned goals, the monitoring procedure should as far as possible use the relevant CEN standards, ISO standards or national or international standards which will ensure the provision of data of an equivalent scientific quality. The monitoring procedure includes:

- location of sampling sites (e.g. EN 15529)
- choosing of measuring systems (e.g. EN ISO 14956, EN 50379-1-3)
- calibration and use of reference measurement methods
- setting of measuring systems
- functioning control
- calculation of uncertainties (e.g. EN ISO 20988)
- availability of measuring systems
- maintenance of measuring systems
- implementation of a quality assurance and quality control system (e.g. EN 14181)
- monitoring of relevant process parameters, such as oxygen content, temperature, pressure, water vapour content, flue-gas volume (mostly calculated), fuels, load conditions (e.g. EN 15529)
- calculation of emission concentrations (selection of raw data, used algorithms) and emitted loads
- reporting.

For general information on how to select a representative sampling location for atmospheric emissions or issues related to timing (frequency of measurements, averaging time, coverage of all relevant operational periods), to availability of measuring systems or the functioning control and calibration and reporting, the reader is referred to the Reference Document on the General Principles of Monitoring [269, COM 2003].

Below only the most relevant sector-specific aspects that should be considered with regard to BAT-associated monitoring are discussed.

2.2.2.2.1 The sampling points

The right location of sampling points strongly influences the accuracy and comparability of the results of emission monitoring. In general, correct sampling points can be selected for every point source of pulp and paper mills, such as combustion plants (e.g. recovery boilers, lime kilns, fluidised bed boilers, dedicated burners for odorous gas incineration, auxiliary boilers e.g. oil- or gas-fired boilers, biomass boilers, e.g. bark or multi-fuel boilers, on-site incinerators of rejects, sludge and/or biomass, cogeneration plants, e.g. CCGT) or other sources (e.g. dissolving tanks, pulp line scrubbers for cleaning the residual gases from washing, screening and the bleach plant of kraft pulp mills, dryers of the paper or coating machines).

For the location of sampling points, approved standards are available (such as EN 15529) which should be used. In many Member States a certificate from an accredited expert is required to prove that sampling points are located to enable representative emission monitoring. The representativeness of the sample is essential. Another consideration is to choose the approved measuring systems.

2.2.2.2.2 Sampling and continuous/discontinuous measurement methods

The decision whether a pollutant should be measured continuously or discontinuously depends mainly on the size of the plant, the fuels used, the flue-gas flow, operating hours, load conditions, environmental quality standards, environmental risk associated to the emission and local issues. Approved systems for continuous monitoring (CM) are available on the market for a variety of pollutants, including dust, SO_2, NO_X, CO, C_{org} and HCl. The results of continuous measurements can be used to calculate total annual emissions or to determine temporal variations of the emission during the operation (half-hour value, daily average value, etc.).

In some Member States, dust, NO_X and SO_2 emissions are measured continuously when the capacity of the plant exceeds 30 MW_{th} (CO: 10 MW_{th}). In some Member States, CM is required even at smaller plants in the case of rapidly changing load conditions or if the emission behaviour cannot be controlled accordingly (e.g. as a result of frequent disturbances).

By implementation of a system for CM the operator gets immediate feedback on the current emission situation and the emission trend. With that knowledge, it is possible to improve the emission behaviour of the plant, e.g. by optimising combustion conditions (NO_X, CO, C_{org}), the flue-gas cleaning system (SO_2) or the fuel mix. This is especially important when the characteristics of the fuel mix (e.g. calorific value, water content) and/or load conditions change repeatedly. CO as a combustion control parameter can always be measured continuously at low costs.

Another advantage is the possibility to inform the public of the emissions of the plant via the internet, which has led in many cases to improved relations between operators and the neighbours. The results of CM can also be linked to air quality data to enable an immediate and adequate reaction in the event of exceeding limit values.

The implementation of a CM system is associated with higher investment and operating costs compared to a system for discontinuous measurement of emissions. As a rule, continuous measuring systems are periodically subject to control by means of parallel measurements with the reference methods.

Discontinuous measurement is done periodically by means of a certain number of independent determination procedures. Crucial parameters are the determination of the uncertainty for the measurement and the associated load conditions which should be representative for the plant.

Discontinuous measurements are often used for emission sources with smaller flue-gas flows. Periodical measurements give the state of emissions over the chosen sampling period. If the intention of the discontinuous monitoring is to give a reliable picture of the total emissions over a period longer than the sampling period, e.g. a day, a month or a year, it is crucial to have a statistically well-founded number of samples. If the total emissions are counted on the basis of a few samples representing only a minor time interval of the total operation hours, they are likely to poorly represent the real situation. This is due to the fact that processes are not steady and prevailing process conditions or disturbances may significantly affect the calculated results.

Independent of the applied system, a detailed report of the applied procedures (strategy, instruments, systems, uncertainty, raw data, process parameters, load conditions, used fuel, functioning of flue-gas cleaning systems, sampling, sampling treatment) and the results of emission monitoring should be made available to the operator and the authority.

Reporting obligations may include in addition to total dust measurements the determination of PM_{10} and $PM_{2.5}$ (determined by size distribution). The composition of dust is determined by single measurements, e.g. once or twice per year.

Table 2.5 shows the methods normally used for sampling atmospheric emissions within some Member States that have provided data on their monitoring practice (other countries have not provided data or only incomplete or unclear data). The examples give sufficient evidence that continuous measurements are applicable to most points of emission:

(i) Austria: As a general obligation, continuous emission monitoring is required for:

- combustion of liquid and solid fuels for
    - particulates and CO, when the rated thermal input exceeds 10 MW
    - NO_X and SO_2, when the rated thermal input exceeds 30 MW
- for combustion of gaseous fuels for
    - CO, when the rated thermal input exceeds 10 MW
    - NO_X, when the rated thermal input exceeds 30 MW.

However, some authorities require continuous measurements even at lower capacities. If waste is co-incinerated continuous monitoring may be required for additional pollutants or for lower capacities according to the EU Waste Incineration Directive (*source*: Umweltbundesamt, 2010).

(ii) Finland: Table 2.4 and Table 2.5 show that in many pulp and paper mills most parameters are measured continuously; some other mills measure periodically.

(iii) Poland: All emission sources equipped with mechanical ventilation are taken into consideration. Therefore, additionally to the major emission sources compiled in Table 2.5 the following emission points are included: pulp washing and screening installations, bleaching installation, tall oil plant scrubber, smelt tank scrubber, lime slaker, dust separators on paper cutting installations, in some cases also emissions from storage tanks, lime mud and green liquors filters.

(iv) Portugal: Additionally to the measurements on the major emission sources compiled in Table 2.4 and Table 2.5 in Portuguese kraft pulp mills, periodic measurements of flow, dust, SO_2 and TRS or H_2S are carried out at the dissolving tank exhaust gases and the pulp line scrubber that cleans the residual gases and diffuse emissions from pulp line tanks and process equipment (from washing, screening, O_2-delignification, bleaching and ClO_2 plants). Additionally, after the pulp line scrubber, Cl_2 is measured periodically. Occasionally VOC are measured at the recovery boiler, the lime kiln and the separate burner for odorous gases.

(v) Sweden: According to the Swedish EPA, most of the parameters are measured continuously at recovery boilers, lime kilns, TRS burners, auxiliary boilers and waste co-incinerators. In cases where an installation for the co-incineration of waste is operated on site (e.g. combustion of rejects, deinking sludge and other materials from processing paper for recycling), more parameters are normally monitored and measured, according to the Waste Incineration Directive (WID) [203, Directive 2000/76/EC 2000].

On-line measurements in a kraft pulp mill are often more challenging than for example the energy boiler measurements due to the different physico-chemical properties of the gases. For example, recovery boiler ash is easily built up on the surface of a measuring device. Also, flue-gas moisture may cause problems. Pulp mill measurements therefore demand more maintenance than in other processes. However, as can be seen in Table 2.4, many mills apply continuous measurement of most parameters.

Additional information on the description of continuous monitoring systems can be found in the Reference Document on the General Principles of Monitoring (MON) [269, COM 2003].

Table 2.4: Continuous and periodic monitoring of process emissions from kraft pulp mills in five example Member States

Parameter	**Recovery boiler (RB)**					**Lime kiln (LK)**					**Dedicated burner for odorous gases**					**Weak gases**				
Country code	**AT**	**FI**	**PL**	**PT (5)**	**SE**	**AT**	**FI**	**PL**	**PT (5)**	**SE**	**AT**	**FI**	**PL**	**PT (5)**	**SE**	**AT**	**FI**	**PL**	**PT (5)**	**SE**
Flow	C/FA	FA, C or PM	PM	C or PM	FA	C/FA	FA, C or PM	PM	C or PM	FA	C/FA	PM	PM	PM	FD	Not measured as almost all weak gases are collected and incinerated		Not measured		Spot
SO_2	C	C, PM	PM, C	C or PM	C	C, PM	C, PM	PM, C	C or PM	C	PM	C, PM	PM	PM	C					NA
TRS or H_2S(1)	C, PM	C, PM	PM, C	C or PM	C	C, PM	C, PM	PM	C or PM	C	PM	C, PM	PM	PM	PM					1–4/yr (6)
NO_X	C	C, PM (4)	PM	C or PM	C	C, PM	C, PM (4)	PM	C or PM	C	PM	C, PM	PM	PM	C					NA
Dust	C, PM	PM, (C trials)	PM, C	C or PM	C	C, PM	PM, (C trials)	PM, C	C or PM	C	NM	PM	PM	PM	NA					NA
CO (2)	C	PM	PM, C	C, PM	C	C	PM	PM, C	C, PM	C	PM	PM	PM	PM	C					NA
Heavy met.	NM	PM	NM	PM	NA	NM	PM	NM	PM	NA	NM	PM	NM	NM	NA					NA
Dioxin/Fur.	NM	PM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA	NM	NM	NA					NA

NB:
(1) TRS includes H_2S; (2) Usually not reported to authorities; (3) Cl_{tot} ($Cl_2 + ClO_2$) emissions are measured in the bleach plant (periodical measurement).

Abbreviations used:
NA = Not available; **C** = continuously monitored, **PM** = periodical measurement **FA** = determined from fuel analysis (C,H,O,N,S, ash, moisture and energy content are analysed in a fuel analysis and are used as data input for mathematical modelling thus calculating flow); **FD** = fan data; **NM** = not measured.

Austria: Pöls and M-real measure dust at one RB continuously and the other RB periodically; TRS is measured continuously at the Pöls mill only. CO, NO_X and SO_2 are measured continuously at all RB. At the LK, the Pöls mill measures dust, CO, NO_X and SO_2 and TRS continuously; the other mills periodically. S*ource:* Umweltbundesamt, 2010.

Finland: (4) NO_X emission of recovery boilers and lime kilns are measured continuously in many mills

Poland: Fine particulate matter (PM_{10} or $PM_{2.5}$) is determined by campaign measurements, S*ource:* Association of Polish Papermakers, 2009.

Portugal: (5) Besides the major emission sources, exhaust gases from the pulp line scrubber (washing, screening and bleach plants' residual gases scrubber) and from the dissolving tank are measured periodically. *Source:* CELPA Associates, 2009.

Sweden: (6) Weak gases are emitted from different parts of the process (around 20 – 40 emission points). Remaining emissions of weak gases that are not completely collected are monitored in campaigns, often as seldom as once a year. Samples are collected in gastight plastic bags. Flow, temperature and pressure are monitored. The samples are analysed with gas chromatography. The relevant reduced sulphuric compounds are H_2S, methyl mercaptan (MM), dimethylsulphide (DMS), dimethyldisulphide (DMDS). Although results from monitoring at the same sampling point can vary much over time (minus 70 % to plus 100 % around the average), the total amounts emitted from a mill vary much less from campaign to campaign. *Source:* Swedish EPA, 2010.

Norway: At the RB and the LK flow, dust, CO, NO_X, SO_2 and TRS are measured continuously; at other RBs and LKs flow, NO_X, and heavy metals are measured periodically. For the separate burner for odorous gases periodic measurements are carried out for the flow, dust, CO, NO_X, SO_2 and TRS. LCP boilers and waste incinerators measure flow, dust, CO, NO_X, SO_2 continuously. Other auxiliary boilers periodically. Depending on the fuel (co-incineration) TOC, HCl, heavy metals and dioxins/furans are also determined. Similar to Sweden, diffuse emissions (weak gases) which not are collected and treated are normally determined/calculated 4 times a year. *Source:* Norwegian EPA, 2009.

Table 2.5: Continuous and periodic monitoring of the atmospheric emissions of combustion plants in five example Member States

Parameter	Auxiliary or bark boilers, fluidised bed combustion					Reject, sludge co-incineration				
Country code	**AT (4)**	**FI (5)**	**PL (6)**	**PT (7)**	**SE**	**AT**	**FI**	**PL**	**PT**	**SE**
Flow	C	FA, C or PM	C (6) and PM	C (7) or PM	FA	C	C, PM	No installation in operation	No installation in operation	FA
SO_2	C	C (5) or FA and PM (5)	C (6) and PM	C and PM (7) or C or PM	FA/C	C	C, PM			C
NO_X	C	C(5) and PM (5), FA	C (6) and PM	C and PM (7) or C or PM	C	C	C, PM			C
Dust	C	C (5) and PM (5)	C (6) and PM	C and PM (7) or C or PM	C	C	C, PM			C
CO (2)	C	PM	C (6) and PM	C and PM (7) or C or PM	C	C	C, PM			C
Cl_2 (3)	NM	PM	NM	NM	NA		C, PM			NA
HCl	C in some cases, PM	NA	NA	NM	NA	C, PM	C, PM			NA
TOC (or C_{org})	C in some cases, PM	NA	NA	PM	NA	C	C, PM			NA
Heavy met.	PM in some cases	PM	NA	PM (7)	NA	PM	PM			NA
Dioxin/Fur.	PM (only if RCF rejects are co-incinerated	PM	NA	NM	NA	PM (only if RCF rejects are co-incinerated	PM			NA

NB:
(1) TRS includes H_2S; (2) Usually not reported to authorities; (3) Cl_{tot} ($Cl_2 + ClO_2$) emissions are measured in the bleach plant (periodic measurement).

Abbreviations used:
NA = Not available; **C** = continuously monitored, **PM** = periodic measurement, **FA** = determined from fuel analysis (C,H,O,N,S, ash, moisture and energy content are analysed in a fuel analysis and are used as data input for mathematical modelling thus calculating flow); **FD** = fan data; **NM** = not measured.

Austria: (4) Data refer to fluidised bed combustion with rated thermal input between 4.8 and 133 MW. Most of the fluidised bed boilers co-incinerate waste. For steam boiler plants the following applies: solid and liquid fuels - continuous measurement of dust and CO for plants > 10 MW_{th}; continuous measurement of NO_X and SO_2 for all plants > 30 MW_{th}; for gaseous fuels - CO (> 10 MW_{th}), NO_X (> 30 MW_{th}), T, O_2 (or CO_2) is measured continuously. CCGT measure NO_X and CO measured continuously, S*ource:* Umweltbundesamt, 2010.

Finland: (5) The emissions of dust, NO_X and SO_2 of LCP boilers (auxiliary boiler >50 MW) are in most cases measured continuously.

Poland: (6) The emissions of flow, CO, dust, NO_X and SO_2 of LCP boilers (auxiliary boiler >50 MW) are in most cases measured continuously.

Portugal: (7) The emissions of dust, NO_X and SO_2 of LCP boilers (auxiliary boiler >50 MW) are measured continuously and periodically. Also, periodic measurements of VOC are carried out.

Sweden: *Source:* Swedish Environment Protection Agency, 2009.

2.2.2.2.3 Major parameters and analytical methods

Table 2.6 shows the measurement methods for atmospheric emissions by compound and source used in Finland.

Most of the measurement methods are based on standardised methods. There are some measurement methods for atmospheric emissions that vary over Europe. One of them is the determination of PM_{10} (some mills have their own systems for the particle size distribution). Others are e.g. VOC, TRS and the determination of the flue-gas flow.

Table 2.6 shows that the parameters included in the regular monitoring programme can all be monitored continuously. Competent authorities may require continuous, periodic or occasional measurements depending on the mass flow of the pollutant, the fuels used, operating hours, load conditions or local conditions.

Table 2.6: Measurement methods by compound and source for atmospheric emissions applied at pulp and paper mills (situation in Finland)

Parameter	Recovery boiler	Lime kiln	Auxiliary boilers (all boilers except waste incineration burners)	Separate burner for odorous gases	Waste co-incineration
Volumetric flow rate	Ultrasonic flow meter, S-pitot tube method or calculation from heat and mass balance				Ultrasonic flow meter, S-pitot tube method or thermal mass flow
Dust/ particulate matter	Indirect (surrogate parameter) continuous measurement: Light scattering, optic measurement, triboelectrical effect or gravimetric method: EN 13284 -1 or SFS 3866				Indirect continuous measurement: Light scattering, optic measurement, triboelectrical effect or gravimetric method (EN 13284-1)
PM_{10}	Determined by single measurements either by plant measurements or by using a known fraction coefficient				
SO_2	Direct continuous measurement: UV-fluorescence, non-dispersive infrared sensor (NDIR) or Fourier transform infrared spectrometer (FTIR) Indirect (surrogate parameter) continuous measurement: mass balance/fuel analysis				
TRS (indicate the compounds included in TRS)	TRS converter + UV-fluorescence, NDIR (FTIR) Direct continuous or periodical measurement/indirect continuous or periodical measurement		Not applicable	TRS converter + UV-fluorescence or NDIR (FTIR) Direct continuous or periodical measurement/indirect contin. or periodical measurement	Not applicable
NO_X	Direct continuous or periodical measurement: chemiluminescence, IR absorption or FTIR: ISO 11564:1998, ISO 10849:1993, EN 14792:2005				
CO	Continuous direct measurement: IR absorption, NDIR or FTIR: ISO 12039:2001, EN 15058:2004. Measured always in connection with other emission measurements. CO is an operation control parameter (measured in the boilers)				
TOC	Not included in regular monitoring programmes but followed up with other methods, e.g. calculation. All compound-specific measurements for waste incineration burners are also applicable to all other processes when relevant				FID or FTIR Direct continuous measurement
NMVOC					FTIR Direct continuous measurement
Metals					EN 14385, EN 13211: Direct periodical measurement
Dioxins/ furans					EN 1948: Indirect continuous measurement
NH_3					Emission factor: Calculated value
PCDD/F					Measurement or calculation
PAH-4					Measurement or calculation
HCl					EN 1911-1-3:2003 Measurement or calculation
HF					Measurement or calculation

Source: Finnish Environment Institute and Finnish Forest Industries Federation, 2009. Nearly identical methods were reported by AT, DE, SE and PL.

2.2.2.2.4 Reference conditions

Results of air emissions monitoring are normally given as mass concentrations (mg/Nm^3) for a given time period referring to standard conditions and are normalised to a certain oxygen content. If not otherwise mentioned in this document, the standard conditions for measurements of volume flows and concentrations of flue-gases are related to the following definitions:

Nm^3/h	Volume flow: the volume flows refer to the vol-% oxygen indicated for the emission source in question and standard state
mg/Nm^3	Concentration: the concentrations of gaseous substances or mixtures of substances refer to dry flue-gas at the vol-% oxygen indicated for the emission source/fuel in question and standard state
Standard state	Refers to a temperature of 273.15 K (0 °C), a pressure of 101.3 kPa and dry flue-gas, i.e. after deduction of water vapour content

Air emissions ranges expressed as concentration values always refer to a defined reference oxygen level in vol-% O_2 as indicated for the emission source in question although the actual oxygen level within the firing process might be lower or higher. Different countries have different reference oxygen levels as shown for some examples in Table 2.7.

Table 2.7: Reference oxygen levels for different combustion plants in selected countries

Type of combustion	Reference O_2 vol-% level in Portugal	Reference O_2 vol-% level in Austria	Reference O_2 vol-% level in Finland
Recovery boiler	8 %	5 %	6 %
Lime kiln	8 %	5 or 6 %	6 %
Auxiliary bark boiler	6 % or 8 %	11 or 13 %	6 %
Auxiliary fuel oil boiler	8 %	3 %	3 %
Auxiliary natural gas boiler	8 %	3 %	3 %
Biomass boiler	8 %	11 or 13 %	6 %
Cogeneration plant (CCGT)	15 %, except VOC that is 8 % and CO 8 %	15 %	6 %
Separate burner for odorous gas incineration	NA	3 %	3 %

NB: NA= Not available
Source: CELPA Associates, Environment Agency Austria, Finnish Environment Institute, 2009.

To make emission concentration data based on different oxygen levels comparable and traceable, a simple calculation according the calculation formula shown below should be applied:

$$E_R = \left| \frac{21 - O_R}{21 - O_M} \right| * E_M$$

E_R (mg/Nm^3): emissions concentration related to the reference oxygen level O_R
O_R (vol-%): reference oxygen level
E_M (mg/Nm^3): emissions concentration related to the measured oxygen level O_M
O_M (vol-%): measured oxygen level

Additional useful information on monitoring can be found in the Reference Document on the General Principles of Monitoring (MON) [269, COM 2003].

2.2.2.2.5 Interrelationship between concentration and specific emission loads

Emission measurements expressed in concentration can be transformed into specific emission loads. Emission data in both forms are very useful for the regulator and operator. However, when comparing or converting data in these forms, care is needed regarding how the emission loads were calculated.

In Figure 2.4, an example is shown for the dust emissions (annual average values) of a pulp mill. A calculation is carried out to show how to convert the concentration of a pollutant of concern (mg/Nm^3) into the specific emission factor (kg/ADt of pulp or paper).

The calculation of the emission load and the specific loads and flows is based on reliable knowledge of the following data (example of dust, yearly average values):

- dust concentration on an annual average basis (mg/Nm^3)
- off-gas flow rate on an hourly basis (Nm^3/hour)
- yearly operating time (hours/year)
- annual net production (ADt of pulp/year).

The calculation goes as follows:

– measured dust concentrations during one year (mg/Nm^3): **a**
– annual average dust concentration (mg/Nm^3), which is normally summed up from all valid values from continuous monitoring: **b**
– off-gas flow rate on an hourly basis (Nm^3/hour): **c**
– yearly operating time (hours/year): **d**
– annual off-gas volume (Nm^3/year): **e = c × d**
– annual dust emissions (kg of pollutant/year): **f = b × e**
– annual net production (tonnes of air dry pulp/year): **g**
– specific emission factor (kg/ADt of pulp): **i = f / g**
– specific off-gas volume (Nm^3/ADt): **h = e / g**

The same calculation can be carried out for monthly and daily emission average values and for the other emission parameters.

Figure 2.4: Example for the conversion of the concentration of an air pollutant of concern (mg/Nm^3) into the specific emission factor (e.g. kg dust/ADt)

The following calculation of a real case of a sulphite pulp mill shows the interrelationship between measured concentration, daily emission load and product-specific load as an example for the parameter SO_2. The calculation is carried out for monthly average values in this case.

The net pulp production (ADt) of the mill was 3 928 ADt/month. In January 2008, the average SO_2 concentration in the exhaust gas of the recovery boiler was 102 mg SO_2/Nm^3 (continuously measured). The corresponding average flue-gas flow (standard state conditions) was 34 538 Nm^3/h. The total SO_2 emission released during this month is calculated by multiplying the SO_2 concentration with the average flue-gas flow of 34 538 Nm^3/h and with the monthly operating hours, 744 hours in this case, which gives a total mass of 2 621 kg SO_2/month.

The specific load is calculated by dividing the total mass of SO_2 emissions of the month by the net pulp production (air dry) = 2 621 kg SO_2/3 928 ADt = 0.67 kg SO_2/ADt.

The specific gas flow is: average flue-gas flow (Nm^3/h) × operating hours/net pulp production (air dry) = 34 538 Nm^3/h × 744 hours/3 928 ADt = 6 542 Nm^3/ADt.

2.2.2.2.6 Measurement of diffuse emissions in kraft pulp mills

Diffuse sulphur emissions at kraft pulp mills can be production process-based, i.e. directly linked to the process (see Section 3.3.15) or non-production process-based i.e. linked to the supporting activities like wood handling (chip heaps) and waste water treatment.

The only accurate method to determine strong and weak gas emissions from various points of emission is the almost complete collection and incineration of these gases and reporting these as part of the total emissions of point sources.

The uncertainty in determination of these emissions – if not completely collected – grows due to the fact that the number of sources is high and that the determination of the gas or evaporated volumes is extremely challenging even though the concentrations could be adequately measured. The uncertainty of the total amount of diffuse emissions increases with the growing number of sources outside gas collection systems.

Achievable situation with the use of modern gas collection systems
At modern mills where effective collection systems are applied, diffuse emissions from all production process sources are collected and incinerated and significant diffuse emissions do not occur in practice - except from those streams that are not considered collectible because of their negligible sulphur content. For pulp mills with an effective gas collection system, diffuse emissions cannot be reported separately because they are already included in the total releases. Collection and incineration can cover more than 99 % of the total production process-based emissions of gaseous sulphuric compounds (see Section 3.3.15).

Even efficiently designed and operated gas collection systems will not always completely collect the gases from all sources and during all operating conditions. Significant diffuse emissions typically occur under exceptional conditions e.g. during shutdown and start-up situations and during accidents. In these cases, incineration needs to be momentarily bypassed or an available back-up treatment system used because of the danger of explosion.

Normally, these untreated releases cannot be accurately measured but, according to the monitoring programme, they need to be assessed or calculated using reliable methods like modelling of the exceptional situations. These calculation methods need to be established in the monitoring programme of the plant and data needed for these calculations should be included in normal data collection (i.e. fuel consumption). It is also possible to carry out simulation measurements during these abnormal situations and use the measured data for the estimation. Exceptional diffuse emissions can contribute a very high percentage of the total sulphur emissions of the mill due to low-sulphur emissions during normal operating periods.

This effect can be seen in Table 2.8 where data from measured point sources in the process and assessed non-point source weak gases for some Swedish kraft pulp mills are compiled. As the mills apply BAT in the process and operate effective emission control techniques, the point sources from the processes (recovery boiler, lime kiln, dedicated burner for odorous gases) release relatively low-sulphuric emissions. Assessed emissions from non-point sources (diffuse emissions) contribute the same or even more sulphur emissions than are emitted from the point sources.

Table 2.8: Gaseous sulphuric emissions as S from point and non-point sources from Swedish market kraft pulp mills

Kraft pulp mill	Gaseous sulphuric compounds as S		
	Yearly average point sources in the process (kg/t kraft pulp)	Non-point source weak gases (kg/t kraft pulp)	All process sources (kg/t kraft pulp)
Mönsterås	0.15	0.16	0.32
Skutskär	0.03	0.62	0.64
Mörrum	0.10	0.23	0.33
Värö	0.15	0.15	0.30
Source: Swedish statistics on emissions from pulp and paper industry (2007).			

Other cases

In European kraft pulp mills, there are differences in the reported total sulphur emissions, i.e. more or less of the emissions of different sulphur compounds are included in the reported sulphur releases. There are kraft pulp mills in Europe where collection and incineration systems for weak gases are still inadequate, causing high diffuse odorous emissions from the mill area. Typical sources are tank areas at mills with such a disperse layout that, in practice, technologically and economically viable collection applications are more difficult to implement.

In these cases, monitoring requirements should apply to all process-based diffuse emissions and, thus, diffuse emissions need to be measured or otherwise assessed.

Determination of actual diffuse emissions is challenging due to the fact that the assessment of emitted gas volumes periodically is very difficult as the volumetric flow rate of the different emission sources varies over time. Sampling devices which can be used in such cases are sampling hoods, flux hoods or tunnels depending on the source design. Gas concentration analysis is carried out by standard methods in the laboratory. Also, direct measurement with e.g. portable FTIR might be applicable. In case of odour, the measurements can be carried out by dynamic olfactometry (EN 13725:2003).

As an indicative monitoring method, odour inspections by trained personnel can be carried out. The personnel should be trained to recognise the odour type of the diffuse emissions. If these odours are perceived at the border of the installation site the source of these emissions should be investigated. If the source is assessed as relevant, suitable measures should be taken to reduce or to avoid these emissions. A description of this procedure can be part of the environmental management system, where relevant.

A measurement method that is e.g. practiced in Finland determines the diffuse emissions from the mill by ground-level measurement of TRS at the mill boundary: measurement stations are placed around the mill at locations that due to the typical wind direction are areas where the effect of those diffuse emissions can be measured.

In Sweden, the remaining weak gases that are not collected and are emitted from different parts of the process (around 20 – 40 emission points) are monitored in campaigns, often only once a year. Samples are collected in gastight plastic bags. Flow, temperature and pressure are monitored. This can be quite difficult at many of the sampling points. The samples are analysed with gas chromatography. The relevant reduced sulphuric compounds are hydrogen sulphide (H_2S), methyl mercaptan (MM), dimethylsulphide (DMS), dimethyldisulphide (DMDS).

Results from monitoring at the same sampling point can vary a lot over time. Variations of minus 70 % to plus 100 % around the average have been reported. However, the total amounts emitted from a mill vary much less from campaign to campaign. Nonetheless, there is a particular uncertainty when comparing remaining weak gas emissions (TRS as S) from non-point sources in European kraft pulp mills.

For mills with a very efficient emission collection system, measuring diffuse emissions may not be justified as these are captured and burnt and thus are included in the point source emissions. Only in cases of operational disturbances or failures of the gas treatment system are diffuse emissions released, e.g. during bypass, time intervals should be recorded and estimated emissions should be reported as 'collected but untreated weak gases'.

2.2.2.3 Monitoring of solid waste

The producer of waste monitors the various waste fractions generated during production. This includes information on the amount, quality, properties and origin of the waste generated (i.e. general requirement for bookkeeping). Knowledge about the environmental and health effects of the waste and of characteristics that affect further treatment and final disposal should also be available.

Operators are required to keep records on wastes generated, collected, stored, transported, utilised or disposed of as well as on wastes sold or transmitted. Also, the delivery destinations and dates, transportation, utilisation and disposal methods have to be recorded when the waste is delivered elsewhere from the place of generation. Annually, the authorities have to be informed of the amount, disposal, utilisation, storage or transportation of the wastes generated or obtained elsewhere. The report is drawn up on a special form using the specified waste codes from the consolidated 'list of waste' [50, Decision 2000/532/EC 2000].

There are specific requirements for landfilling that include an evaluation of the suitability of wastes for landfilling. To be accepted for landfilling, the composition, leachability and long-term behaviour of the waste has to be determined. The evaluation of the waste is based on investigations of the waste properties by carrying out a number of physico-chemical tests. These tests may include an analysis of:

- the physico-chemical composition of the waste;
- the organic content and degradation properties of the waste;
- the content and leachability of compounds;
- ecotoxicological effects of the waste and the leachate from the waste.

The suitability of a waste for landfilling is usually tested by expert laboratories specialised in leachate and other tests for determination of the properties of the waste.

2.3 Receipt, storage and handling of fibrous materials and chemicals

The major raw materials for pulp and paper manufacturing are fibres (wood, paper for recycling), water, thermal (heat and steam) and electrical energy and process chemicals or chemical additives. The supply and handling of these materials are described in Sections 2.3 to 2.6. For good housekeeping in paper for recycling storage and handling, the reader is referred to Section 6.3.1.

2.3.1 Wood handling

This section applies to all chemical and mechanical pulp and paper mills.

2.3.1.1 Wood yard operations

Wood handling and the mill wood yards include all functions to prepare and store the wood raw material between the mill gate and the pulping plant. The wood raw material usually consists of roundwood and wood chips (sawmill residues). Wood handling includes the measuring of the roundwood and chips received (weight, volume, moisture content), unloading, the storing of roundwood, debarking, chipping, chip screening and the storage of the chips in piles. The handling and storage of bark and wood residues are also included in the wood handling. Modern wood yards have to meet high standards for the quality and consistency of the products and have the same technical sophistication as other departments of the mill such as computer control, monitoring, etc.

In groundwood pulping, logs are used but in chemical and NSSC pulping, TMP and CTMP pulping chips are used. Kraft pulping, mechanical pulping, groundwood and TMP require fresh wood to obtain a high brightness pulp. When storing logs for mechanical pulping in the summertime, it is often necessary to spray the woodpiles with water to prevent the wood from drying and darkening. Particularly in sulphite pulping it is desirable to store the chips in order to obtain a controlled degradation of extractives in the wood by oxidative and enzymatic mechanisms in order to get a pulp with a low extractives content.

Wood is transported to the mills from the felling site by truck, rail or ship/barge and is received in the wood yard either as logs or chips. Logs are mainly delivered with the bark and have to be debarked before further processing (see Section 2.3.1.2). Eucalyptus *(E. globulus*) is often debarked at the harvesting site. Sawmill and other off-site chips are normally free of bark and can be used directly after screening.

Debarking should be done in such a way so as to ensure a clean and uniform wood raw material with minimum loss of wood, to make the bark as dry and uncontaminated as possible for use as a fuel and to minimise any air or water pollution arising from the wood handling and the debarking. In the handling of wood, chips and bark, it is important to minimise any contamination by earth or soil, to minimise the risk for process disturbances and the amount of bark and wood residues contaminated with sand and stones. The wood yard area and particularly the surfaces used for the storage of logs and chips are often paved.

Debarked logs are reduced to chips in a chipper so that water, chemicals, and heat can penetrate throughout quickly and uniformly. A consistent chip size distribution is necessary to achieve high efficiency pulping processes and high-quality pulp. The more uniform the chips after the chipper, the lower the raw material consumption due to the improved possibility to optimise the pulping process and the pulp yield. Chip size is also important for attaining optimal packing conditions, allowing proper filling of hoppers and/or the proper flow of surrounding liquor in chemical pulping. After the chipper the chips are screened in order to remove oversized chips and sawdust. Chips are commonly screened for thickness, as this is a critical parameter in pulping. Often, the overall screening optimum is reached by sacrificing some raw material to secure stable processing conditions, which, in turn, promote better pulp quality and less pollution. Oversized chips may be reprocessed in a rechipper in order to increase the yield and reduce the residues of the process. The material removed in the screening operation can be burnt in an auxiliary boiler with heat recovery or sold externally.

The screened chips should be handled gently in order to prevent breakage and the formation of slivers and splinters that may negatively interfere with the cooking process and pulp quality. For this reason, band conveyors are preferred for handling. Such conveyors are also energy-efficient and cause less noise than other transportation alternatives.

Bark and screening rejects from chipping and chip screening are residues generated in this process stage. They are usually collected and incinerated for energy recovery in a special bark, biomass or wood waste boiler (See Section 5.3.10).

Mills commonly store wood chips, either produced on site or purchased, in chip piles. Figure 2.5 shows an example of a chip pile at a sulphite pulp mill.

Figure 2.5: Example: Chip pile with concrete paving at M-real Hallein AG

During storage there is some degradation of resinous compounds (extractives) within the wood by oxidative and enzymatic mechanisms. The pile of wood chips can become quite warm during this maturation period. Storage for longer periods may reduce the amount of pulp obtainable from wood (pulp yield) and pulp strength.

It is important for the chips that enter the pulping process (chemical or mechanical) to be of even size and quality and have about the same dry content.

Wood handling and the wood yards are often an important source of noise in a mill. When planning for a new wood-handling facility or a rebuild, the location, layout and the equipment including trucks should be carefully evaluated and planned to minimise noise and potential disturbance from the area. The trucks and other moving machinery should fulfil requirements for noise abatement.

2.3.1.2 Debarking

European softwoods and hardwoods are commonly received at the wood yard with bark (but wood without bark may also be delivered in some cases) and are normally debarked on the mill site.

Depending on species and age, the bark of eucalyptus can differ appreciably and different debarking approaches are therefore applied. Young and freshly felled *E. globulus* trees are relatively easy to debark and are well-suited for debarking in a mechanical debarker at the pulp mill. The bark of mature and stored eucalyptus (and of fresh spruce harvested during the growth period) contains strong stringy fibres that wrap around rotating parts of a drum-type debarker and block it. It is common practice to debark the wood from mature eucalypt trees at the harvesting site and plantation eucalypts at the pulp mill.

The most common method for debarking is drum debarking. Bark is removed as the logs rub against each other inside the rotating drum. Bark, wood fragments, etc. are separated from the barked logs through openings in the drum shell. Debarked logs are commonly showered with water before entering the chipping operation. In cold climates, the logs entering the debarking operation have to be thawed and snow and ice removed to facilitate debarking. This can be achieved in special conveyors with warm water or by steam and hot water at the entrance of the debarking drum.

In dry debarking, process water is used only for log washing and is recirculated with a minimum generation of waste water and water pollutants. Dry debarking results in bark with lower water content, which in turn results in higher energy efficiency when burning the bark. Bark from the debarker is shredded and pressed and may be dried before burning.

Dry debarking gives low BOD and COD effluent loads, as well as low amounts of organic compounds like extractives leaching out of the bark and into the waste water stream. Some of these substances are toxic to aquatic life. Dry debarking dominates the industry, and wet systems are in the process of being phased out. In new or rebuilt wood yards, dry debarking is almost exclusively used.

Any excess of water from log washing and bark press filtrate should be sent to the effluent treatment unit. Due to the low volume of bark press filtrates, their potentially toxic effect is reduced by mixing with other process waters' inflows in the equalisation tank before biological treatment so that these waters can be treated together in the common biological treatment plant. Bark press filtrates may also be recycled to the kraft pulping process, e.g. to the chemical recovery.

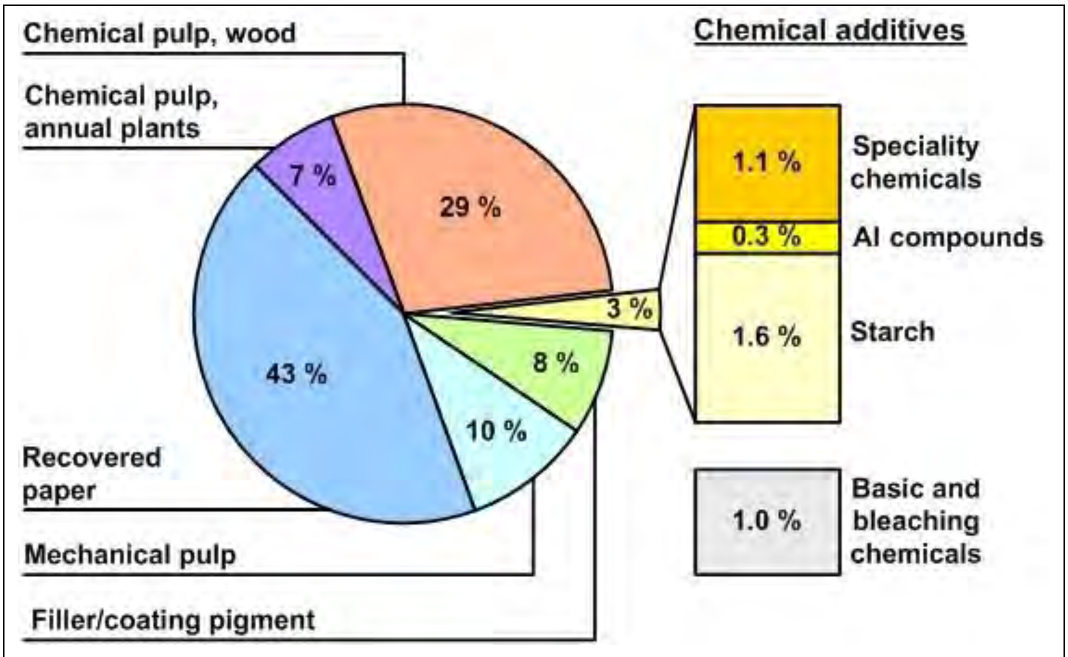
Biological treatment has been shown to be very efficient in eliminating the toxicity of debarking effluents. The waste water volume from dry debarking is usually below 2 m^3/ADt. In some sulphite pulp mills, debarking is effluent-free (dry tumbling debarking) and does not cause any waste water. For winter conditions and freezing during winter months in cold climates, dry drums are equipped with a de-icing step before the drum.

2.3.2 Storage and handling of chemicals and chemical additives

2.3.2.1 Use of basic chemicals and chemical additives

For the production of both pulp and paper products, various basic chemicals and chemical additives are used. For the production of bleached kraft pulps, chemicals such as chlorine dioxide, hydrogen peroxide and chelants are used (see Section 3.2.2.2). In addition, it is common for fossil fuels such as oil or gas to be used as fuels in the integrated production of alkali (see Section 3.1.11) and also as fuels for auxiliary boilers (see Section 2.6.1.1). Information on chemicals used for sulphite pulping can be found in Section 4.2.2.2; regarding chemicals used for the production of bleached mechanical pulp, the reader is referred to Section 5.2.2.6.

On a global scale, paper consists of approximately 98 % natural material. As shown in Figure 2.6, 89 % consists of chemical and mechanical pulps and paper for recycling. About 8 % are added fillers and coating pigments, mainly in the form of China clay and calcium carbonate. The remaining 3 % include the chemical additives. Slightly more than half of this is starch, which is also derived from renewable raw materials, and one tenth of it is aluminium compounds, e.g. the traditional chemical papermakers' alum (aluminium sulphate). Only 1.1 % of the raw materials used for paper and board production are synthetic chemical additives (speciality chemicals). All values in Figure 2.6 are calculated on the basis of a dry content of product in relation to the world paper production of 375 million tonnes in 2005.



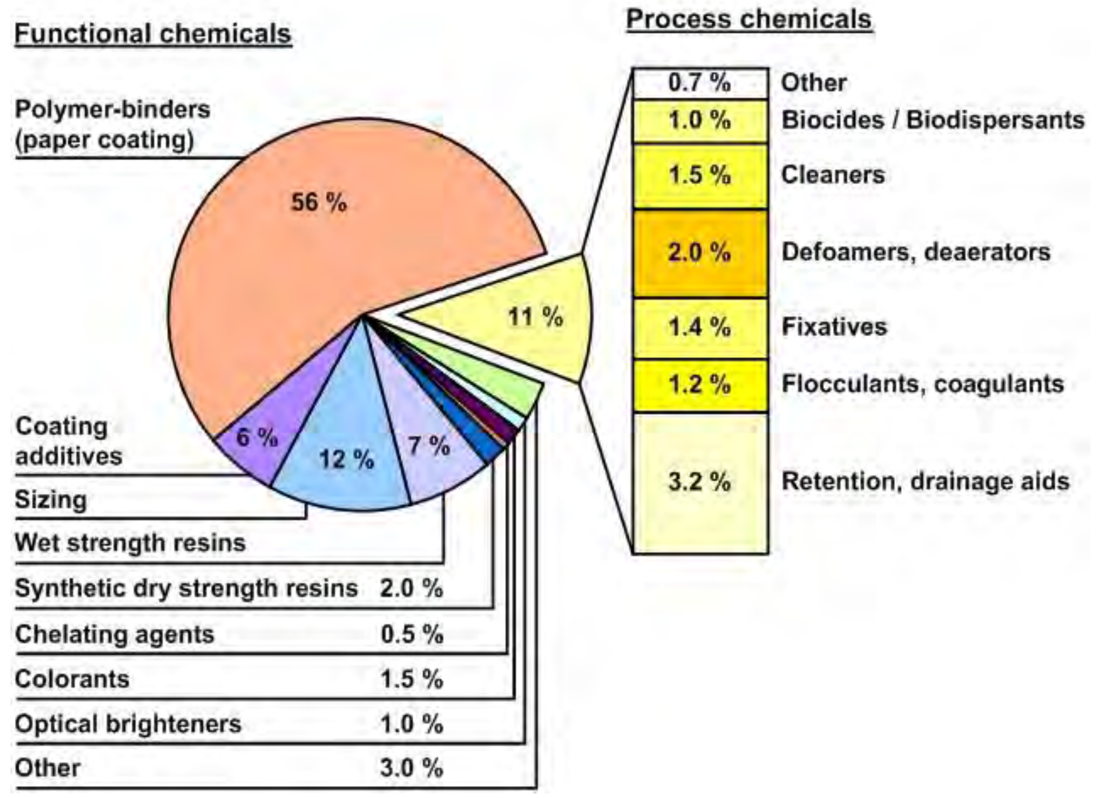
Source: [165, ZELLCHEMING 2008]

Figure 2.6: Raw material consumption of paper and board in relation to world paper production in 2005 (volume shares)

In addition, it is necessary to use about 1 % basic chemicals and bleaching chemicals like sodium hydroxide or sulphuric acid for pH regulation. These chemicals do not end up in the final product, are mainly inorganic and for the most part are either used up in the process or are recovered and recycled. In the effluent from the mill only ions remain (sodium, calcium, sulphate or chloride), which are then released to water bodies.

Further chemicals and materials that are not denoted in Figure 2.6, barrier materials such as aluminium, ethylene vinyl alcohol (EVOH), polypropylene (PP) and polylactic acid (PLA) are often used in packaging and liquid board products.

Figure 2.7 shows the market shares of various chemical additives grouped by function. Differentiation is made between chemicals needed for the production process itself (process chemicals) and those providing special functional properties in the final product (functional chemicals). Functional chemicals account for almost 90 % of all chemical additives based on dry volume. As can be seen in Figure 2.7, within this group polymer binders dominate with a 56 % market share. Process chemicals improve the productivity and runnability of paper and board machines. Within this group, retention and drainage aids together with fixatives and flocculants/coagulants have a market share of 53 %.



Source: [165, ZELLCHEMING 2008]

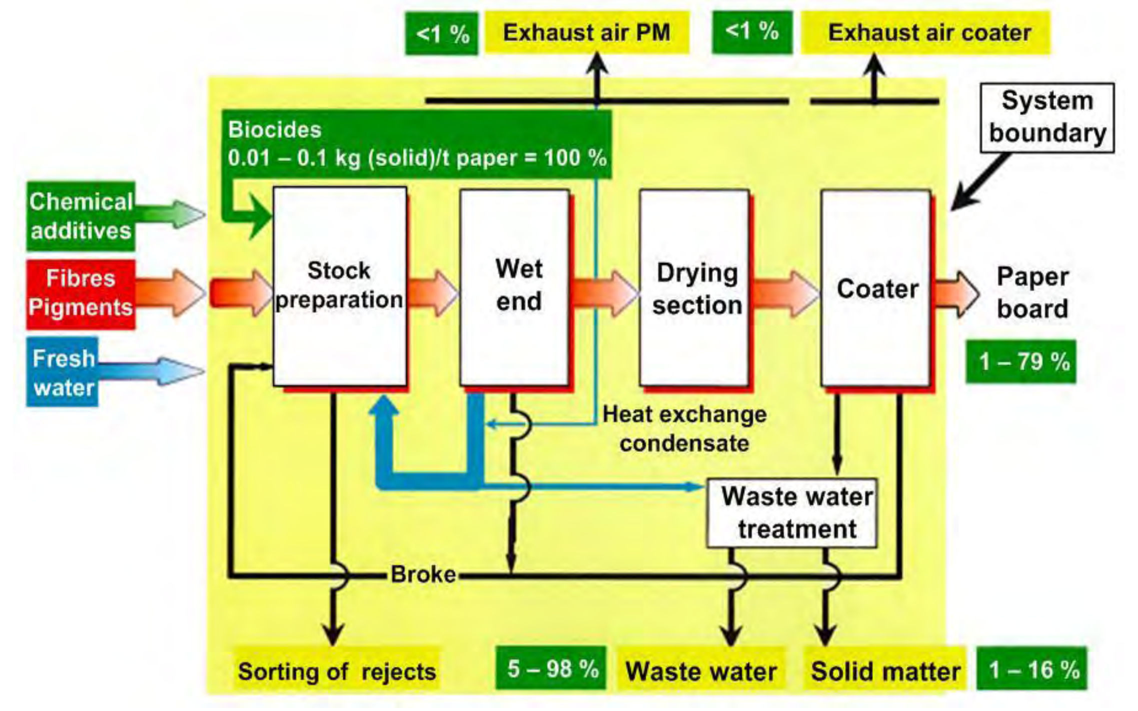
Figure 2.7: **Market share of speciality chemicals for world paper and board production (dry volume shares)**

Other chemicals used in pulp and paper mills (and not included in Figure 2.6) are chemicals applied to the treatment plants for process and waste water (e.g. urea, phosphoric acid, flocculation agents, polymers, sodium hydroxide, sludge conditioners and waste water anti-foamers/defoamers) and flue-gas scrubbers (e.g. alkali), if in use. Chemical additives are also used in the preparation of boiler feedwater.

Chemical additives help to optimise the production process and increase the economic efficiency of production. They help to modify certain properties of the finished paper and may be indispensable for achieving these properties. Chemicals are thus a vital component in the production of pulp and paper. The number of chemical additives used in some cases emphasises the importance of the safe and responsible handling and use of chemicals from an environmental and occupational health point of view (see Section 2.9.2.3 to 2.9.2.5).

With regard to a comprehensive assessment of the risks to the environment, data on retention in the paper product, on biodegradability, toxicity or other detrimental effects on the environment should be considered. Many paper mills conduct internal assessments using commercially available databases (see Section 2.9.2.4) that facilitate the responsible selection, use and handling of these chemical additives. One mill applies a screening of the chemicals used according to their retention and their elimination in the waste water treatment (see Section 2.9.2.5).

The 'Chemical Additives' Technical Committee, part of the German papermakers association ZELLCHEMING, has investigated the potential environmental impacts of the major groups of chemical additives listed in Figure 2.7 and has proposed a systematic approach that estimates the distribution of the chemical additives between the exhaust air, the paper, the waste water and the solid waste (rejects, sludge). This is because all of the ingredients of chemical additives find their way into these physical elements depending on the chemistry and physics of the additive components and of the raw materials of the paper as well as on the conditions for chemical application. Figure 2.8 uses biocides as an example to show how the fate of additives in the paper manufacturing process have been assessed by this expert group.



Source: [165, ZELLCHEMING 2008]

Figure 2.8: Fate of chemical additives in the paper manufacturing process for biocides

The mass balance shows the principles of this analysis. In the example, the dosage of biocides varies according to the chemicals used for this purpose (application of biocides between 10 and 100 g/t of paper, i.e. low dose active agent). Most of the dosed biocides stay in the water circuits and react there. A maximum of 79 % of the biocides dosed could be expected in the produced paper (in other cases only 1 %). A maximum of 98 % of the dosed material could in theory be found in the effluent (5 % only in other cases). The detection of the biocides in the effluent is often very difficult due to the low dosage levels and the quick reaction and decomposition of the chemicals used. The approach of ZELLCHEMING is of interest due to the distribution of the biocides between paper, waste water (after treatment), solid matter (sludge from waste water treatment) and exhaust air from the drying section of the paper machine and the coating machine respectively (<1 % in the case of biocides). For biocides, the investigation found relatively wide ranges because of the wide variety of biocides used (oxidising and non-oxidising biocides, bio-dispersants, etc.) and the fact that a lot of assumptions were made to assess the possible dispersion of biocides to various parts of the environment.

The expected discharge of chemical additives to water is directly related to the retention of the chemicals in the paper sheet (retention in the process) and their elimination in the waste water treatment plant. The major groups of chemical additives are discussed in [165, ZELLCHEMING 2008].

The retention factor describes the share of applied chemicals which is retained in the paper product and which is thus not passed to the environment (water, air, and land). The higher the retention the lower the discharge to the effluent and the lower the potential environmental effect of the applied additives. In the case of product aids, a maximum degree of retention is desirable from an economic (loss of additives) and ecological point of view. Since functional chemicals are designed to give paper a particular characteristic, for reasons of cost and efficiency, they generally have a relatively high level of retention in the cellulose fibres. Process chemicals are usually not retained to the same extent in the finished paper sheet. A certain amount is therefore discharged via the mill effluent. Knowledge of the retention of chemical additives is therefore important. Excess additives also leave the system via rejects and sludge. Some of these additives may have a negative influence on the practical functioning of the waste water treatment plant and/or the quality of the receiving water if they are released unintentionally in higher concentrations.

However, with the improved control of the properties of chemicals that may result from the REACH Regulation (see Section 2.3.2.2) and with systematic work in the mills to replace certain chemicals with ones that are environmentally safer (see Section 2.9.2.4) the risk that these residual discharges may disturb the functioning of a waste water treatment plant and/or the quality of the receiving water is decreasing.

Knowledge of the degradability of a substance is crucial for assessing the amount of substances that will end up in the aqueous environment. Supposing that most effluents from paper mills are treated in biological waste water treatment plants, the retention factor together with the biodegradability makes it possible to carry out a rough estimation of the amount of substances released to the receiving water body (see Section 2.9.2.5).

Finally, if substances are not retained in the paper web or eliminated in the waste water treatment plant, data on aquatic toxicity and the potential for bioaccumulation are of special importance.

Particular care should be exercised in the case of chemicals which are designed to have a biological effect such as biocides, disinfectants and slimicides. Build-up of slime in mill systems should, in the first place, be prevented by proper design and operation of the systems to avoid having equipment, pipes and tanks where pulp suspensions can be left standing for prolonged periods of time and by choosing operating temperatures at or above about 40 °C. These measures may not be sufficient at all times to entirely manage slime growth but will lead to the use of chemical additives only occasionally and/or in low quantities. Practical experience says that recycled mills for printing papers and tissue commonly operate the systems at about 45 °C and for packing material up to 50 °C to avoid the formation of slime. A large RCF mill, for example, manufacturing packaging paper successfully applies dispersing agents and enzymatic treatment when the bacteria of the process water systems are forming slime, thus completely substituting the use of biocides. [90, J.Schrijver et al. 2008] suggests a combination of biocides and bio-dispersants help to reduce the amount of biocides used.

The chemicals are most commonly delivered to the mill site by truck, rail or ship and some are prepared on site. Typically, low volume speciality chemicals will be delivered ready for use whereas the higher volume chemicals may be delivered or prepared on site. One example of a high volume chemical prepared on site is precipitated calcium carbonate (PCC) for use in papermaking.

Technical and product development results in a constantly shifting use of chemicals, particularly of the low volume speciality additives. To review and evaluate chemicals for a particular purpose to select the most efficient ones from a process and product point of view which is also environmentally benign is thus a very important activity (see Section 2.9.2.4 and 2.9.2.5).

2.3.2.2 EU regulations on the storage, handling and use of chemicals

The REACH regulation

The Regulation of the European Parliament and of the Council concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals [200, REACH Regulation (EC) No 1907/ 2006] is designed to provide updated facts about all chemicals used in quantities above certain threshold values. REACH is based on the principle that it is for manufacturers, importers and downstream users to ensure that they manufacture, place on the market or use substances that do not adversely affect human health or the environment. To this end, manufacturers or importers of a substance, either alone or in a mixture, in quantities of one tonne or more per year must submit a registration to the European Chemicals Agency (ECHA). The supplier of a substance or a mixture must furthermore provide the recipient of the substance or mixture with a safety data sheet in accordance with the principles set out in the Regulation. The safety data sheet must contain information on the identification of the substance/mixture, on hazard identification, composition, handling and storage, ecological and transport information.

More stringent requirements on chemical use may apply to paper or boards that are in contact with food, medicines or surgical instruments. Within the EU, rules for food packaging are under development (Council of Europe, Resolution AP (2002) 1 on paper and board materials and articles intended to come into contact with foodstuffs). In some countries, the German XXXVI Recommendation for paper and paperboard for food contact, issued by the German Federal Institute for Risk Assessment (BfR), is used.

The Seveso Directive

Council Directive 96/82/EC on the control of major accident hazards involving dangerous substances (the Seveso II Directive) [214, Seveso II Directive (96/82/EC) 1996] and Directive 2003/105/EC of the European Parliament and the Council amending it also apply to some hazardous substances (chemicals) stored and handled in pulp and paper mills. The Seveso II Directive lists a number of substances to which it applies, some of which are used in some pulp and paper mills including sulphur dioxide (R9-22-51/53), sodium chlorate (R23-24), LPG gas (R12), methanol and oxygen. Hydrogen peroxide and chlorine dioxide normally do not fall under the Directive due to it being used in dilute solutions. The Directive defines categories of substances (toxic, oxidising, explosive, flammable) for which it applies.

The Directive provides for three levels of controls, where larger quantities of chemicals mean tighter controls. A company which holds a quantity of a dangerous substance below the lower threshold levels given in the Directive is not covered by this legislation but will be subject to general provisions on health, safety and the environment provided by other legislation which is not specific to major accident hazards.

The Directive requires that a safety management system be in place. Emergency plans for response measures to be taken inside establishments have to be drawn up by the operator and to be supplied to the local authorities to enable them to draw up external emergency plans. Emergency plans have to be reviewed, revised and updated, where necessary. Operators are required to consult with their personnel on internal emergency plans and the local authorities to consult with the public on external emergency plans.

The CLP Regulation

The new EC Regulation, EC 1272/2008 of the European Parliament and of the Council, on classification, labelling and packing of substances and mixtures (the CLP Regulation), came into effect on 20 January 2009. It applies immediately in the whole EU without having to be implemented in national regulations. Transitional provisions apply and work has started to classify chemical substances and mixtures in accordance with new criteria and to label with new danger symbols (pictograms) with applicable hazard and safety directions. The regulation will lead to more uniform labelling and packaging of chemical substances and will facilitate identification and handling of substances and thus enhance workplace and environmental safety.

Biocidal Product Directive

The use of biocidal products is regulated by Directive 98/8/EC of the European Parliament and the Council concerning the placing of biocidal products on the market (BPD) and by Regulation (EU) 528/2012 of the European Parliament and of the Council concerning the making available on the market and use of biocidal products. The scope of the BP Directive covers 23 different product types. These include slimicides and chemicals used for the preservation of products and materials. The basic principles of the Directive are given below.

- Active substances are assessed and the decision on their inclusion in Annex I to the BPD shall be taken at the Community level.
- Biocidal products are authorised at the national level. Only products which contain active substances included in Annex I can be authorised.
- Mutual recognition: a biocidal product authorised in one Member State shall also be authorised upon application in another Member State unless there are specific grounds to derogate from this principle.

There are distinct decisions concerning the non-inclusion of substances in Annexes I, IA or IB to the BPD. The consolidated list of existing active substances for which a decision of non-inclusion has been adopted also contains the dates by which products containing these active substances shall no longer be placed on the market for the relevant product types.

Effects of other legislation
Of the substances used previously in the pulp and paper industry, certain substances are prohibited in current legislation. Nonylphenols and nonylphenol ethoxylates have been used as tensides and dispersion agents. Now the use of these substances is prohibited. Some substances regulated in legislation and used in large quantities, e.g. in slimicides and sizing agents, have been found at paper mills in low concentrations.

Directive 2008/105/EC on environmental quality standards in the field of water policy includes in its Annex I a list of priority substances. According to CEPI (2010), none of the listed priority substances are used in the pulp and papermaking processes (e.g. nonylphenols, inorganic compounds, DEHP). Although not used, it is however possible for these priority substances to be present in the emissions from waste water treatment plants, due to either entering the site via imported pulps or via upstream abstracted surface water used within the papermaking process.

2.3.2.3 Storage, handling and transportation of chemicals

Many of the chemicals and chemical additives used in pulp and paper mills are characterised as hazardous if released in concentrated form. Solid, liquid and gaseous substances are used. Therefore, the control of the chain of transportation, unloading, storage and transportation to the use in the process is of great importance to minimise the risk to personnel and the environment (see Section 2.9.2.3).

2.4 Water supply for processes and cooling

2.4.1 Raw water treatment

The requirements for water quality vary widely in the paper industry depending on the water use (cooling or process water), the product quality and the production processes employed in the given pulp and paper mill. Consequently, the raw waters used and their sources (groundwater, surface water) vary considerably between mills. The main impurities of the raw water that need to be removed if they are present are colour (natural brownish or yellowish colour) and turbidity (small particles of suspended organic and inorganic substances) in the case of surface waters (after the first mechanical cleaning), hardness (dissolved calcium and magnesium salts) and iron and manganese. Their presence depends mainly on the water source used. In many European countries all raw water used by pulp and paper mills is surface water. Others also use groundwater for a portion of the process water. Water quality can be improved through a range of treatment measures that may depend on the intended use of the water and the water quality needed for this purpose.

2.4.1.1 Process water treatment

In pulp and paper mills, water treatment is usually carried out to remove solids, colour and organic substances, iron and manganese. In a few cases, dissolved salts are also removed and water is disinfected. With the exception of solids removal, most of the above require some form of chemical treatment (ion exchange is also applied for process water in a few cases, and for boiler feedwater in most cases) which is associated with contaminated flushing water that is normally treated together with the process water effluents. The mechanical treatment by use of screens and filters is usually performed before chemical treatment and removes small organisms, leaves, grass, and other debris.

For chemical treatment, water is often aerated, appropriate chemicals are added and mixed for coagulation and flocculation; then flocculation takes place (with the addition of coagulating agents if necessary) and the flocs formed are separated from the liquid phase by clarification and sand filtration. For flocculation, coagulants such as aluminium sulphate are added. Another commonly used coagulant is sodium aluminate. For decarbonisation, $Ca(OH)_2$ and $Fe(Cl)_3$ may be added. Supplementary coagulants are used in cases where floc formation would otherwise be unsatisfactory. Other chemicals are used mainly for pH adjustment. Most of the flocs formed during coagulation and stirring are removed during clarification. This takes place either by sedimentation or by flotation. In the production of fresh water for the pulp and paper industry, the flocs that have passed through with the clarified water from chemical treatment are removed by filtration. The filter beds of the filters are flushed clean from time to time with water, or a mixture of air and water. The flushing water is normally sent to the waste water treatment plant. Before the treated water is led into storage tanks or the supply network, the water is sometimes disinfected.

Process water treatment consumes electrical energy and generates sludge to be handled and treated.

2.4.1.2 Boiler feedwater treatment

Water for boiler plants is normally treated by use of ion exchange. The treatment includes condensate being returned to the power plant of the mill and the production of power plant feedwater and make-up water. In most cases, condensates are first filtered to remove impurities originating from the pipelines. The filtered water is led to an ion exchange unit. These are usually mixed bed ion exchangers (containing both anionic and cationic exchange resins). In the case of plants producing de-ionised make-up water, the water is first chemically treated before being passed through anionic, cationic, and mixed bed units. Depending on the type of ion exchange resin used, the column is regenerated with acid, alkali, or sodium chloride solution. The resulting waste water is collected and neutralised before being discharged to the waste water treatment plant.

The wash water from the ion exchanger regeneration contributes to the mill's total discharge of salts and is a concern particularly for mills that run very closed water circuits as this water carries a considerable salt load.

Additional treatment of boiler feedwater may include the addition of bisulphite, ammonia or hydrazine for control of pH and as oxygen scavengers in order to reduce corrosion.

2.4.2 Cooling systems and use of cooling water

Besides the utilisation of air, pulp and paper mills and the associated power-generating facilities have traditionally used large amounts of water from lakes and rivers for cooling purposes. The function of such a cooling system is to remove heat from processes or equipment such as motors or rotating machines in general, hydraulic systems, transformers, condensers, compressors, as well as comfort ventilation, etc. to control the temperature of the process and waste water and to improve the physical environment for the workforce. Heat removed from the process is transferred to the cooling water or to air. The transfer of heat from process waters or equipment increases the temperature of the cooling water, which is either discharged or recirculated after recooling or is used as warm water in the process.

In some countries, there are specific environmental regulations for the operation of water-based cooling systems and the use and discharge of the chemicals used for prevention of corrosion, scaling and/or biological growth. For details on BAT for industrial cooling systems the reader is referred to the Reference Document on the application of Best Available Techniques to Industrial Cooling Systems [270, COM 2001].

2.4.2.1 Types of cooling systems in pulp and paper mills

Cooling systems can generally be divided into three major types: once-through systems, closed recirculating facilities and open recirculating systems where cooling towers and evaporators are most common. The heated cooling water is either discharged with an increased temperature into a receiving water body (once-through cooling system) or is recooled and reused (recirculating cooling system). The choice of the solution differs depending on the location and cooling concepts of the individual mill, i.e. it depends on the availability of fresh water and the heat intake capacity of the receiving water body.

a) Once-through cooling systems

Cooling systems that use the cooling capacity of the water once are called once-through cooling systems. Large volumes of water are necessary for even the smallest once-through systems. Therefore, a plentiful water supply at a suitably low temperature is needed. The once-through cooling (OTC) systems are installed where there is a good supply of river or lake water. The mills release the used cooling water directly back to the river/lake at an increased temperature. Normally authorities set requirements with regard to the tolerable heat load to the water body (as maximum °C in summer and winter and maximum Δ T compared to the natural conditions) and concerning an appropriate mixing with the surrounding water.

The only external treatment generally applied to a once-through system is mechanical screening to protect downstream equipment from serious damage due to foreign material intrusion. No significant change in water chemistry occurs. No corrosion control or scale control chemicals are used. During wintertime, warmed-up cooling water may be used for the production of chemically purified water to secure good purification results.

b) Water cooling and reuse (open and closed recirculating systems)

An open recirculating cooling system uses the same water repeatedly to cool process equipment or process water. Heat absorbed from the process and transferred to the cooling water is dissipated to the atmosphere to allow the reuse of the water for cooling purposes. The most common type of open circulating cooling systems is the cooling tower. The heated cooling water is partially evaporated in the cooling tower as upflowing air comes into contact with the downflowing water. Cooling is achieved through evaporation of a fraction of the water. Evaporation results in a loss of pure water from the system and a concentration of the remaining dissolved solids. The loss of evaporated water into the atmosphere is replaced by make-up water. Some water has to be removed from time to time in order to control the increase of impurities; fresh water needs to be added then to replenish the system.

Open recirculating cooling systems save a large amount of fresh water compared to once-through cooling. Chemical treatment of the cooling water is necessary to prevent corrosion, scaling or biofouling and results in intermittent releases of these substances into the receiving water body. As make-up water introduces new dissolved minerals and microorganisms into the circuit, the introduction of treatment chemicals must be constant in this type of circuit. In some cases, shock treatment may be applied. Treatment chemicals are also used to replace the chemicals lost through blowdown.

In a closed recirculating cooling water system, water circulates in a closed cycle and is subjected to alternate cooling and heating without air contact. Heat, absorbed by the heat-carrying water in the closed system, is normally transferred by a chiller that can remove heat from a liquid via vapour compression or through the absorption refrigeration cycle, from which the heat is lost to atmosphere. For closed circulating systems, chemical treatment of the cooling water is necessary to prevent corrosion, scaling and/or microbiological growth. Even then the continuous replacement of a smaller part of the circulating water is necessary. The purged streams allow the suspended matter and accumulated salt in the circuit water to be removed. The applied deconcentration factor depends on the raw water chemistry in the circuit and on the applied treatment. The purged streams should be treated together with the process water. Products used for water treatment and for deposit control are e.g. oxidant and non-oxidant biocides. Anti-scaling agents are used to prevent scale and crystal formation.

Depending upon the location, the type of mill and cooling systems chosen, the non-contact heated cooling water may be used as process water and combined with process effluents prior to the effluent treatment and discharged with the treated process effluent as a combined flow. In this case, there is no separate discharge of cooling water as it is completely converted into process water. In a few cases, the non-contact cooling water may be combined with the process effluent after effluent treatment and discharged as a combined flow; or the cooling water is discharged from a separate non-contact cooling water discharge point. Figure 2.9 illustrates these options for use and discharge of cooling water.

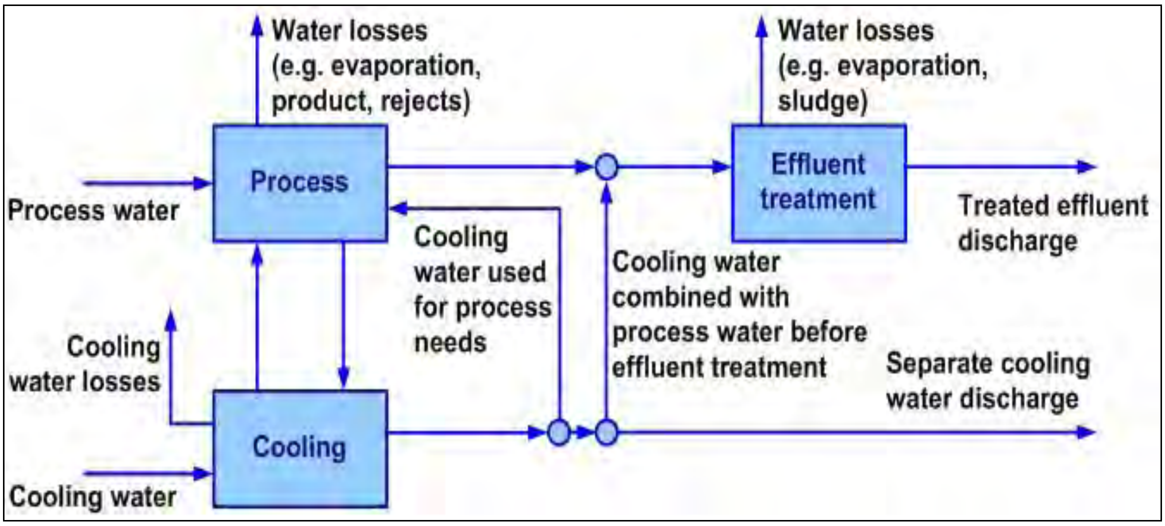


Figure 2.9: **Options for use and discharge of cooling water**

In this document, cooling water is only included in the presented process water flow (m^3/ADt) when it is used as process water or when contaminated flows are purged and treated together with the process water in the common treatment plant.

2.5 Energy consumption in pulp and paper mills

Pulp and paper production is an energy-intensive industry. On a global scale, it is the fourth largest industrial consumer of energy, consuming 5.7 % of total industrial energy use [197, IEA 2007]. Production of pulp and paper requires energy input in the form of heat and power.

Heat energy, commonly in the form of high-pressure steam, is used to generate electrical power in turbo generators. Then steam extracted from the turbine as medium- or low-pressure steam is mainly used for the following purposes:

- heating water, wood chips, pulp fibres, air and chemicals to process temperature;
- heating the cooking liquor in chemical pulping;
- evaporating water from spent kraft and sulphite pulping liquors in the evaporators before firing the liquor in the recovery boilers;
- dispersion in paper for recycling stock preparation (heating of the stock in dispergers in some cases);
- evaporating water from the pulp or paper sheet in the dryer section of the paper or pulp machine;
- drying of coated paper.

Electric power is used for many purposes in pulp and paper mills such as:

- grinders and refiners for the production of groundwood pulp, TMP and CTMP;
- pulpers to slush purchased pulp or in recycled fibre pulping;
- pulp beating and pulp refining;
- drives for paper machines and other pulp and paper machinery;
- transports with pumps, fans, belt and screw conveyors;
- mixing of fluids and suspensions;
- chemical preparation on site;
- vacuum pumps;
- compressors.

The following trends generally increase the specific electricity consumption of pulp and paper production:

- higher quality requirements for paper (increased electricity consumption in mechanical pulping and drying of coatings);
- increased speeds of paper machines;
- new pressing and drying technologies that reduce heat consumption (for example, electric infrared dryers);
- tightened environmental requirements and control techniques involved (e.g. waste water treatment, and flue-gas cleaning);

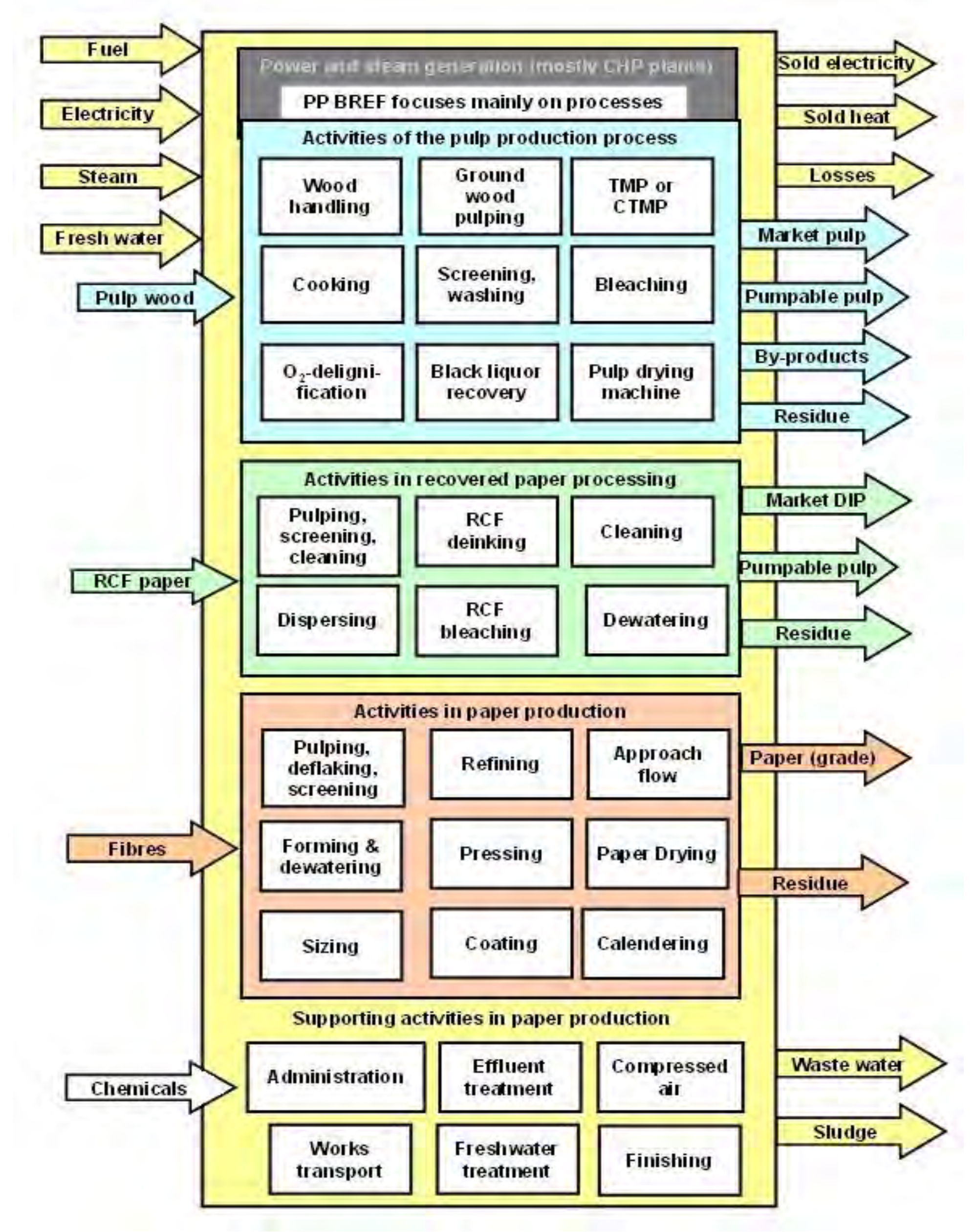
By introducing new modes of operation and tools such as energy efficiency analysis or energy audits (see Section 2.9.5), process integration or newer equipment, significant energy efficiency improvement is possible. The efficiency of both paper production and energy production can be improved by the development of advanced process monitoring (see e.g. Section 2.9.10). Skilled and motivated personnel and the availability of reliable process information enable the use of energy-efficient ways of running mills and power plants. Further information on energy efficiency can be found in the Reference Document on Best Available Techniques for Energy Efficiency (ENE) [268, COM 2009].

A comparison of pulp and paper mill energy consumption can include factors that cause uncertainties and misunderstandings. A typical mill produces more than one type of paper/pulp from various wood species and often different mixes of fibre raw material. Each grade typically has a specific energy consumption level, but total yearly consumption varies depending on the distribution of production, the pulping yield, whether the pulp is dried or not and on the time of year (higher heat consumption during winter than summer). Benchmarking between different mills is not an easy task because of the variety of products produced at different mills. This section outlines some of the issues, some typical figures for energy consumption in pulp and paper mills and the relevance of certain processes for the energy balance of mills. Further details that are related to the energy consumption for the manufacturing of a specific pulp or paper grade are discussed in Chapters 3 to 7.

2.5.1 Issues to consider when reading reported energy consumption data

When comparing energy consumption data one has to keep in mind that energy data recording and reporting is not yet uniform [249, Blum et al. 2007]. The comparability of energy consumption between mills may be difficult in many cases because various relevant factors influence energy consumption. There are many individual energy consumers within a mill and sometimes only a few measurement points have been installed in order to monitor energy consumption. Within one pulp or paper grade, there are differences in raw material composition, product properties and in installed process equipment (see Table 2.10).

When assessing or comparing energy data in pulp and paper mills, the completeness of activities included in the energy balance should be considered. In some cases, a seemingly better energy efficiency level can be explained by a given mill having excluded relevant energy consumption units that another mill has included. For example, some plants include effluent treatment, finishing, administration and different activities of the pulp production process and other plants eliminate this from their data. Figure 2.10 gives a schematic overview of subsystems to be considered when comparing energy balances of pulp and paper mills and shows the main energy flows (input and output) in the upper part of the figure. Fibre feedstock, products manufactured and residues are also indicated because their type, amount and characteristics may have an influence on the specific energy consumption of the mill too. Relevant subsystems that consume energy are compiled within the three processing areas of pulp production, processing paper for recycling and papermaking. These processing areas contain typical process steps (subsystems). Each of these subsystems consumes energy and hence affects the energy balance of the entire mill. For example, when evaluating the energy situation of a mill with a mechanical pulp line, it is important to know whether the applied pulping process is based on groundwood or TMP refining. Other aspects in the schematic balance are less significant, such as the supporting activities, e.g. administration (see Section 2.5.4).



Source: [194, Francis 2007] modified by EIPPCB

Figure 2.10: Schematic overview of subsystems to consider when comparing energy balances of pulp and paper mills

Reference values for the total primary energy consumption (fuel, electricity, and steam input) of a pulp and paper mill or for the energy consumption for process heat and electricity in the manufacturing processes for a certain pulp/paper production should refer to the same type of production and should include comparable subprocesses. However, the recorded and reported data often do not reach this level of detail. Therefore, the energy consumption data presented in this document have a rather indicative character in that they cover a number of similar cases but not necessarily all.

Bearing in mind that energy consumption is strongly dependent on the system that is analysed (system boundaries), the type of mill (integrated or non-integrated), the type of pulping (kraft or sulphite pulp, GW, TMP, CTMP, RCF processing, etc.), the paper grade, grammage and quality manufactured and the processes involved, the user of the energy reference values should be aware of this interrelationship when using energy figures for benchmarking.

2.5.2 Examples of total process energy consumption of pulp and paper mills

Energy consumption figures of some example pulp and paper mills are given in Table 2.9, representing actual process energy consumption values (the power plant and consequently the conversion of primary fuels into power and steam are not included) for some important paper grades. For integrated mills, the specific energy consumption values refer to the total paper production including mechanical pulping or processing of paper for recycling. The values in Table 2.9 are derived from different data sources. The system boundaries (in each case the entire mill is considered without taking into account the losses during the conversion of fossil fuels for steam and electricity generation, see Figure 2.10) and the production rate referred to (here net shippable production) are the same for all mills presented.

Table 2.9: Specific energy consumption directly used in the manufacturing process and the production-related ancillary installations of some example pulp and paper mills

Type of pulp/paper produced	Range of energy consumption		Data source
	Units	from – to	(No of mills)
Non-integrated kraft pulp	Power (kWh/ADt) Heat (kWh/ADt) (7)	700 – 800 3 800 – 5 100	(1) (5 mills)
Integrated uncoated wood-containing paper (includes mechan. pulping (MP) and may refer to GW, TMP or other types of fibres) (5)	Power (kWh/t) (6) Heat (kWh/t) (7)	1 200 – 1 400 1 000 – 1 600	(2) (1 mill); (4) (2 mills)
Integrated coated wood-containing paper (includes mechan. pulping (MP) and may refer to GW, TMP or other types of fibres) (5)	Power (kWh/t) (6) Heat (kWh/t) (7)	1 200 – 2 100 1 300 – 1 800	(2) (2 mills); (3) (8 mills); (4) (3 mills)
Integrated TMP-based printing paper (> 90 % TMP)	Power (kWh/t) Heat (kWh/t)	2 500 – 2 700 330 (8)	Afconsult (1 mill)
Non-integrated coated wood-free paper	Power (kWh/t) (6) Heat (kWh/t) (7)	600 – 1 000 1 200 – 2 100	(3) (5 mills); (4) (2 mills)
RCF without deinking (packaging) paper	Power (kWh/t) (6) Heat (kWh/t) (7)	300 – 700 1 100 – 1 800	(2) (1 mill); (3) (11 mills); (4) (7 mills)
RCF with deinking (graphic) paper	Power (kWh/t) (6) Heat (kWh/t) (7)	900 – 1 400 1 000 – 1 600	(2) (1 mill); (3) (7 mills); (4) (4 mills)
RCF-based cartonboard (with deinking)	Power (kWh/t) (6) Heat (kWh/t) (7)	400 – 700 1 000 – 2 700	(2) (1 mill); (3) (4 mills); (4) (5 mills)
Non-integrated tissue mill (no TAD use)	Power (kWh/t) (6) Heat (kWh/t) (7)	900 – 1 200 1 900 – 2 300	(2) (2 mills); (3) (4 mills)
RCF-based tissue mill (no TAD use)	Power (kWh/t) (6) Heat (kWh/t) (7)	800 – 2 000 1 900 – 2 800	(2) (1 mill): (4) (3 mills)
Wood-free speciality paper	Power (kWh/t) (6) Heat (kWh/t) (7)	600 – 3 000 1 600 – 4 500	(2) (3 mills); (3) (3 mills)

NB:

(1) Swedish EPA, statistical data of Swedish kraft pulp mills, 2005.

(2) PTS, Examination studies: Energy optimisation in European mills (not published), Munich 2004 to 2007.

(3) PTS, Internal data collection of German pulp and paper mills (not published), Munich 2004 to 2006.

(4) Institution for Paper Science and Technology GmbH, Questionnaire-based survey (not published) Darmstadt, 2007.

(5) For integrated wood-containing paper, it should be noted that the combined specific energy consumption of papermaking and mechanical pulping is a directly proportional function of the share and type of mechanical pulp in the furnish. Power consumption for TMP (thermomechanical pulp) is normally higher than for PGW/SGW (pressurised/stone groundwood) and much higher than for RCF (recovered fibre). For more details, the reader is referred to Section 5.2.2.7.

(6) No primary energy is considered, except for gas (lower calorific value) for IR or air dryers or shrink ovens. The power plant is outside the system boundary. To convert the purchased power demand into primary energy used, the energy yield of electricity production of the given country (if known) or at EU level has to be taken into account. e.g. at EU-25 level the total primary energy for generating 1 kWh electricity is 2.62 kWh cumulated energy requirement (source: Global Emission Model for Integrated Systems GEMIS, data taken from EU DG-TREN 2003: European Energy and Transport Trends to 2030 (PRIMES)).

(7) Heat consumption figures exclude heat for electricity production. To convert from [kWh] into [MJ] multiply [kWh] by 3.6; to convert from [MWh] into [GJ] multiply [MWh] by 3.6.

(8) The power consumption for the TMP-refining operation is 2 500 – 2 700 kWh/t of pulp. For more information see Section 5.2.2.7. Of this electricity input, 75 – 80 % is recovered as low-pressure steam, which mainly covers the steam consumption in the paper mill. If everything operates according to good practice, only approx. 1.2 GJ/t (or 330 kWh/t) of additional heat in the form of steam is required.

Sources: All data sources are quoted in [249, Blum et al. 2007].

The figures of power consumption represented in Table 2.9 do not consider the primary energy input of fuels for the generation of power. For heat, the consumption values refer to the thermal capacity of the used steam and the lower calorific value for gas in case of IR or air dryers. Electric infrared (IR) dryers are responsible for part of the power consumption. Gas infrared systems are included in the heat consumption. The minimum values for power and heat for a particular grade do not necessarily belong to the same mill. The same applies to the maximum values. Hence, adding the power and heat consumption of one grade in order to calculate the total energy consumption for a mill may lead to incorrect results in some cases.

For more detailed information on the energy consumption of the different types of pulp and paper manufacturing, please refer to the 'current consumption and emission levels' sections in Chapters 3 to 7. For BAT reference levels on energy consumption, the reader is referred to sections on BAT conclusions in Chapter 8.

General aspects

Some general aspects that may influence the specific energy consumption levels as shown in Table 2.9 within one grade range are discussed below.

Location of the plant

To a certain extent, the heat demand of some consumers depends on the environmental conditions of the production site. There are differences between mills in northern and southern Europe like hall ventilation and types of heating, use of fresh water and process water and cooling.

Age of the plant (date of foundation)

Very old pulp and paper mills may have initially faced unfavourable infrastructure (e.g. energy distribution systems) which could lead to increased energy consumption for general mill services. However, many mills that have been in operation for more than 100 years have gradually modernised their infrastructure so that today no correlation between the age of the mill and energy efficiency can be observed. This can be shown by means of energy consumption figures of existing plants which have continuously improved their energy efficiency due to investments in new technologies and energy management. In many cases, updating of permit conditions has triggered the installation of new equipment thus improving the energy efficiency. On the other hand, for some recent greenfield kraft pulp mill projects (e.g. new eucalyptus pulp mills in South America), the power consumption is significantly lower than for comparable older mills, see Table 3.33 in Section 3.3.27.

Age of equipment

The age of the paper machines or the pulp line equipment has an influence on the energy consumption as do any other aggregates installed. In many cases, newer equipment is more energy-efficient than older equipment. However, after the start-up of a new paper machine or a new pulp line, it takes one or two years to optimise the process and hence also the energy consumption.

Size of the plant

The sizes of European pulp and paper mills that fall under the IED differ from mill to mill, especially for some specific grades. The production rate (in tonnes of pulp/paper produced per year) and the width of the paper machine have the highest impact on the variations of the specific energy consumption. Smaller plants with smaller paper machines have less favourable energy consumption conditions.

Grade and process-related aspects

In addition to the general aspects, grade and process-related aspects influence the specific energy consumption levels as shown in Table 2.9. These process-related aspects are discussed in more detail below.

- For non-integrated kraft pulp mills, those efficient in steam-saving projects exhibit significantly better use of heat and power. More efficient mills are able to sell more biomass-based electricity or provide district heating. Apart from differences in energy management, variations in energy consumption can be caused by the raw material used (wood species used), the make-up of the pulpwood (whether the purchased pulpwood is already chipped or not), the on-site production of oxygen, and the final brightness required. The heat consumption levels of pulp mills quoted in Table 2.9 refer to process heat consumption. Heat for the production of electricity, sold heat and conversion losses in the power plant are excluded.
- For wood-containing grades, the wood raw material, the kind of pulping process (thermomechanical pulp, groundwood, pressurised groundwood pulping) and their share of the entire fibre sources used is essential. For integrated wood-containing paper, it should be noted that the combined specific energy consumption of papermaking and mechanical pulping is a directly proportional function of the share of mechanical pulp in the furnish. For example, if TMP is highly refined, the specific electricity consumption of the mechanical pulp is 3.6 MWh/BDt pulp (see Section 5.2.2.7) and the combined power usage of the paper machine and mechanical pulping is easily over 3 MWh/tonne of wood-containing paper when chemical pulp is largely replaced with TMP in the furnish. For mechanical grades, the broad range of fibre composition leads to a considerable variation in energy consumption in mechanical paper production: power consumption for TMP (thermomechanical pulp) is normally higher than for PGW/SGW (pressurised/stone groundwood) and much higher than for RCF (recovered fibre). In return, TMP has the benefit of steam recovery substantially reducing the net heat demand of the subsequent integrated papermaking process. For coated mechanical grades, the coating technology and coat weight has an impact on energy consumption.
- For the wood-free grades, there are fluctuations in power consumption due to differing requirements for refining. The different grammage of the finished paper (g/m^2) may also have an influence. For uncoated wood-free papers, data from only two mills were available, see Table 2.9. One of these mills has a very high level of heat consumption because of an old drying section and the very low grammage of the finished paper.
- For coated, wood-free grades, the reasons for the differences in energy consumption are similar to those discussed for uncoated wood-free grades. Additionally, the applied coating technology and the coat weight have a considerable impact.
- For RCF-based papers with deinking, two grades have been distinguished: graphic papers and cartonboards. Within these two groups, the mills mentioned in Table 2.9 were similar in terms of product specifications, size of the mill and technology applied.
- For hygienic paper, the stated values are from tissue mills with creping cylinder manufacturing. The use of the through-air drying (TAD) technology requires a much higher energy input of approximately 2 500 kWh/t (power) and 6 000 kWh/t (heat) for a non-integrated TAD tissue mill. In the TAD process, pressing of the tissue web is limited to a minimum; the still wet tissue web is dried by blowing hot dry air through the tissue web and the supporting structured fabric at more than 350 °C. This leads to high energy consumption and to a very soft and bulky sheet that can absorb twice as much water as conventional tissue. During the last decade, new hybrid technologies have emerged that also enable the small machines to produce textured or structured tissue (premium grades) that match TAD tissue in softness, bulk and absorbency but require lower capital and production costs than standard dry crepe tissue manufactured by conventional wet pressing (CWP). In terms of energy consumption, these hybrid tissue technologies are somewhere in between conventional and TAD tissue: they have lower energy consumption than TAD tissue but higher than conventional wet pressing tissue (CWP) referred to in Table 2.11. Hybrid technology deployment in Europe is still limited but is increasing.
- The group of speciality papers covers a wide range of products, which is varied in terms of raw material used, manufacturing processes and product properties to be achieved. The values considered in Table 2.9 are taken from decor paper, overlay, photo and inkjet paper mills.

2.5.3 Relevance of process units for total process energy consumption

Table 2.10 gives an indication of the relevant process subsystems for the energy consumption needed for the manufacturing of different paper grades. Chemical pulping is not considered in this table (please refer to Section 3.2.2.3 for kraft pulping and 4.2.2.3 for sulphite pulping). Refining, grinding, pressing and drying are the largest energy consumers of paper mills. However, there are a large number of other consumers which together are also significant for the energy balance of the mill. The table shows which grades these energy-consuming processes are normally used for as well.

Table 2.10: Assessment of subsystems with regard to their relevance for energy consumption

Process (1)	Integrated uncoated mechanical	Integrated coated mechanical	Non-integrated uncoated wood-free	Non-integrated coated wood-free	RCF without deinking	RCF-based graphic (with deinking)	RCF-based board (with deinking)	Non-integrated tissue	RCF-based tissue	Speciality wood-free
Wood handling	░	░	NA	NA	NA	NA.	NA	NA	NA	NA
Refining	■	■	■	■	░	░	░	■	░	▨
Grinding	■	■	NA	NA	NA	NA	NA	NA	NA	NA
Screening	▦	▦	░	░	▦	▦	▦	░	▦	░
HC cleaning	░	░			░	░	░		░	
Thickening	░	░	NA	NA				NA	░	NA
Deinking	NA	NA	NA	NA	NA	░	░	NA	▦	NA
Bleaching	░	░	NA	NA	NA	░		NA	░	NA
Mixing										░
Approach flow	░	░	░	░	░	░	░	▦	▦	▦
Forming	░	░	░	░	░	░	░	░	░	░
Pressing	■	■	■	■	■	■	■	░	░	▦
Drying	■	■	■	■	■	■	■	■	■	■
Coating	NA	▦	NA	▦	NA	NA	░	NA	NA	▨
Calendering	░	░	░	░	NA	░	NA	NA	NA	▨
Finishing	░	░	░	░	░	░	░	░	░	░
Central service	░	░	░	░	░	░	░	░	░	░

■	Very intensive (greatest consumer in the mill)
▦	Considerable (major consumer)
░	Low (has only a minor impact on the energy situation of the mill)
	Negligible
NA	The process is not applied in the manufacturing of this grade
▨	Varying because of differences in process and production within this grade

(1) Explanatory remarks related to the processes are given in the text below the table.

Source: [249, Blum et al. 2007]

Explanatory remarks related to the processes that are listed in the left hand column of Table 2.10 are given below.

- Wood handling covers the debarking, chipping, preheating and conveying of pulpwood for mechanical mills.

- Refining: energy-intensive refiners are used for mechanical pulping (e.g. TMP refiners) and for the post-refining of GWP mills. In paper mills using virgin fibres, refining affects the mechanical properties of the pulp and paper product. In mills where a refining process is applied, it is normally the largest power consumer in the mill.
- Grinding is applied in GWP mills to produce mechanical pulp from pulpwood.
- Screening is operated in all paper mills to classify pulp qualities by fibre length and to remove contaminants. Therefore in mills using virgin fibres, the energy intensity is lower.
- HC cleaning refers to the use of hydrocyclones for removing heavy contaminants from the raw material in the stock preparation.
- Thickening is the mechanical dewatering of pulp. It is needed for pulp washing, a subsequent HC-bleaching process, and for loop separation.
- Bleaching is where energy is used for heating the bleaching tower and for the preparation of the chemicals. Consumption depends on the bleaching process and the brightness requirements of the product.
- Mixing includes the production of the blend for the paper machine. Energy is needed for pumping and agitating the various components for the paper product.
- Approach flow is where pumping energy is needed for moving the first white water circuit where the stock reaches the water system of the paper machine.
- Forming is the core process of papermaking. Energy is used for the drives of the wire section and for the production of mostly low vacuums for web dewatering.
- Pressing takes place in the press section of the paper machine, where the paper web is mechanically dewatered by press rolls. Energy is consumed for the hydraulic units, the drives of the press section and the generation of high vacuums.
- Drying takes place after leaving the press section where the paper is further dewatered by thermal evaporation of the remaining water. Drying is the highest source of heat consumption in papermaking (in integrated kraft pulp mills it is the pulp mill).
- Coating includes the application of pigments and binders on the surface of the raw paper to achieve defined surface properties of the finished paper. It varies between mills, depending on the type of coating and energy consumption.
- Finishing operations are not grade-specific and may differ between mills. Energy consumption depends on how the product is delivered to the customer. Finishing can include rewinding, slitting, wrapping, sheeting, shrink heating and shipment and may or may not be included in the energy figures (see Table 2.11).
- Auxiliaries are central services of the paper mill that are not related to a certain grade. Auxiliaries include raw and waste water treatment, compressed air generation, works transportation services, etc.

More detailed information on the energy use in the different types of pulp and paper manufacturing can be found in the energy-related sections of Chapters 3 to 7.

2.5.4 Energy consumption for supporting activities

Energy consumption values for internal paper mill infrastructure and for the supply of general services that are needed for paper manufacturing are shown in Table 2.11. These services, equipment or installations are common for most mills and are related to a certain paper grade. The energy consumption for these horizontal techniques only has a minor impact on the energy consumption of the entire mill. The majority of the energy is consumed by the manufacturing processes and is related to the production of certain types or grades of pulp and paper. They are therefore discussed in Chapters 3 to 7.

Table 2.11: Typical energy consumption values of general mill services

Energy-consuming processes/activities	Energy consumption (power or heat)	Explanatory notes on energy consumption values
Biological effluent treatment • mechanical + aerobic treatment e.g. for coated wood-free graphic paper	4 – 8 kWh/t power	Use of pumps, agitators, aeration; values refer to 1 or 2 stage aeration, sedimentation as primary and secondary clarifier
• mechanical + aerobic treatment for integrated RCF-based/ wood-containing paper mills	10 – 25 (1) kWh/t power	Data include all pumps and other aggregates, primary clarification, turbo aerators for biological treatment, secondary clarification, sand filters, sludge dewatering.
- mechanical + anaerobic/aerobic stage (biogas not considered)	5 – 10 kWh/t power	Generation and use of biogas not considered.
- mechanical + anaerobic/aerobic stage (biogas considered)	15 – 20 kWh/t heat surplus (useable biogas as lower calorific value)	Energy balance with the use of biogas: The surplus of biogas is based on a COD load of 15 kg/t, COD degradation of 70 %, reduced biogas rate of 0.3 m^3/kg COD and a lower calorific value of biogas of 7.5 kWh/m^3. (Treatment of RCF mill waste water may generate approx. 25 kWh/t heat – lower calorific value)
Raw water treatment	2 – 5 kWh/t power	Use of raw water pumps and preparation
Compressed air	20 – 30 kWh/t power	Use of compressors and air dryers applying to paper mills without larger finishing departments; values can go up to 50 kWh/t in mills with sheeting departments.
Works transport	1 – 2 kWh/t power	Use of forklifts, industrial trucks
Finishing (without packaging)	10 – 40 kWh/t power	Use of rewinders, slitters, broke pulping.
Finishing (with packaging)	30 – 80 kWh/t heat	Including the packaging line (sheeting, wrapping, shrink oven, shipment); values refer to the lower calorific value of natural gas used for shrink ovens.
Administration	NA	Negligible (for offices, cafeteria, etc.)

NB: NA= not available

(1) The upper end of the range refers to mills that apply tertiary treatment such as sand filters or ozonation + biofiltration. Efficient treatment systems for RCF-based paper mills with only secondary treatment achieve energy consumption values of around 10 – 15 kWh/t. Generally, the energy consumption of WWTPs for integrated chemical or mechanical pulp and paper mills are higher than those of non-integrated paper mills.

Source: PTS, Examination studies: Energy optimisation in European mills, Munich 2004 to 2007, unpublished commissioned study containing the results of investigations in European paper mills, quoted in [249, Blum et al. 2007]; personal communication (09/2010) with some UPM RCF mills in AT and DE.

2.6 Steam and power generation in pulp and paper mills

This section deals with different combustion plants designed to produce steam and power in pulp and paper mills. The combustion plants in pulp and paper mills differ in size, fuels, load conditions and purpose.

There are a variety of combustion plants in operation which have already been described in the BREFs on Large Combustion Plants [271, COM 2006] or on Waste Incineration [273, COM 2006]. To avoid duplication of information only combustion plants not covered by the above-mentioned BREFs are dealt with here (sometimes in the literature they are referred to as 'auxiliary boilers'). These are:

- combustion plants with between 5 MW_{th} and 50 MW_{th} rated thermal input including combined cycle gas turbines, steam blocks, fluidised bed reactors;
- combustion plants with <50 MW_{th} rated thermal input using pulp- and paper-specific residues or by-products as fuels (e.g. bark, certain types of sludge, waste paper, rejects) irrespective of their size (> 50 MW are covered by the LCP BREF).

Outsourcing of combustion plants does not exclude these plants from being covered by the PP BREF.

For conventional larger combustion plants (such as gas- or oil-fired steam boilers exceeding 50 MW_{th}) reference should be made to the BREF on Large Combustion Plants (LCP BREF). The LCP BREF contains extensive information related to applied techniques and abatement measures for combustion plants that use commercial fuels such as natural gas, liquid fuels, coal, lignite, biomass and peat.

Because of its high share in the total production costs, energy supply is one of the principal production factors of pulp production and papermaking. Depending on the type of process (see Chapters 3 to 7), the paper industry produces most or practically all of the heat it requires and a large portion of the electricity it needs (approximately 44 %, CEPI 2008) in its own power plants. Traditionally, internal steam and power supply has been a core business of the pulp and paper industry. Competitive mills have intensively focused on cogeneration concepts using different types of fuels (see Section 2.6.1.2.2). Others (mainly paper mills) have outsourced energy supply and reduced their internal energy production capacities. Chemical pulp mills (see Chapters 3 and 4) do not outsource their energy supply due to the need for a recovery boiler, which is essentially integrated into the chemical regeneration process.

'Process boilers' or kraft and sulphite recovery boilers, as well as lime kilns designed to recover the pulping chemicals and also to produce steam and power, are not discussed here but in the chapters describing the pulping processes (see corresponding sections in Chapters 3 and 4). For more details regarding the combustion of rejects, sludge and other materials from processing paper for recycling, the reader is referred to Section 6.3.14. Stationary internal combustion engines and smaller combustion plants of <5 MW_{th} are outside the scope of this document.

2.6.1 Applied combustion processes and techniques

The type and number of combustion plants that are technically connected to the manufacturing of pulp and paper depend on the raw materials used, the processes involved and their energy requirements, and on the energy supply strategy of the individual mill. The boilers in the pulp and paper industry are of a variable size (from about 5 to above 200 MW_{th}). Larger combustion plants operated in pulp and paper mills are comparable in size with combustion plants of energy suppliers (up to >200 MW_{th}).

In general, the types of techniques described below can be found in the pulp and paper sector.

- Recovery boilers (kraft pulp, sulphite pulp): see Chapters 3 and 4.
- Soda boilers (sulphite pulp): see Section 4.3.13.
- Lime kilns (kraft pulp): see Chapter 3.
- Fluidised bed reactors (<5 MW_{th} – >100 MW_{th}, all types of fuels and waste): see Section 2.6.1.2.3. Stationary/bubbling fluidised bed (BFB) or circulating fluidised bed (CFB) boilers are used.
- Fixed or moving grate boilers mainly for coal and coal dust, lignite and other mixed solid fuels (e.g. co-combustion of waste). Their use in pulp and paper mills is decreasing.
- Combined cycle gas turbines (CCGT); <20 MW_{th} – >100 MW_{th}: In many paper mills CCGT are operated in the heat-orientated mode, which means that the heat demand of the paper mill determines the design and operation of the CCGT. The production of power can be seen as a beneficial side-product. This makes the main difference to CCGT operated by public energy suppliers (see Figure 2.12 and for a process description also the LCP BREF).
- Gas- or oil-fired steam boilers (steam blocks): these boilers are sometimes operated to cover base load demand. However, for economic reasons they are generally used for peak loads or as reserve boilers during maintenance of the main combustion plants. As fuels mostly gas and heavy fuel oil (older boilers) are used.
- Recently, small biofuel boilers using powder or pellet firing have been installed in non-integrated paper mills.
- Package boilers (boiler units already fitted with insulation, electrical panels, valves and gauges) for combusting of diluted non-condensable gases (NCG) and concentrated NCG.
- Gas turbines: Very few mills generate power, releasing the excess heat into the environment. However, this is not cost-effective and is no longer supposed to be practised.
- Gasification techniques can provide fuel gas for CCGT, gas boilers or lime kilns. Within the pulp and paper sector, industrial applications are in use for bark at the Södra Värö mill (SE), and recycled liquid carton at the Stora Enso Varkaus mill (FI). In the Södra Värö mill, the produced gas is used as fuel in the lime kiln.
- Flares.
- Gas engines using gas from anaerobic digestion.
- Other stationary internal combustion engines.
- Emergency power generators.

The boilers and the energy supply systems that are operated on site at pulp and paper mills can be further differentiated according to the fuels used (see Section 2.6.1.1), the type of furnace (see Section 2.6.1.2.3), the integration of the heat recovery boiler into the paper mill energy system (see Section 2.6.1.2) and whether they are used for steam or power production only (see Section 2.6.1.2.1), or operated as combined heat and power plants (CHP), see Section 2.6.1.2.2.

2.6.1.1 Main fuels utilised and pretreatment

The main (combination of) fuels used for steam (and warm water) and power generation in the pulp and paper industry are as follows.

I. Biomass such as bark, wood residues, and in some cases wood chips.
II. Black liquor (in chemical pulp mills black liquor is the main fuel, see Chapters 3 and 4) that is also regarded as biomass, e.g. according to the EU ETS Directive. Kraft pulp mills also use generated non-condensable gases as fuel.
III. Various types of sludge (biosludge from waste water treatment, fibrous sludge, deinking sludge, etc.) from both virgin pulp production and/or processing paper for recycling and own pulp or paper mill residues (rejects, non-recyclable paper for recycling, plastics).
IV. Fossil fuels such as natural gas, fuel oil (heavy fuel oil, gas oil), coal, lignite or peat.

V. Sometimes waste or refuse-derived fuel are incinerated to recover energy or for other environmental reasons (e.g. the contribution of low calorific fuels such as sludge to energy recovery is low to almost zero).

In many steam boilers or power plants, a mix of fuels is used (combined combustion of sludge, bark, wood residues, pulp and paper process residues and fossil fuels).

In Figure 1.25 of Section 1.7 the fuels used to generate heat and power in the European pulp and paper industry (CEPI members) are summarised; the main fuel is biomass in the form of spent cooking liquors, bark and fibre sludge (52.5 %). Gas also contributes a major share (38.8 %) while fuel oil, coal, other fossil fuels and others together account for about 9.4 %.

Traditionally, biomass in the form of bark, wood waste and wood has been extensively used in the pulp and paper industry. To further reduce emissions of greenhouse gases, the pulp and paper industry seeks to reduce the combustion of fossil fuels and to increase the share of renewable energies. The latter is favoured in many countries and considerable subsidies are being granted.

Different types of fuel need to be pretreated to enable proper feeding, good combustion and to lower emissions, but also to increase the availability of plants. Pretreatment is aligned to the individual requirements of the furnace and the boiler but is of particular importance in fluidised bed reactors. Common types of pretreatment for the relevant fuels are listed below.

I. Biomass (bark, wood) is chipped and screened. Wet bark is normally pressed before use as a fuel and may in some cases be dried before being incinerated in the boiler. Impurities such as stones, metals and other unwanted materials are removed by screening and sorting.
II. Various sludge may be stabilised, dewatered or dried. Although an improvement of the energy yield is achievable (see Section 2.9.6.1.4) drying is often not considered to be economically viable.
III. Waste wood and some waste fractions need pretreatment steps such as shredding or grinding, sieving, and the removal of ferrous and non-ferrous metals and other unwanted materials.
IV. Rejects from RCF-based paper mills manufacturing corrugated medium or cartonboard are classified by screening. Larger rejects (e.g. with a size of more than 50 mm) are shredded. Ferrous material is then removed by magnetic separation. A travelling grate is used for feeding rejects to the drying and gasification chamber.

Although the pretreatment steps necessary to achieve good combustion are case-specific, the general aim of pretreatment is the removal of unwanted materials, a reduction of pollutants and the homogenisation of the fuels with respect to calorific value, size and other physical parameters (such as density). Since pretreatment operations such as size reduction and sieving are often subject to disturbances, most plants have installed storage facilities for pretreated fuels.

It is especially important to keep the content of Cl, K and Na within the design limits of the boiler in question. This reduces high-temperature corrosion and maintenance and repair work, leading to higher overall plant availability and lower emissions.

Excess heat (with low steam parameters, i.e. low pressure, low temperature) from the production process can be used for the drying of sludge and biomass, thus increasing the yield of high pressure steam. Depending on the specific circumstances, waste gas from the pretreatment operations as well as from storage facilities can be used as combustion air, reducing odour and pollutant emissions.

In many mills a quality assurance system for fuels and residues/wastes to be incinerated is in place. This includes declarations by suppliers, separated storage of fuels/waste, the storage of back-up samples, and the implementation of a monitoring and reporting system. As an additional control for the operator, fuel analyses, such as calorific heat value and elemental composition, and periodic analyses of flue-gas and ashes are useful to obtain information on the fuel composition.

2.6.1.2 Energy production

As pulp and paper mills need power and steam for the production process most mills apply combined heat and power generation using extraction condensing turbines or back-pressure turbines (see 2.6.1.2.2). However, heat-only plants are also operated at some paper mills, mostly to cover peak loads, start-up situations or as a reserve.

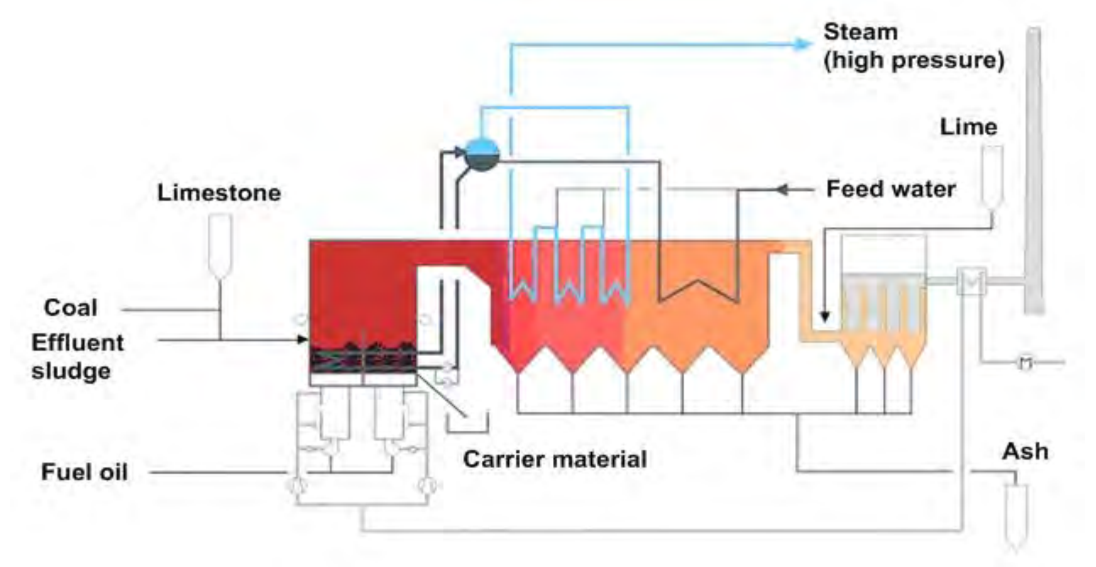
One of the main differences between boilers in the pulp and paper industry and those in the conventional utility sector is that they operate for almost the whole year, up to over 8 000 hours. Boilers in the utility sector often stop for the entire summer period. Another difference is that pulp and paper boilers constantly have to adapt to the mill operation and thus have to accommodate large and rapid load changes. Utility boilers normally operate under more stable and predetermined operating conditions.

In paper mills in particular, the demand for steam may change unexpectedly and rapidly due to e.g. paper web breaks and other disturbances. Owing to market reasons, maintenance and other factors, the steam demand may also be lower than during normal operation for considerable periods.

The flue-gas from the combustion of certain waste types and biomass may contain high concentrations of alkali chlorides, which can lead to high-temperature corrosion. As a rule, corrosion will occur at wall-temperature levels above 450 °C or flue-gas temperatures above 650 °C. High steam parameters (i.e. T >420 °C, p >40 bar) can only be achieved by using corrosion-resistant materials or by applying special measures (e.g. cocurrent flow at the superheater). When applying typical steam parameters, the electrical efficiency of combustion plants fired with waste or biomass is in the range of 14 – 25 % in the condensation mode.

2.6.1.2.1 Steam generation plants

In some mills there is no on-site power generation. These mills operate steam boilers or steam blocks only. The boiler may be fed with natural gas, liquid (oil) or solid fuels (bark, coal) or fuel mixtures. The boiler can be of any type and fuel. An example of the water-steam cycle of a larger boiler (fluidised boiler in this case) with pure steam generation is given in Figure 2.11. The emission control techniques, in this case desulphurisation and dust removal with bag filters (see Section 2.9.7), are also shown. In this example, the air cleaning system consists of a four-chamber bag filter and a dosing system for lime injection.



Source: [190, TBU Stubenvoll 2004]

Figure 2.11: Water-steam cycle of an installation with pure steam generation

2.6.1.2.2 Combined heat and power (CHP) plants

For a general description of CHP plants the reader is referred to the LCP BREF [271, COM 2006]. Combined heat and power (CHP) plants in the pulp and paper industry normally apply steam turbines and/or gas turbines (GT). Steam turbines are connected to a boiler producing high-pressure steam and are fired by any type of fuel (black liquor, bark, waste, liquid, solid or gas fuels). Gas turbines, unless hot flue-gases are used in a dryer, are combined with heat recovery steam generators (HRSG). Different configurations are used depending on whether all the steam generated is fed to different steam consumers (simple cycle) or GT and HRSG are combined with a back-pressure steam turbine or an intermediate steam extraction condensing turbine (combined cycle - CCGT). The benefit of combined heat and power production (CHP) is a better overall efficiency and flexibility.

For CHP plants using fossil fuel or biofuels (this is the case for most pulp mills), the overall efficiency with a back-pressure turbine is 85 – 90 %. The power to heat ratio is approximately 0.30 in many cases. The power generation needs to be balanced towards heat production. In Table 2.12 the ranges for total efficiency are calculated using the lower calorific value for the fuels, with moisture compensation for biomass (see glossary). The electrical efficiency range is calculated by dividing the power generation by the fuel input, and the range for power to heat ratio is approximated according to energy-efficient mills.

Table 2.12: Key figures for different CHP plant types

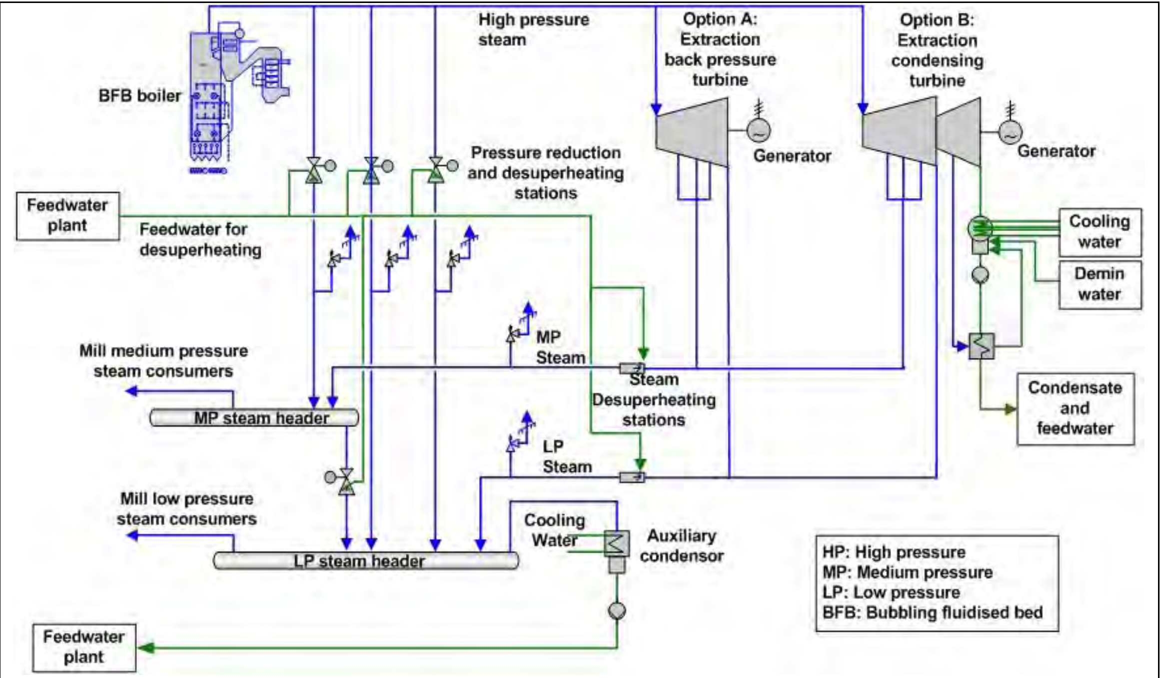
CHP plant type	Total efficiency (LCV) (fuel utilisation rate)	Power to heat ratio (1)
Gas-fired boiler and extraction turbine	85 – 90 %	0.20 – 0.35
Biomass boiler and extraction turbine	85 – 90 %	0.20 – 0.35
CCGT with steam turbine with power production for internal use	85 – 92 %	0.40 – 1.10
CCGT with steam turbine with power production for the market	75 – 80 %	1.50 – 2.00
Difference for a similar 20-year-old plant with proper maintenance	1 – 4 %	NA

NB: NA = Not applicable

(1) The power to heat ratio is also dependent on the amount of steam led to the condensing part of the steam turbine, hence the large span for power to heat ratios for CHP applications where the steam turbine is the only power-generating unit. If the need for heat energy increases, the electrical efficiency decreases because the energy from fuel divides more towards heat production (and vice versa).

Source: [167, BMUJF 1999], [170, Pöyry 2010]

The capacities for CHP production differ from <1 MW_{th} for small paper mills up to >500 MW_{th} for the recovery boilers of large pulp mills. Figure 2.12 and Figure 2.13 show examples of CHP in the paper industry. The boiler shown in Figure 2.12, in this case a bubbling fluidised bed boiler, can be of any type and fuel. Either an extracting back-pressure (Option A in the figure) or a condensing turbine (Option B in the figure) can be used, or both.

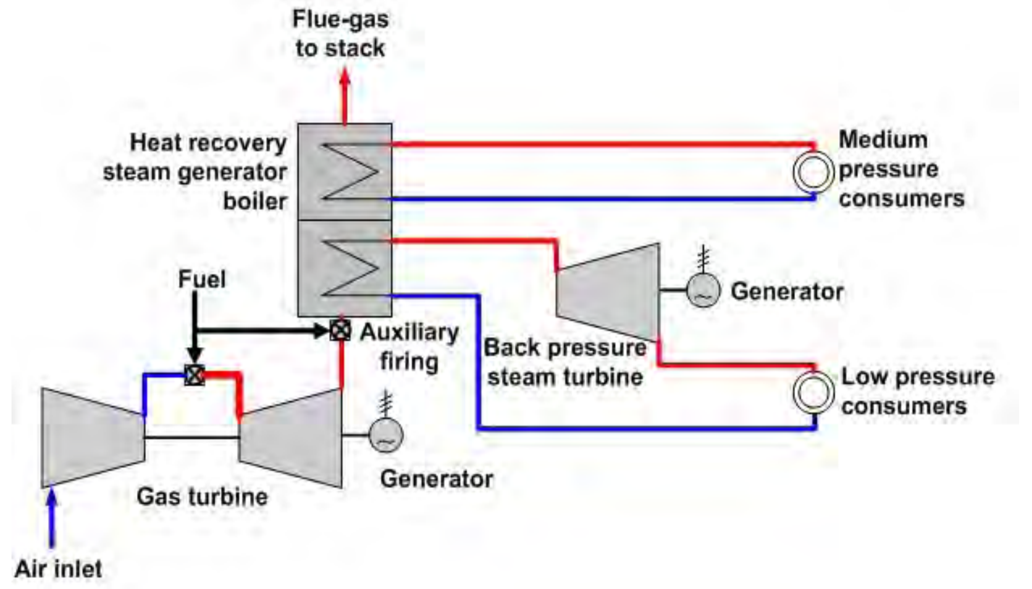


Source: S.Kankkonen, Pöyry Finland Oy, 2010

Figure 2.12: Example of a CHP plant at a pulp/paper mill

This technology has been used in the pulp and paper industry since early last century. All kraft pulp mills have steam turbines, as do large paper mills.

A special case CHP plant is the combined cycle gas turbine (CCGT) unit where oil or natural gas is burnt in the gas turbine, which directly drives a generator. In addition, the energy content of the hot flue-gases from the gas turbines are transformed into useful energy (steam and/or power) in a heat recovery boiler. The functional principle of such a CCGT unit as a CHP producing unit at a mill with both a back-pressure steam turbine and a saturated steam circuit is shown in Figure 2.13. A simple cycle is configured in a similar way but there is no steam turbine, and normally saturated steam is obtained from the boiler.



Source: S.Kankkonen, Pöyry Finland Oy, 2010

Figure 2.13: Example of a CCGT unit as a CHP producing unit at a mill with both a back-pressure steam turbine and a saturated steam circuit

Installation of gas turbines at industrial plants began in the late 1980s. Nowadays, their installation is widespread.

When producing CHP with a combined cycle gas turbine (CCGT) unit the overall efficiency is 85 – 92 % and the power to heat ratio is often higher than for other CHP plants. It can reach more than 1.0.

The flexibility with respect to the heat demand of the consuming parts of the paper mill can be improved by burning gas in the heat recovery boiler with the excess oxygen from the gas turbine (supplementary firing; see Figure 2.13).

The main improvements for the equipment used in CHP production have been largely due to the utilisation of new computer-aided tools in design and manufacturing. The efficiencies have improved for steam and gas flows in turbines as well as for the combustion process in the boilers, thus also generating lower emissions.

2.6.1.2.3 Fluidised bed boilers

In the pulp and paper industry, fluidised bed boilers are particularly suitable when 'difficult' mixed fuels with varying properties are incinerated. In fluidised bed combustion, common fossil fuels/biomass, residues or waste are fed into a sand bed fluidised by combustion air. At a temperature range of 750 – 900 °C, the fuels are transformed with the combustion air into hot flue-gas and ash.

There are two main types of fluidised bed systems: bubbling and circulating fluidised bed boilers (BFB and CFB). In BFBs, the sand bed inside the boiler is fluidised and kept in the lower part of the boiler, except for a small part escaping the bed. In CFBs, the sand bed extends up beyond the first heat exchange part, after which the sand is separated from the flue-gases in a large cyclone and returned back to the bottom of the bed. Normally, with boilers of up to

50 MW_{th} BFB combustion is applied. CFB technology is usually applied for bigger boilers only, e.g. of >50 MW_{th}. If the fuel is high in coal content, the circulating bed type is better at preventing the excessive concentration of heat, generated by coal burning in the bed.

Due to the spontaneous burning and the great variety of temperature control options, fluidised bed combustion allows for a broad range of calorific values and fuels. The fluidised bed boilers used in the paper industry mainly serve to cover the base load of steam.

In terms of fuels utilised, fluidised bed combustion plants may be charged with fossil fuels (lignite and coal, fuel oil, natural gas), biogas, biomass (e.g. bark), wood residues, wood waste and other internal production residues and sometimes also external waste or refuse-derived fuel. In addition, various types of sludge (e.g. sludge from biological waste water treatment) may be co-incinerated. In most cases, the energy content of dehydrated sewage sludge (20 – 40 % dry solids) is just sufficient to cover the flue-gas losses of the flue-gas produced by burning the sewage sludge. In paper and reject sludge incineration, both conventional grate-fired boilers and fluidised bed boilers can be used. The fluidised bed technology, however, has more flexibility with regard to tolerable fuel characteristics. Due to the homogeneous conditions in terms of temperature, mixing of fuels, control of combustion air and other measures (see paragraphs below) lower emissions of CO, SO_2 (in situ reduction is possible) and NO_X can be achieved compared to grate-fired systems.

The water content of typical fuels burnt in the sector is an important design and operational parameter: The calorific value of bark from wet debarking or peat at 40 – 60 % moisture is 4.5 – 10.5 MJ/kg. In contrast, the mechanically dewatered pulp sludge has a lower calorific value amounting to 2.5 – 6.0 MJ/kg due to its often higher moisture and ash content. The calorific value of dry pulp waste can reach over 20 MJ/kg. The higher the humidity of the fuel, the lower the overall energy economy of the boiler and also the more difficult the operability unless efficient technology is applied. A fluidised bed boiler is less sensitive to fuel humidity and a higher ash content of the fuels than a grate-fired boiler.

The main difference of grate firing and fluidised bed technology is in the heat transfer method. In grate firing, the fuel particles are heated mainly by radiation. This makes the combustion temperature and residence time very important and the system performance can easily drop when fuel humidity increases. Variations in sludge dryness at the grate-fired boiler entrance render it difficult to maintain efficient burning because of temperature drops. In the fluidised bed boilers the main heat transfer method is by conduction, which, by the aid of a fluidised sand bed inside the boiler, stabilises the system heat capacity and makes it less sensitive to fuel humidity and heating value fluctuations. It is also less sensitive to a higher ash content of the fuels (e.g. if deinking sludge is burnt).

Improvements in grate-fired boilers coupled with the upgrading of heat recovery and external flue-gas cleaning can improve their economic and environmental performance, but not to the level of fluidised bed systems. The burning in a fluidised bed boiler takes place at a lower temperature (750 – 950 °C) than required in grate firing. This is beneficial for the reduction of NO_X emissions. In addition, the heat transfer per unit area is a little higher with fluidised bed systems. As the importance of grate-fired boilers is decreasing in the pulp and paper sector, they are not discussed in more detail here.

The fluidised bed systems provide in situ SO_2 and NO_X emission control in addition to low CO emissions.

Emission monitoring with on-line gaseous compound meters is often used because of their improved reliability and acceptable costs. Multi-point temperature and oxygen monitoring of the boiler is also common.

A reduction of emissions can be achieved by the following measures in the combustion chamber:

I. installation of staged combustion to reduce NO_X formation;
II. guaranteeing sufficient residence time, temperature, turbulence in the combustion chamber and avoidance of overloading to reduce CO and hydrocarbon pollutants (C_{org}) and keep them at a very low level;
III. injection of lime or limestone into the boiler for desulphurisation;
IV. injection of ammonia or ammonia-forming compounds into the combustion chamber (SNCR: selective non-catalytic nitrogen oxide reduction).

The following measures may be applied to control the firing temperature:

I. flue-gas recirculation
II. controlled circulating ash cooling
III. staged combustion.

With a sophisticated firing rate control and air conduction, low emissions of NO_X, CO and $C_{org.}$ can be achieved. With modern air staging it is possible to reach low NO_X emission levels. Normal operating levels of oxygen for modern fluidised bed boilers are between 2 % and 3 % in dry flue-gases.

In terms of secondary flue-gas cleaning plants, the following facilities are used depending on fuel and/or waste as well as the legal requirements to be met:

I. well-designed, operated and maintained electrostatic precipitators,
II. well-designed, operated and maintained fabric filters (also with lime and active coke injection)
III. spray dry scrubbers.

In most plants, exhaust gas cleaning is limited to adsorption and dust removal. The fluidised bed boiler plants do not apply wet and catalytic flue-gas cleaning facilities. Selective non-catalytic reduction (SNCR) facilities are installed in some plants.

2.6.2 Current emissions to air from steam and power generation

2.6.2.1 Dust emissions

The emissions of dust mainly depend on the ash content of the fuel (provided combustion conditions are good). The ash content also varies considerably from close to zero for gas and oil to about 1 – 2 % for wood and bark and up to 20 % for high ash coal. Similarly peat and other fuels may contain varying amounts of sulphur and ash.

Techniques which are commonly used to control emissions of particulate matter (dust) from combustion plants operated on site in pulp and paper mills are fabric filters (FF) and electrostatic precipitators (ESP). Sometimes mechanical/inertial collectors (cyclones/multicyclones) are also used before the exhaust gas enters the filters or as a stand-alone technique in older and smaller biomass boilers.

In Table 2.13 the range for achieved emissions of particulates from boilers using fossil fuels, biomass and mixed fuels and the emission control techniques applied are given. A higher sulphur content for oil is also commonly associated with a higher ash and nitrogen content.

Older and smaller boilers, particularly for biomass, coal and other high ash fuels, may exhibit higher dust emissions due to less efficient combustion and combustion control and less efficient secondary measures to reduce emissions. According to ÅF file data and a report carried out for

CEPI [189, Norrström 2010], for such boilers the average yearly particulate emissions may reach emission levels above 50 mg/Nm^3 and up to 250 mg/Nm^3 in some cases. Technically, with the installation of a cyclone dust emission values of 100 mg/Nm^3 can be achieved. Higher values may include situations where secondary dust removal devices are not properly dimensioned, have failed or are poorly maintained. Dust emission levels above 100 mg/Nm^3 are commonly the result of the operation of a cyclone only. Even very old ESPs achieve dust emission values below 100 mg/Nm^3. Larger plants above 50 MW are subject to the IED and should reach the targets given by this Directive.

In some Member States (e.g. AT) even old fluidised bed reactors (date of commissioning: 1983 – 1986) have been equipped with ESP or fabric filters. None of these combustion plants (eight in total) exceeds an emission level of 30 mg/Nm^3 (as a yearly and monthly average). Another example is the German Technical Instruction on Air Quality Control – TA Luft, which includes an emission limit value (ELV) of 20 mg/Nm^3 for boilers with a rated thermal input exceeding 5 MW$_{th}$. This ELV has to be respected independent of the fuel used. In modern plants and in plants where ESPs or bag filters have been retrofitted, achieved values are in the range of 0.5 – 10 mg/Nm^3 (determined as a daily average value, 6 % and 11 % O_2).

Table 2.13 shows a relatively large variation between the auxiliary boilers operated in European pulp and paper mills. The table aims to give the whole range of measured emissions of auxiliary boilers that use biomass, fossil fuels or mixed fuels.

Table 2.13: Range of achieved emissions of particulates from steam boilers for different fuels and control measures applied (dry gas, standard conditions) in European plants

Fuels	Daily average (mg/Nm^3 at 6 % O_2)	Yearly average (mg/Nm^3 at 6 % O_2)	Emission control technique
Gas	<5	<5	Combustion control
0.05 % S fuel oil	<5	<5	Fuel selection and combustion control
<1 % S fuel oil	310 – 590	450	Some plants do not apply any abatement technique and measure dust twice a year (2)
<1 % S fuel oil	5 – 100	20 – 55	Fuel oil selection and ESP (2)
>1 % S fuel oil	≤20	≤10	ESP
Bark, other biomass, and mixed fuels	1 – 300 (1)	1 – 250 (1)	For higher values cyclones; normally ESP or fabric filter
Coal and mixed fuels	1 – 300 (1)	1 – 250 (1)	For higher values cyclones; normally ESP or fabric filter;

(1) The upper end of the emission range for biomass and coal is taken from ÅF file data (monitoring data from various tests and monitoring studies on boilers; approximately 50 plants): [189, Norrström 2010].
For the lower end of the range data from filled-in questionnaires (2008) and [229, Stubenvoll et al. 2007] were considered; with fabric filters dust emissions are normally well below 20 mg/Nm^3.
(2) Data taken from Portuguese questionnaires 2009

2.6.2.2 SO_2 emissions and other gaseous pollutants

The characteristics and composition of the fuel used in the boilers have a considerable impact on the emissions to air and determine, together with the type and design of the boiler and the type, design and operation of the emission control measures, the final emissions to air from a boiler. The sulphur content of fuels may range from 0.05 % or even lower for biomass and low-sulphur oil up to about 4 % for high-sulphur coal and oil.

The most common and often the most economical way to control SO_2 in the pulp and paper industry is by using a low-sulphur fossil fuel. If bark alone is burnt, SO_2 emissions are low. In fluidised bed boilers, injection of lime into the boiler is an efficient measure. Secondary control technologies include spray dry scrubbers, sorbent injection processes (see Section 2.9.7.3) and wet scrubbers (wet scrubbers are however not applied in the sector with the exception of recovery boilers).

Table 2.14 compiles achieved emissions of SO_2 from different types of auxiliary boilers. In individual cases, factors such as the actual type of fuel and operation conditions will have to be taken into consideration as in most cases the raw data did not give the specific conditions under which these values were measured. The ranges indicated in the table cover a range in the sulphur content of the fuel from about 0.05 % (e.g. forest biomass, low-sulphur oil) to about 1.5 %. Low-sulphur fuel oil with below 0.05 % (weight) sulphur is available in many areas from several suppliers. The low-sulphur oil is also low in nitrogen (about 0.05 % by weight) and in ash (about 0.005 %) thus providing for lower NO_X and particulate emissions.

Some older auxiliary boilers, particularly for coal and fuel oil, may release higher SO_2 emissions due to the higher sulphur content of the fuels, less efficient combustion control and less efficient secondary measures to reduce emissions. Often, besides the main fossil fuel (e.g. gas, oil or coal), some residues or sludge are also co-incinerated (e.g. sludge, residues from production, or other fuels) in the boilers. Some data are compiled for these mixed fuels.

Table 2.14: Achieved emission levels of SO_2 from auxiliary boilers for different types of fuels and control measures applied (at 6 % O_2, dry gas, standard conditions)

Fuels	Daily average (mg/Nm^3 at 6 % O_2)		Yearly average (mg/Nm^3 at 6 % O_2)		Emission control techniques applied
	(mg/Nm^3)	(mg/MJ)(2)	(mg/Nm^3)	(mg/MJ)(2)	
Gas	5	1	5	1	Low-sulphur content
0.05 % S fuel oil	10	3	10	3	NA
1.5 % S fuel oil	50	15	50	15	Scrubber
Biomass	1 – 30	15	1 – 20	10	Clean bark and wood residues (1)
Mixed fuels (e.g. bark, coal, fuel oil, sludge, gas)	35 – 77	No data	6 – 75	No data	Dry scrubber, injection + ESP or FF
0.5 % S coal	150	60	100	40	Dry scrubber, injection
1.5 % S coal	200	80	150	60	Dry scrubber, injection

NB: NA= not available

(1) Biosludge and fibre sludge may increase the sulphur content of the fuel and thus the emissions. On the other hand, a German biomass boiler reported daily average values of 0 – 2 mg/Nm^3 which resulted in an annual average value of 0.63 mg/Nm^3 (*Source*: UBA, 2010).

(2) Reference is made to the effective heat value of the fuel.

Sources: Based on ÅF file data. ÅF file data refer to data from monitoring of new boilers during acceptance tests and from existing boilers for environmental reporting; data from filled-in questionnaires (2008)

2.6.2.3 NO_X emissions

The nitrogen compounds of interest are nitrogen oxide (NO) and nitrogen dioxide (NO_2), collectively referred to as NO_X, and especially for fluidised bed boilers the emissions of nitrous oxide (N_2O).

A possible source of additional nitrogen, and thus nitrogen oxides, is sludge from biological treatment facilities and chemical flocculation of effluents. Some fossil fuels, such as coal and heavy fuel oil also have a comparably high nitrogen content. In addition to the fuel-bound nitrogen, the thermal formation of NO_X also determines the overall NO_X emissions of a combustion plant.

However, the emission of NO_X is also influenced by the amount of excess air, the temperature and the temperature distribution in the furnace. Due to lower combustion temperatures, the thermal formation of NO_X is low in fluidised bed reactors.

Measures to control NO_X emissions from boilers include primary and secondary measures.

a) The following primary measures are applied in fluidised bed reactors in the pulp and paper industry (see Section 2.6.1.2.3):

- minimising excess air
- air staging (over fire air)
- flue-gas circulation.

b) In gas turbines, steam or water injection or the dry low-NO_X (DLN) technique is applied. As a secondary measure, SCR can principally be applied.

Steam/water injection is a common technique (e.g. in Canada; see BREF LCP [271, COM 2006]). Achieved reduction rates for NO_X are between 60 % and 80 %. When simultaneously low CO emissions should be achieved reduction rates are somewhat lower (40 – 60 %).

The dry low-NO_X technique can be used in small (4 – 25 MW_e) as well as in very large (400 MW_e) gas turbines. An emission level of 25 ppm NO_X (corresponding to 50 mg NO_X/Nm^3) is achievable at smaller plants, whereas the NO_X emission level can be further reduced in large plants to <20 mg/Nm^3, (see [271, COM 2006] and [167, BMUJF 1999]). The pulp and paper industry usually runs gas turbines of <50 MW_e. They have emission values of 25 ppm NO_X (50 mg NO_X/Nm^3) at 15% O_2 when the dry low-NO_X technique is applied.

c) For liquid and gaseous fuels, low-NO_X burners are commonly applied. Emission levels for gaseous fuels are in the range of 60 – 90 mg NO_X/Nm^3. It has been shown that, by use of a continuous control system for lambda probes, emission levels can be kept very low. However, that requires the installation of a continuous emission monitoring system (applied, e.g. at Hamburger, AT; Questionnaire 2008).

Examples of secondary measures are:

- SNCR (selective non-catalytic reduction) and
- SCR (selective catalytic reduction).

The SCR method is not yet applied in the pulp and paper industry due to the relatively small boilers and also to the sodium content in the biomass boiler ash which deactivates the catalyst. Therefore, the SCR method will not be further discussed here.

In SNCR systems, ammonia or urea is injected into the furnace within a suitable temperature range. Emissions of NO_X can be reduced by 30 – 70 % by the reaction between the NO_X and reagent to form nitrogen and water. The temperature window for efficient SNCR operation is typically between 800 °C and 1 000 °C. Higher reduction rates may increase the emissions of NO_2. Distribution of the reagent needs to be particularly controlled. Multiple points of injection are commonly used to follow the temperature changes caused by boiler load changes. The benefit of reduced NO needs to be weighed up against the risk of increased NH_3 emissions. In well-controlled SNCR systems, NH_3 emissions (slip) are in the range of 1 – 10 mg/Nm^3 (see LCP BREF).

In Table 2.15, numbers are given for achieved emissions of NO_X from boilers using a combination of the techniques described above. Emission data refer to 3 % O_2 for gas and to 6 % O_2 for other fuels, assuming dry gas and standard conditions. The ranges given in the table primarily reflect the influence of different nitrogen contents in the fuels and the efficiency of the secondary measures applied. Some older boilers with less efficient control measures will show higher emissions: daily average emission levels up to about 200 mg NO_X/Nm^3 or even higher are detected. Auxiliary boilers in the pulp and paper industry operate under varying load conditions, which may affect the NO_X emissions. Emission ranges given in the tables however include partial load conditions.

Table 2.15: Achieved emission levels of NO_X from auxiliary boilers for different fuels and control measures applied

Fuel	Daily average		Yearly average		Emission control techniques applied
	mg/Nm^3	mg/MJ	mg/Nm^3	mg/MJ	
Gas	60 – 150	40	60 – 120	30	Low-NO_X burner or DLN technique
0.05 % S fuel oil	200	50	150	40	Low N fuel, low-NO_X burner, SNCR
1.5 % S fuel oil	240	60	200	50	Low-NO_X burner, SNCR
Biomass	100	45	80	40	SNCR
Biomass	75 – 470	No data	190 – 290	80 – 95	Without SNCR (3 boilers)
Mixed fuels (e.g. bark, coal, fuel oil, sludge, gas)	130 – 330	No data	150 – 300	No data	Fluidised bed boilers
0.5 % S coal	125	50	100	40	SNCR
1.5 % S coal	75	30	60	25	SCR

Source: Based on ÅF file data. ÅF file data refer to data from the monitoring of new boilers during acceptance tests and from existing boilers for environmental reporting; data from filled-in questionnaires (2008) [229, Stubenvoll et al. 2007] are complemented for gas. Data from Austrian UBA on mixed fuel boilers.

2.6.2.4 CO emissions

CO and hydrocarbon emissions are primarily related to the amount of excess air and the combustion conditions. Fuel with a low dry content, with uneven dry content and with rapid load changes can lead to increased levels of CO and hydrocarbon emissions (TOC) that need to be controlled. Operation at a low or uneven heat load tends to result in increased emissions.

Carbon monoxide forms from the carbon contained in the fuels in the case of incomplete combustion. Combustion conditions leading to elevated levels of CO also result in increased emissions of hydrocarbons. To achieve a complete and efficient combustion – and thus minimise the emissions of CO and hydrocarbons – the following boiler and combustion parameters need to be controlled:

- oxygen supply
- furnace temperature
- mixing of fuel and combustion air (oxygen)
- residence time.

Combustion favouring low emissions of CO for example requires the use of high furnace temperatures and sufficient oxygen supply for complete incineration of organic substances. Reduction of the CO content in the flue-gas requires a controlled excess of combustion air. Excess of combustion air will however tend to increase the NO_X emission. Therefore aiming to keep emissions of both NO_X and CO low will, to some extent, be counteractive. Control of the combustion conditions and the combustion air are therefore important elements in controlling CO. Another prerequisite is a stable fuel with respect to heating value and load on the boiler.

Firing rate control should ensure a sufficient supply of oxygen. In a simple control system, air supply is controlled via O_2 monitoring. Complex systems also monitor boiler load, fuel calorific value, fuel supply and other parameters.

The temperature in the furnace can be controlled via flue-gas recirculation, preheating of air, air surplus and fuel mix. Recirculation of flue-gas and air preheating in particular allow for fuels with a broad heat value spectrum to be used in fluidised bed boilers. Particularly in the co-incineration of sludge from the waste water treatment plant, it is important to arrange for the efficient mixing of fuels to safeguard sufficient fuel heat values to ensure satisfactory combustion temperatures.

The design of the boiler should be such as to guarantee sufficient dwell time, combustion temperature, and efficient mixing of combustion air and fuels, etc. to reduce CO and organic pollutants (TOC).

In Table 2.16 achieved emissions of CO from combustion-controlled boilers are given (at 6 % O_2, dry gas, standard conditions). Older boilers without efficient combustion control, uneven fuel and changing operating conditions may show considerably higher emissions, particularly for the daily measurements.

Table 2.16: Achieved emission levels of CO for different fuels and control measures applied

Fuel	Daily average		Yearly average		Emission control techniques applied
	mg/Nm^3	mg/MJ	mg/Nm^3	mg/MJ	
Gas	5 – 15	5	<5	<2	Not specified
0.05 % S fuel oil	15	5	<5	<2	Not specified
1.5 % S fuel oil	25	8	<10	50	Not specified
Biomass	5 – 300	150	140	70	Not specified
Mixed fuels (e.g. bark, coal, fuel oil, sludge, gas)	5 – 150	No data	6 – 100	No data	No data
0.5 % S coal	250	100	125	50	Pulverised coal

Source: Based on ÅF file data. ÅF file data refer to data from the monitoring of new boilers during acceptance tests and from existing boilers for environmental reporting; data from filled-in questionnaires (2008) and [229, Stubenvoll et al. 2007] were considered for the lower end of the emission ranges.

Boilers in the pulp and paper industry often have to handle significant and rapid load changes and variations in the fuel with regard to the dry content and the heat value. Despite advanced control systems and the proper mixing of fuels, this may cause some pronounced CO emissions peaks. The peaks may lead to high figures for daily average emissions although these tend to even out in the yearly average.

2.7 Waste water treatment plants

Effluent loads from the pulp and paper industry can be reduced through process changes and optimisation (a process-integrated approach) and by treatment once the effluent has left the process (an end-of-pipe approach). In practice, the two approaches can be combined in such a way that the desired results are achieved at a minimum cost. There are also a number of applications of in-line treatment in the sector in which the treatment systems are integrated into part of the water circuits and can be interpreted as a kind of ‘kidney’ that permanently removes disturbing substances until a necessary quality level is reached.

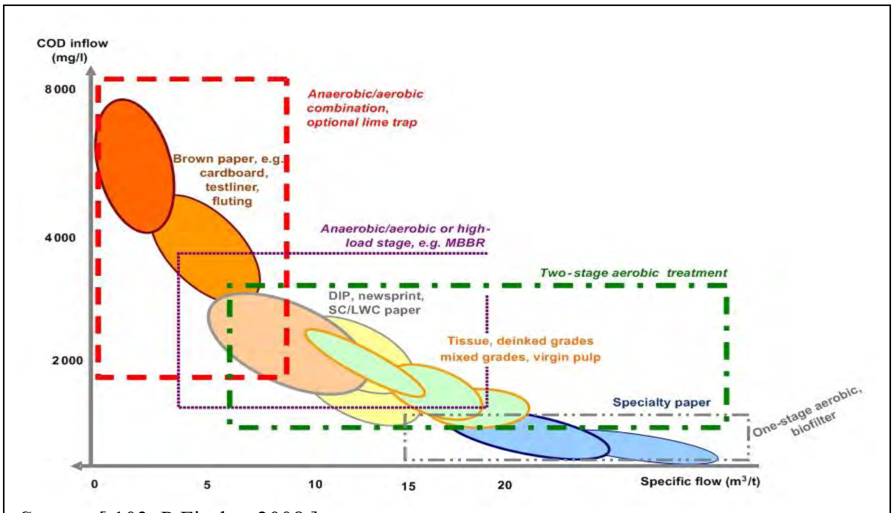
The treatment is always connected to the production process itself. Changes in the process and accidental releases of pollutants in particular will normally affect the treatment plant, especially when it is a biological process. Therefore, optimising the process and the performance of the waste water treatment plants go hand in hand. When designing or operating a waste water treatment plant, the normal starting point is the analysis of the processes and the major effluents generated. Emphasis should be placed on first implementing internal process measures. Process-integrated measures reduce loads at the source, and direct savings can be made in raw material costs (fibre, fillers, and additives) and in energy consumption in many cases. Usually, the necessary measures can be carried out by the personnel of the plant. However, changing over to a less harmful process may result in considerable costs because of the more complex technology required. Efficient solutions are normally a combination of internal and external measures.

If paper mills discharge their effluents via the sewer to an off-site urban or industrial waste water treatment plant, the overall efficiency of the external treatment plant may be affected by the quality and quantity of other waste water streams that are treated together with the paper mill effluents. In some cases, the 'economies of scale' of a treatment plant of a consortium can achieve equal or better emission reduction rates than comparable on-site waste water treatment. This is due to the fact that paper mills and other industries that are connected to the common waste water treatment plant may have access to more effective treatment techniques with appropriate supervision of their operation.

Effluents from the pulp and paper industry contain substances that are extracted from the wood or from the recycled fibres. They also contain some chemicals used in the process that are released from the processes and not retained in the fibres of the manufactured pulp or paper. The effluents contain solids or material in colloidal form or dissolved substances. With few exceptions (eucalyptus pulping), the original levels of nitrogen and phosphorus are low and are added to biological waste water treatment plants to feed the biomass. The effluents can also be coloured, notably those from chemical pulp production. Some untreated effluents are toxic to fish, for example those from the debarking of wood.

Depending on the type and load of the waste water generated, pulp and paper mills operate different treatment systems that are suitable for cleaning the incoming loads in an efficient way. Normally effluent treatment consists of the equalisation of variations in effluent flow and composition, followed by the removal of solids (e.g. primary sedimentation). Physical or physico-chemical treatment methods remove mainly solids and high molecular mass colloids. Biological methods remove dissolved organic compounds that are biochemically oxidised or transposed into biomass. The undesired release of this biomass is controlled by the use of carrier material (biofilm), secondary sedimentation, flotation or filtration, in some cases.

Depending on the waste water quality and the organic load, different treatment concepts are used in pulp and paper mills. Figure 2.14 gives an overview of common biological waste water treatment methods and their possible application in the paper industry. The picture shows which treatment systems are used for the effluents of example paper grades (chemical pulping is not included) manufactured either from virgin or recovered fibres (or a fibre mix) and which are often found in the sector. The specific water consumption (m^3/t) and initial COD concentrations before treatment plotted on the x- and y-axis are only indicative. Other treatment concepts, e.g. one-stage activated sludge plants, can also result in good removal efficiencies. Existing applications of these treatment systems, technical descriptions of the techniques used and their performance are discussed in the respective Chapters 3 to 7 that deal with anaerobic or aerobic waste water treatment.



Source: [103, P.Fischer 2008]

Figure 2.14: Different concepts of biological waste water treatment applications for different paper grades and simplistic trends of the organic loads

There is a wide variety of designs of aerobic treatment of pulp and paper mill effluents: activated sludge systems, such as (but not limited to) conventional one-stage or multistage activated sludge reactors, sequencing batch reactors, high performance compact reactors and aerated lagoons; and biofilm systems, such as (but not limited to) aerobic submerged biofilters, suspended carrier biofilm reactors or moving bed biofilm reactors (MBBR), trickling filters and rotating biological contactors (RBC). These treatment steps are used as one or more step applications or in combination with each other. Furthermore, anaerobic treatments are also used (see Section 2.9.11.2.2). The main technologies for biological treatment and the concentration range for suitable application are shown in Figure 2.15.

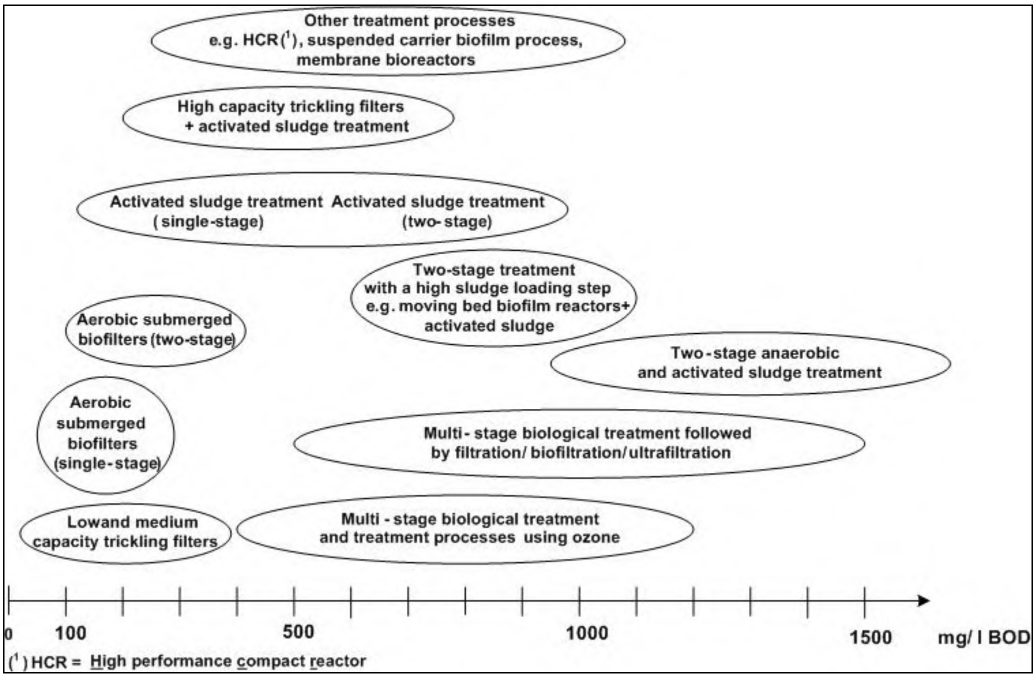


Figure 2.15: Main processes for the treatment of pulp and paper mill waste water and the ranges of suitable application

The concentration values refer to inlet concentrations and should be understood as a rough orientation which provides a general overview of applied waste water treatment systems in pulp and paper mills. The purpose of the figure is not to exclude or discriminate against a certain application or treatment system, e.g. if the organic load is not in the indicated range (according to [113, PTS 1998]).

In Table 2.17 an overview is given of the most important biological treatment systems, their suitable range of application, some advantages and drawbacks as well as some additional remarks.

Table 2.17: Biological treatment of waste water from pulp and paper mills

Process	Application (average BOD inlet concentration)	Advantages	Drawbacks	Remarks
Aerobic submerged biofilters (single-stage)	20 – 100 mg/l	Safe process; immobilised biomass; low concentration of suspended solids in the effluent	Sensitive to higher concentration of suspended solids	NA
Aerobic submerged biofilters (two-stage)	100 – 300 mg/l (or more)	NA	NA	NA
Low to medium capacity trickling filters	<400 mg/l	Simple construction; low energy consumption; cooling of the waste water, quick recovery after short-term toxic shock (1)	In some cases risk of clogging; odour caused by stripping, higher P emission required for optimum operation (1.0 – 1.5 mg/l)	Risk of clogging and odour are minimal with proper nutrient management. Lifetime expectancy of 15 years or more when properly operated
High capacity trickling filters + activated sludge	200 – 800 mg/l	NA	NA	NA
Activated sludge (single-stage)	100 – 1 000 mg/l	Conventional process with a number of variants; well-established treatment technique	Energy consumption; excess sludge; problems with bulking or floating sludge	NA
Activated sludge (two-stage)	300 – >1 000 mg/l	NA	NA	Separation of sludge circuits is important
Activated sludge (two-stage with high sludge load step)	600 – 1 200 mg/l	Improved properties of activated sludge process	Energy consumption; excess sludge	NA
Moving bed biofilm reactors, MBBR (fixed biomass on mobile carrier material)	300 – 1 500 mg/l	Fixed biomass; smaller reactor volumes; no return sludge; less sensitive to peak loads	Excess sludge	Allows high volume load
Rotating biological contactors (RBCs): Fixed biofilm system/biodiscs	Applied as bulk removal step or for advanced treatment	Cost-effective for smaller mills; low energy demand (<0.3 kWh/kg BOD_5 removed)	In many European countries there is less experience with RBCs	Successful application in US and Italy in paper industry
Activated sludge as sequencing batch reactor (SBR)	100 – 1 000 mg/l	More flexible process operation	More efforts for process control; discontinuous process	NA

NB: NA = not available
(1) *Source*: Water treatment handbook, Chapter 11.2 trickling filters, 6th edition, Degrémont.
Source: [113, PTS 1998], amended by EIPPCB.

During biological treatment, dissolved organic matter is converted into biomass, which accumulates as biosludge (for the amount of sludge, please refer to the four examples below). Fibre sludge from the pre-sedimentation tank and excess sludge from the activated sludge plant is thickened in separate thickening tanks. Dewatering can take place using a screw press with a pre-concentrator or in dewatering machines with belt presses. The dewatered sludge is often mixed with bark and burnt in the bark boiler. Other options are combustion in a biomass power plant, a fluidised bed sludge incinerator or in the recovery boiler. In other cases, the sludge is delivered to external waste management contractors for biogas production, disposal of landfills or other alternatives.

2.8 Overview of production residues and solid waste

Pulp and paper manufacture gives rise to different types of residues such as those exemplified in Table 2.18.

Table 2.18: Examples of residues generated in pulp and paper processes

Process	Examples of generated solid residues/waste
Wood handling	Bark and wood fragments, sand and stone
Raw water treatment	Sludge from flocculation
Kraft pulping	Excess lime, dregs and grits from the recovery system; extracted ESP ash; rejects and fibre from the fibre line
Sulphite pulping	Ash from the recovery boiler; sludge from the cooking liquor system; rejects and fibre from the fibre line
Mechanical pulping	Sand and wood fragments from chip washing; rejects and fibre from the fibre line
Processing paper for recycling	Rejects from stock cleaning (non-fibre rejects, e.g. sand, metal scrap), fibre rejects and deinking sludge
Papermaking	Rejects and fibre, fibrous sludge, coating pigments
Power boilers	Ash
Effluent treatment	Fibre sludge, biosludge and chemical sludge
Common residues	Metals, plastics, glass, building waste, domestic waste, hazardous residues such as chemicals, spilled oil and lubricants

Some of the materials listed above that result from the production process may be regarded as not being waste according to point (1) of Article 3 of the Waste Framework Directive (WFD) but as being a by-product if the conditions listed in Article 5 of the WFD [205, WFD 98/EC 2008] are met.

There is considerable variation in the amount and nature of residues generated in different types of mills. The major waste fractions and major routes for recovery, reuse or disposal are discussed in the corresponding sections of Chapters 3 to 7.

According to the consolidated 'list of waste' [50, Decision 2000/532/EC 2000] the major types of 'wastes from pulp, paper and cardboard production and processing' are:

03 03 01 bark and wood (bark, sawdust, rejects from coarse and fine screening)
03 03 02 dregs and green liquor sludge (from recovery of cooking liquor in kraft pulping)
03 03 05 deinking sludges from recovered paper processing
03 03 07 mechanically separated rejects from pulping of waste paper and cardboard
03 03 08 wastes from sorting of paper and cardboard destined for recycling
03 03 09 lime mud waste (kraft pulp mills)
03 03 10 fibre rejects, fibre-, filler- and coating-sludges from mechanical separation
03 03 11 sludges from on-site effluent treatment other than those mentioned in 03 03 10
03 03 99 wastes not otherwise specified

This list of non-hazardous waste accounts for 88 % of the total generated production waste from pulp and paper mills [139, ASPAPEL 2008].

Depending on the energy supply of the pulp and paper mill and the steam and power generation operated on site, the following waste materials have to be additionally considered:

10 01 waste from power plants and other combustion plants such as
10 01 01 bottom ash

10 01 02 coal fly ash
10 01 03 peat and (untreated) wood fly ash and some others.

Common residues/waste

In most pulp and paper mills, non-industry-specific common residues/waste occur. These residues may include:

- metal parts and metals from maintenance
- electric and electronic equipment and parts including light bulbs, fluorescent lights, etc.
- wires and felts
- building waste such as glass, wood, concrete, bricks, etc.
- chemicals including coating residues
- waste from laboratories (mostly chemicals)
- spill oil and lubricants
- packaging material (containers for chemicals, pallets, etc.)
- domestic waste (from canteens and offices)

To handle this common waste in the most efficient way, systems to sort the waste into main fractions have been implemented in many mills. Such systems facilitate reuse, further recycling and/or recovery and minimise the amounts having to be sent for disposal or special handling.

Hazardous materials should always be collected separately and the collection organised in different 'classes' such as residual solvents, spill oil and lubricants, spent chemicals, etc. The further handling of such material should be done by certified firms.

2.9 General techniques to consider in the determination of BAT common to all mills

This section describes techniques (or combinations thereof), and associated monitoring, considered to have the potential for achieving a high level of environmental protection in the activities within the scope of this document. The techniques described will include both the technology used and the way in which the installations are designed, built, maintained, operated and decommissioned.

It covers environmental management systems, process-integrated techniques and end-of-pipe measures. Waste prevention and management, including waste minimisation and recycling procedures are also considered, as well as techniques that reduce the consumption of raw materials, water and energy by optimising use and reuse. The techniques described also cover measures used to prevent or to limit the environmental consequences of accidents and incidents, as well as site remediation measures. They also cover measures taken to prevent or reduce emissions under other than normal operating conditions (such as start-up and shutdown operations, leaks, malfunctions, momentary stoppages and the definitive cessation of operations).

Annex III to the Directive lists a number of criteria for determining BAT, and the information within this chapter will address these considerations. As far as possible, the standard structure in Table 2.19 is used to outline the information on each technique, to enable a comparison of techniques and the assessment against the definition of BAT in the Industrial Emissions Directive.

This section does not necessarily provide an exhaustive list of techniques which could be applied in the sector. Other techniques may exist, or may be developed, which could be considered in the determination of BAT for an individual installation.

Table 2.19: Information for each technique

Headings within the sections
Description
Technical description
Achieved environmental benefits
Environmental performance and operational data
Cross-media effects
Technical considerations relevant to applicability
Economics
Driving force for implementation
Example plants
Reference literature

2.9.1 Environmental management systems (EMS)

Description
A formal system to demonstrate compliance with environmental objectives.

Technical description
The Directive defines ‘techniques’ (under the definition of 'best available techniques') as ‘both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned’.

In this respect, an environmental management system (EMS) is a technique allowing operators of installations to address environmental issues in a systematic and demonstrable way. EMSs are most effective and efficient where they form an inherent part of the overall management and operation of an installation.

An EMS focuses the attention of the operator on the environmental performance of the installation; in particular through the application of clear operating procedures for both normal and other than normal operating conditions, and by setting out the associated lines of responsibility.

All effective EMSs incorporate the concept of continuous improvement, meaning that environmental management is an ongoing process, not a project which eventually comes to an end. There are various process designs, but most EMSs are based on the plan-do-check-act cycle (which is widely used in other company management contexts). The cycle is an iterative dynamic model, where the completion of one cycle flows into the beginning of the next (see Figure 2.16).

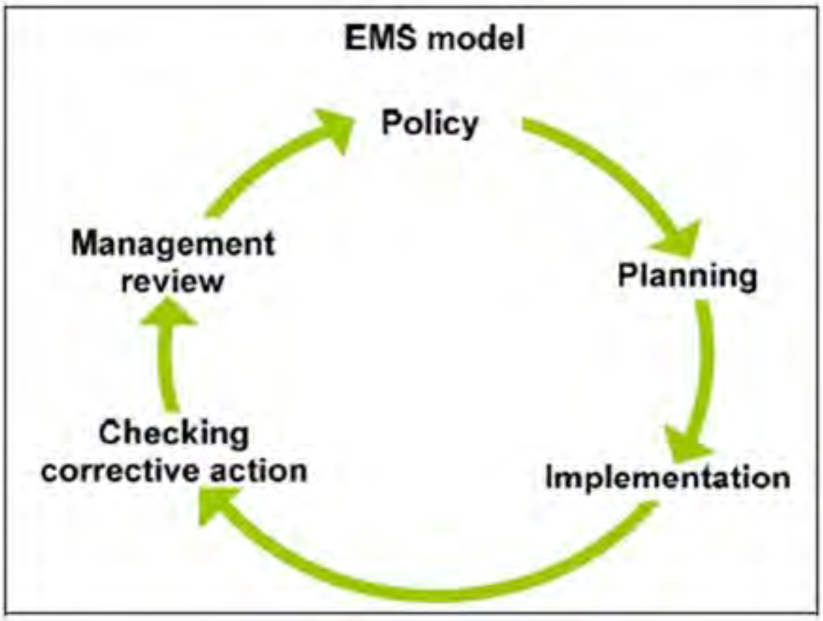


Figure 2.16: Continuous improvement in an EMS model

An EMS can take the form of a standardised or non-standardised (‘customised’) system. Implementation and adherence to an internationally accepted standardised system, such as EN ISO 14001:2004, can give higher credibility to the EMS especially when subjected to a properly performed external verification. EMAS provides additional credibility due to the interaction with the public through the environmental statement and the mechanism to ensure compliance with the applicable environmental legislation. However, non-standardised systems can, in principle, be equally effective provided that they are properly designed and implemented.

While both standardised systems (EN ISO 14001:2004 or EMAS) and non-standardised systems apply in principle to **organisations**, this document takes a narrower approach, not including all activities of an organisation, e.g. with regard to their products and services, due to the fact that the Directive only regulates **installations/plants**.

An EMS can contain the following components:

1. commitment of management, including senior management;

2. definition of an environmental policy that includes the continuous improvement of the installation by the management;
3. planning and establishing the necessary procedures, objectives and targets, in conjunction with financial planning and investment;
4. implementation of procedures paying particular attention to:

   (a) structure and responsibility
   (b) training, awareness and competence
   (c) communication
   (d) employee involvement
   (e) documentation
   (f) efficient process control
   (g) maintenance programmes
   (h) emergency preparedness and response
   (i) safeguarding compliance with environmental legislation;

5. checking performance and taking corrective action paying particular attention to:

   (a) monitoring and measurement (see also the Reference Document on the General Principles of Monitoring) [269, COM 2003]
   (b) corrective and preventive action
   (c) maintenance of records
   (d) independent (where practicable) internal and external auditing in order to determine whether or not the EMS conforms to planned arrangements and has been properly implemented and maintained;

6. review of the EMS and its continuing suitability, adequacy and effectiveness by senior management;
7. following the development of cleaner technologies;
8. consideration for the environmental impacts from the eventual decommissioning of the installation at the stage of designing a new plant, and throughout its operating life;
9. application of sectoral benchmarking on a regular basis.

Achieved environmental benefits

An EMS promotes and supports the continuous improvement of the environmental performance of the installation. If the installation already has a good overall environmental performance, an EMS helps the operator to maintain the high performance level.

Environmental performance and operational data

The European paper industry, through CEPI, has committed itself to the target of putting in place certified environmental management systems (EMS/ISO 14001).

Cross-media effects

None reported. The systematic analysis of the initial environmental impacts and scope for improvements in the context of the EMS sets the basis for assessing the best solutions for all environmental media.

Technical considerations relevant to applicability

The components described above can typically be applied to all installations within the scope of this document. The scope (e.g. level of detail) and nature of the EMS (e.g. standardised or non-standardised) will be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

Economics

It is difficult to determine accurately the costs and economic benefits of introducing and maintaining a good EMS. There are also economic benefits that are the result of using an EMS and these vary widely from sector to sector.

External costs relating to verification of the system can be estimated from guidance issued by the International Accreditation Forum [31, IAF 2010].

Driving forces for implementation
The driving forces for the implementation of an EMS include:

- improved environmental performance
- improved insight into the environmental aspects of the company which can be used to fulfil the environmental requirements of customers, regulatory authorities, banks, insurance companies or other stakeholders (e.g. people living or working in the vicinity of the installation)
- improved basis for decision-making
- improved motivation of personnel (e.g. managers can have confidence that environmental impacts are controlled and employees can feel that they are working for an environmentally responsible company)
- additional opportunities for operational cost reduction and product quality improvement
- improved company image
- reduced liability, insurance and non-compliance costs.

Example plants
EMSs are applied in a number of installations throughout the EU. 83 % of the EU pulp and paper plants have implemented an EMS. In 2010, environmental management systems have been certified in 469 pulp and paper mills in Europe (76 % of the total), *source*: CEPI). In Spain for instance, 94 % of the total production of pulp and paper was produced by EMS certified mills (*source:* ASPAPEL: Update sustainability report 2009).

Reference literature
EMAS Regulation (EC) No 1221/2009: [83, Reg. 1221/ 2009]; DG Environment EMAS website: [30, DG Environment 2010]; EN ISO 14001: 2004: ISO 14000 family standards website: [29, ISO 2004]; ISO 14000 technical committee: [25, ISO 2010]; [79, Dyllick and Hamschmidt 2000], [82, Clausen J., M. Keil and M. Jungwirth 2002].

2.9.2 Handling and storage of raw materials

2.9.2.1 Reduction of emissions from wood handling

Description
The most relevant environmental aspects of wood handling and measures to reduce them are compiled in Table 2.20. The effluents to water from wood handling originate from the debarking drum and from any spraying of woodpiles with water. Effluent from debarking can be minimised by applying dry debarking (see Section 2.9.2.2). In spraying piles the amount of water should be minimised by controlling the ambient temperature and humidity to match the evaporation of water from the piles. Contamination of soil and groundwater should be avoided by paving the wood yard area (particularly the surfaces used for storage of chips) and by using water collection systems. Further treatment of polluted water might be required, while non-polluted water may not require any treatment.

Some dusting of wood fragments from the chips and chip piles will occur as well as from the wood yard area itself. This is normally a very local issue and seldom of any consequence outside the mill site. Wood and chip piles emit volatile organic compounds (VOC) originating from the extractives. No control measures for VOC reduction are applied in practice.

Table 2.20: Environmental aspects and measures to reduce environmental impacts from wood handling

Environmental aspect	Measures/techniques
Effluents to water	Minimise effluents by dry debarking, recycle bark press filtrate to the kraft process, organise separation of solids in wood yard effluent before secondary treatment or flocculation. When sprinkling woodpiles with water, the flow should be controlled to minimise run-off; for sprinkled woodpiles water collection systems in the wood yard prevent discharge of organic substances (COD, toxicity).
Air emissions	Prevention of dust formation and wind drift from the wood yard area and from the chip piles.
Solid waste	Bark and wood residues are contaminated by sand and stones. Minimise their amount by clean handling. Recover bark and fines.
Energy use	Use bark and wood fragments as fuel or prepare their use for energy recovery. Strive for high dry content by pressing and drying to increase the calorific value.
Noise	Suitable layout and location of wood yard. Locate debarking drums, chippers and chip screens indoors if possible. Use of low-noise trucks and band conveyors.

Bark and any wood residues from the wood yard should be collected in as dry and uncontaminated a form as possible for use as a fuel, either in a bark or biofuel boiler at the mill or in a boiler with heat recovery outside the mill. Despite careful handling it is inevitable that some of the material gets contaminated with sand and stones. Such material can often be used for soil improvement.

The most important energy aspect in wood handling is to use the available residual biomass (bark, wood residue) as efficiently as possible to generate energy. Suitable types of boiler and the environmental measures are discussed in the section on steam and power generation (see Section 2.6).

Power use in the wood yard is commonly about 10 kWh/m^3 solid under bark of processed wood. This means about 25 kWh/tonne pulp for a mechanical pulp mill and below 60 kWh/tonne for a chemical pulp mill. To keep power use low, suitable dimensioning of the electric motors and motor controls should be applied. Band conveyors provide a low power use alternative for chip transportation within the wood yard.

There are several sources of quite high noise levels in the wood yard area such as the debarking drum and the chipper(s). Ways to reduce the noise (see also Section 2.9.13) are primarily to locate this equipment in buildings or to construct noise protection barriers. Trucks used in unloading and handling logs and chips are noisy in themselves. Noise in the form of impulse sounds is additionally created when logs are dropped onto piles or receiving tables. Purchase of low-noise trucks and training in 'soft' driving are measures that should be applied. Noise protection barriers may also be considered to shield receiving tables.

Achieved environmental benefits
Reduced emissions to water and air, noise reduction, energy savings.

Environmental performance and operational data
No information provided.

Cross-media effects
The technique has mainly positive effects, preventing pollution of all media.

Technical considerations relevant to applicability
Measures/techniques can be applied to all mills.

Economics
No information provided.

Driving force for implementation
No information provided.

Example plants
No information provided.

Reference literature
No information provided.

2.9.2.2 Dry debarking

Description
In wood handling the discharges of organic compounds and suspended solids and water consumption can be reduced with dry debarking. In wet debarking 3 to 10 m^3 of water per tonne of pulp are discharged. Organic compounds like resin acids, fatty acids, etc. and highly coloured materials leach out of the bark and into this waste water stream.

In dry debarking, process water is used only for log washing and de-icing (in cold climates water or steam is used for the thawing of wood) and is recirculated effectively with minimum generation of waste water and water pollutants. Dry debarking results in bark with a lower water content, which results in a better energy balance for the mill. Less water is needed in the debarking and the dissolved amount of organic substances is reduced. Spray water is used on the inlet of the debarking drum in order to reduce the dust emissions. Raw effluents from a debarking plant are toxic to aquatic life. Biological treatment has proven to be very efficient in eliminating toxicity. The COD and BOD load is significantly reduced compared to wet debarking (see Table 2.21).

Achieved environmental benefits
Reduction of water consumption and of emissions of organic substances.

Environmental performance and operational data
Dry debarking gives a very satisfactory debarking result for most types of wood and for all types of products. Debarking of certain eucalyptus species may be impossible if the logs have been stored after felling (dry or wet debarking present the same problems though).

With dry debarking, the wood handling waste water volume is usually in the range of 0.5 – 2.5 m^3/ADt. A decrease in waste water amount is obtained by increased internal water circulation. By changing from wet debarking to dry debarking, the waste water amount often decreases by 5 – 10 m^3/ADt. With dry debarking, the total COD load can be reduced by up to 10 %. Typical discharges of dry debarking are shown in Table 2.21. Note that the numbers refer to chemical pulping. The numbers per tonne of product will be approximately halved in cases of mechanical pulping due to the higher yield of mechanical softwood (spruce) pulps (> 90 – 95 %) than bleached Nordic soft- (44 – 46 %) and hardwood (47 – 49 %). Eucalyptus (*Eucalyptus globulus*) has yields of around 51 – 54 %.

Table 2.21: Pollution load of wet and dry debarking effluent before biological treatment

Debarking technique	Effluent flow (m^3/t of pulp)	BOD_5 (kg/t of pulp)	COD (kg/t of pulp)	Tot-P (g/t of pulp)
Wet debarking and bark press	3 – 10	5 – 15	20 – 30	25 – 35
Dry debarking and bark press	0.5 – 2.5	0.5 – 2.5	1 – 10	10 – 20
NB: BOD_7 has been converted into BOD_5 by use of the formula $BOD_7/1.16 = BOD_5$ proposed within the same report; kg pollutant/m^3 wood has been converted into kg pollutant/t of pulp by assuming a typical pulpwood consumption of 5 m^3 wood/t of pulp. 5m^3 wood/ADt is based on chemical pulping; mechanical/semimechanical pulping has significantly lower specific consumption of wood. *Source:* [1, Finnish BAT Report 1997] and ÅF Engineering file data (2009).				

Cross-media effects
Energy consumption in debarking may increase due to the operation of the debarking drum in dry debarking mode. This is entirely offset by the substantial amount of energy gained if the bark is used as an auxiliary fuel due to the lower water content in bark from dry debarking. Better energy efficiency in the bark boiler results in a reduction of emissions per MJ of produced energy.

Technical considerations relevant to applicability
Dry debarking can be applied in both new and existing mills and for most debarking purposes (softwoods, hardwoods) and for all pulping processes (mechanical pulping, chemical pulping etc.). Dry debarkers already dominate the industry, and wet systems are in the process of being phased out. New mills almost exclusively and an increasing number of existing mills use dry debarking. However, owing to quality reasons wet debarking may be necessary when producing high brightness TCF bleached sulphite pulps.

Economics
The cost of a dry drum debarker does not differ significantly from a wet system. Typical investment costs of a completely new dry debarking system from log feed to conveyors (including the chipper and associated conveyors) is about EUR 15 million for a capacity of about 1 300 ADt of kraft pulp per day (ÅF Engineering file data (2009)).

The conversion of an existing wet debarking system to a dry debarking system costs EUR 4 – 6 million. These costs include equipment and installation. Possible site-specific needs for new buildings, special noise abatement measures or similar are not included but they may further increase the costs. Operating costs are EUR 250 000 – 350 000 per year but in both cases it may involve considerable investment in equipment.

Driving force for implementation
Dry debarking decreases TSS, BOD and COD loads as well as helping to reduce the amount of organic compounds like resin acids, fatty acids leaching out of the bark and into the waste water streams. Some of these substances are regarded as toxic to aquatic life. The measure also increases energy yield.

Example plants
Most plants in Europe.

Reference literature
[1, Finnish BAT Report 1997], [75, Pöyry 1997], [130, SEPA report 1997].

2.9.2.3 Safe storage and handling of basic chemicals and chemical additives

Description and achieved environmental benefits

Many of the chemicals and chemical additives used in pulp and paper mills are characterised as hazardous to waters if released in concentrated form. Control of the chain of transportation, unloading and storage in the process is essential to minimise the risk to personnel and the environment. Some general guidelines are given below.

- Drivers in charge of chemical consignments should have proper (certified) training to correctly handle the loading and unloading of the cargo. They should also have training in all applicable emergency procedures.
- Before a truck or railcar is allowed onto the mill site, the responsible person at the mill should be notified and if necessary guide the transport to the proper unloading locality.
- Openings for loading tanks for chemicals on the mill site should be unique and/or clearly marked to prevent filling a tank with the 'wrong' chemical.
- Areas for the loading and unloading of chemicals should be equipped with impermeable surfaces to make it possible to recover or otherwise treat any chemicals spills.
- Chemicals should be stored, handled and used in such a way that any spills and leakages are prevented from escaping and polluting the ground, surface water or groundwater.
- Chemical containers should be located on impermeable surfaces and within bunds or equipped with similar safeguards (e.g. double-walled tanks) with sufficient volume to hold the contents of the largest container plus a reasonable share of the contents of the other containers within the same bund. Collection chambers may not have any discharge openings.
- Tanks for chemicals should be equipped with alarms for overfill.
- Leakages from all parts of the facility that come into contact with hazardous substances should be detected quickly and reliably (leak indicator).
- Tanks, containers, piping and pipe bridges for chemicals should be clearly marked and protected from damage by vehicles by suitable protective arrangements.
- Specially trained staff should be in charge of the handling of potentially hazardous substances; regular control and maintenance of tanks, pipes and the dosing systems should be carried out.
- Operating instructions including monitoring, maintenance and alarm plans should be drawn up and observed.

Environmental performance and operational data

The guidelines for safe storage and handling of basic chemicals and chemical additives described above are commonly in use at pulp and paper mills. If deficiencies are found in the environmental risk assessments and environmental management audits, the corrective measures are implemented as soon as possible.

Cross-media effects

The technique has positive effects, preventing pollution of all media.

Technical considerations relevant to applicability

Measures/techniques can be applied in new and existing mills.

Economics

No information provided. Cost figures are considered case-specific.

Driving force for implementation

Legal requirements.

Example plants and reference literature

Most pulp and paper mills in Europe have implemented measures to prevent the release of chemicals in concentrated form to soil and water.

2.9.2.4 Environmental assessment system for chemicals

Description

In order to prevent and reduce possible negative environmental impacts and to minimise the risk of accidental or normal hazardous discharges to the environment, all types of chemicals used in the pulp and paper processes should be regularly reviewed and, where possible, replaced by chemicals which are environmentally safer. They should be used correctly, i.e. in the lowest practical amounts.

A number of mills have a chemical environmental assessment unit in place responsible for evaluating the current use of chemicals and for replacing potentially hazardous chemicals with environmentally safer ones when available. Such a unit will normally comprise a competent group of representatives for the different departments in the mill including logistics and health and safety functions. The representatives will commonly have received training in how to use and interpret the available environmental information databases.

The unit will be responsible for keeping an updated record of the chemicals used in the mill and the quantities. Compiling information on chemical use in the mill for reporting to relevant national authorities and tasks within the framework of REACH is also often assigned to the group. Another main responsibility is to review on a continuous basis the chemicals currently in use in the mill and suggest replacements where more environmentally lenient alternatives can be identified.

Any new chemical which is to be used in the mill will be checked for environmental and other hazards by the competent group before it is cleared for use. Other tasks assigned to such a group could be to make sure that the requirements of the Seveso Directive, if applicable, are fulfilled. Further aspects are requirements in connection with the contact of food with the manufactured paper, if relevant. Testing and assessing the fate of chemical additives in the waste water treatment system (absorption, elimination, biodegradability in waste water treatment plants) can be another task of the expert group, or ensuring the absence of substances generally known as critical, e.g. 'substances of very high concern (SVHC)'.

A key element in the work of the chemical environmental assessment unit is the access to reliable and updated environmental information on chemicals. Information from REACH, other databases and chemical data sheets is thus important input. A practicable procedure to reach a successful assessment system might be to involve particular responsible specialists, e.g. chemists/specialists for storage and water protection, responsible staff for food contact aspects, the safety officer for occupational health and safety or experts for ecolabelling. Each of them has to deal with the issues associated with the use of certain chemicals. The whole procedure can create various benefits for the company and should be documented.

Achieved environmental benefits

Minimising the risk of undesired discharges to the environment of all types of chemicals used in pulp and paper processes. A regular review of the chemicals used and, where possible, replacement with chemicals which are environmentally safer, and their correct use (i.e. in the lowest possible amount), reduces the release of potentially harmful substances to the environment.

Environmental performance and operational data

A common tool for pulp and paper mills in Europe is the use of chemical databases that provide access to environmentally relevant information on chemicals and facilitate the work done by the assessment group. These databases are available online for customers and contain, e.g. in the case of a Swedish database, information on more than 17 000 chemical products and 8 000 chemical substances. This database includes an advanced model for risk evaluation and supports the reporting according to REACH and the CLP Regulation. It also contains information on the physical and chemical properties of chemicals as well as extensive information on the health and environmental effects of chemical products and their components. The chemical database is especially useful for replacing potentially hazardous chemicals.

Cross-media effects
No negative aspects.

Technical considerations relevant to applicability
This technique is applicable to both new and existing mills. The system can be applied by any paper mill using significant numbers or quantities of chemical products. This is relevant for some special paper mills; for the production of bulk grades like newsprint or corrugated paper, fewer chemical additives are used but in larger quantities which may justify the implementation of such a system. The scale and complexity of the chemical assessment expert group will depend on the size of the mill and the amount and type of chemical additives in use.

Economics
The effort required for a chemical assessment unit depends on the complexity of the mill and the number of chemicals that are used. On average about one employee per year and mill may be required. In addition, several persons are usually involved. A cash budget should be available for data sheets, subscriptions to databases, etc. These cash costs are in any case commonly required for compliance with the REACH Regulation. By choosing a suitable size unit, the effort should be worthwhile for most mills.

Driving force for implementation
Responsible use of hazardous substances. Legal regulations at European and national levels.

Example plants
Chemical databases are common tools in the pulp and paper industry. Many mills have been successfully applying an environmental assessment system for chemicals for several years.

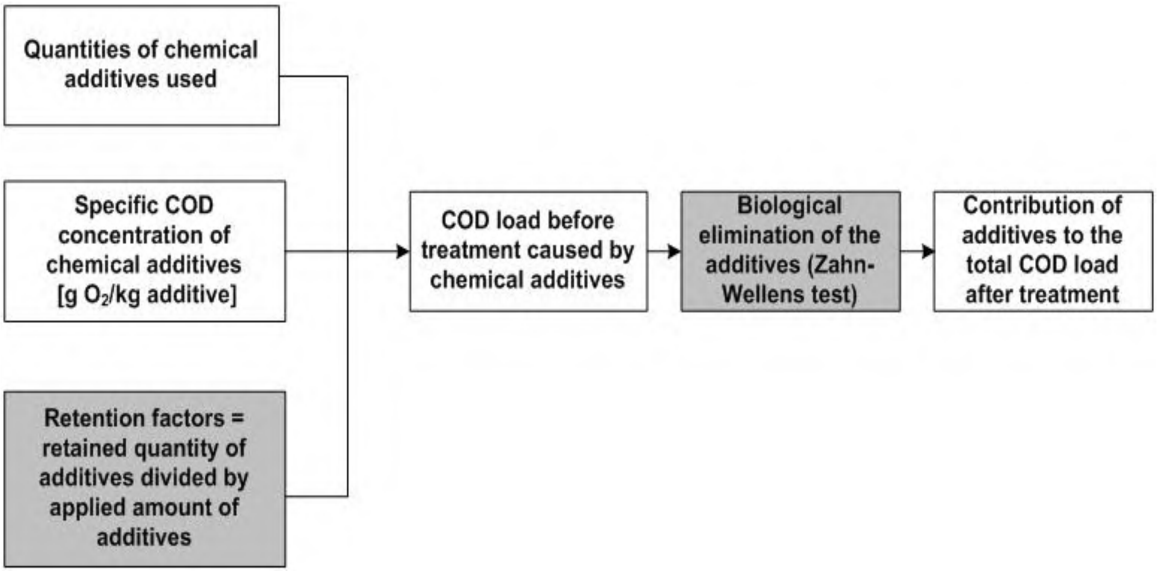
2.9.2.5 Substitution of potentially harmful substances with less harmful alternatives

Description
In the paper industry water is the medium where most of the released substances may end up because usually the additives are added to the aqueous fibre-filler suspension and are then either retained in the paper or come to the white water. Air emissions are of less importance and soil may be affected via waste disposal (composting, use of paper sludge in agriculture, landfilling).

The expected discharge of additives to water is directly related to the retention of the chemicals in the paper product, the degradability of the substances and the retention in the waste water treatment plant. The higher the retention, the lower the discharge to the effluent and the lower the potential environmental effect of the applied additives. In the case of product aids, a maximum degree of retention is desirable from an economic (loss of additives) and ecological point of view. Since product aids are designed to give paper a particular characteristic, for reasons of cost and efficiency they generally have a relatively high level of retention in the cellulose fibres. Process aids are usually not retained to the same extent because they produce their effect in the water circuits of the pulp and paper mills. A large proportion is discharged with waste water. Furthermore, it should be noted that broke is normally re-pulped so that some of the additives are returned to the water circuit. Knowledge of the retention of additives is therefore important. Knowing the degradability of a substance, on the other hand, is crucial to avoid the risk of accumulation of a given substance in the environment and organisms.

Some water authorities use both the retention factors and the biodegradability of substances to assess and minimise the contribution of additives to the COD load after treatment. In Germany, for example, the application of the method shown in Figure 2.17 resulted in a reduced application and/or substitution of some of the additives that caused a significant share of the

COD load after treatment (substitution principle). Furthermore, the mill had to report how and why various chemicals had been used.



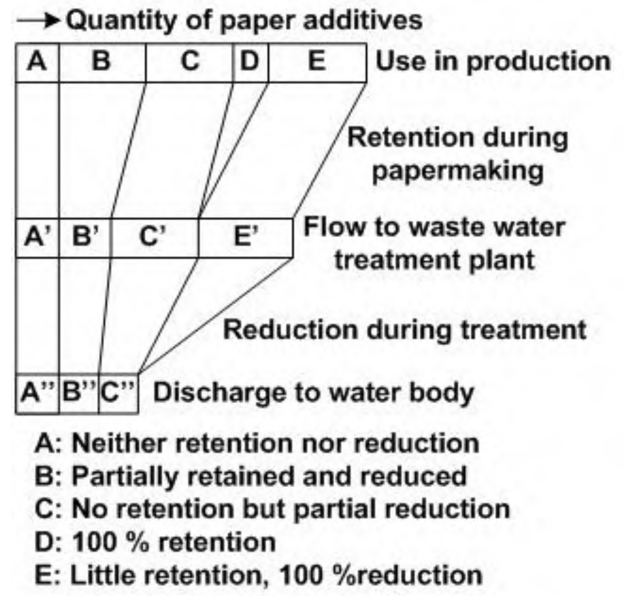
Source: [68, IFP 1997]

Figure 2.17: Pragmatic approach for assessment of the amount of not readily biodegradable additives to be expected in effluents from paper mills after treatment

Besides a general approach for the reduction of releases of chemical additives to water, some candidates might exist for substitution/replacement from an environmental point of view. In particular, this might be the case when chemicals are considered hazardous and there are less hazardous substitutes available that can achieve the same purpose. Biodegradable, non-toxic and non-bioaccumulating chemicals should be favoured whenever possible. Chemicals suspected of posing a risk to humans or the environment should be avoided, e.g. those with ozone-depleting effects, suspected endocrine disruptors, CMR (carcinogenic, mutagenic, reprotoxic) substances. Hydrocarbons such as benzene (carcinogenic), toluene (toxic), and xylene (toxic) originating from solvents and detergents that might be used for the cleaning of wires, felts and machines should be replaced by solvents that show less toxic effects. Alternatives (e.g. esters), which are also to some extent biodegradable, are available.

Achieved environmental benefits

A possible result of such an approach for the monitoring of additives might be similar to the one that is shown in Figure 2.18. Some substances, mainly process aids, are not retained or biologically degraded (substance A). In this case the applied additives end up completely in the receiving water body. Others are partially retained and partially eliminated in the waste water treatment plant (substance B), while others are nearly 100 % retained and do not even reach the treatment plant. It can be assumed that most of the product aid additives are both partially retained and to a certain extent eliminated in the waste water treatment plant. Process aids have a low retention in cellulose fibres and can therefore be expected to end up in the waste water.



Source: [68, IFP 1997]

Figure 2.18: Schematic presentation of the fate of chemical additives in paper manufacturing including external treatment

Environmental performance and operational data

For chemical additives and auxiliaries, a 'transparent' information system is still missing in which manufacturers, importers and users of chemicals could carry out 'self-assessments' of chemicals for the life cycle stage that they are responsible for. Relevant data would then be passed from one company to the next to avoid the duplication of work. Some governments provide guidance and audit assessments of companies on chemicals, others also want companies to do more to improve the 'eco-efficiency' of chemicals manufacture, using fewer resources and emitting less residues per unit of product. An overview of the development and current state of selected environmental risk assessment schemes of substances is given in [165, ZELLCHEMING 2008].

Some non-exhaustive examples for positive experience with replacements of substances of concern are given in the following:

(a) ***Use of bio-dispersants instead of biocides as anti-slime and anti-deposit agents***

Example: RCF NL 1. The mill replaced biocides completely with slime dispersants to control the deposits of slime [89, RFC NL 1 2010].

Special features: relatively high temperatures in the process waters (up to 55°C), relatively low volume water circuits and tanks avoiding long dwelling times for bacteria growth, maximum avoidance of dead edges in the water and sewer systems and specific (lower) quality demands for RCF-based corrugating base paper that allow running small pits.

Conclusion: The possibility of avoiding biocides is mill-/product-specific. For those mills that can run the process under circumstances comparable to those described above, this could be a preferred production method. Biocides used for microbiological deposit control in paper mills often show relatively fast decomposition, are used in very low active concentrations and thus are difficult to detect in the final effluents; however biological decomposition efficiency can be affected, especially when anaerobic effluent treatment is carried out.

(b) Use of catalytic disinfection to remove germs and biofilms

Examples: a) RCF DE 6, b) Papierfabrik Vreden GmbH, c) RCF DE 7, d) Hakle-Kimberly Deutschland GmbH [German comments D 1].

Description: Using a solid metal catalyst and a hydrogen peroxide solution as an 'activator', microorganisms are killed by oxidation. Due to the positive charge of the catalyst the negatively charged microorganisms are drawn towards the catalyst, which will take electrons away from the microorganisms and thus partially destroy them. The remaining fragments and their biotenside properties will lead to a detachment of biofilms present in the water system. The biofilms in turn are then attracted by the catalyst and destroyed.

Achieved environmental benefits:

- no formation of hydrogen sulphide or odour, organic acids or other toxic products,
- no microbiologically induced corrosion,
- no undesirable side effects for humans, the environment or materials,
- H_2O_2 is considerably less dangerous than other biocides.

Operational data:

Catalytic disinfection is permanently used in paper mills (examples a) to c), see Table 2.22) with a paper output between 10 and 100 kt/yr and closed water loops (water volume: 700 – 1 000 m^3, COD: 25 – 40 g/l, fresh water: 1 – 2 m^3/t product). The consumption of aqueous 30% H_2O_2 solution in the first six months is 140 litres per week. The removed biolayer has to be separated. After the first six months the consumption of the solution is only 20 – 30 litres per week. The solution has to be dosed near the catalyst surface. Other biocides or other biocide methods are not necessary. In one case it was possible to halve the consumption of flocculants.

Table 2.22: Example of mills using catalytic disinfection

Plant	RCF DE 6	Papierfabrik Vreden	RCF DE 7
Paper quality	cardboard	paper for corrugating medium	paper for corrugated board
Paper output in t/yr	12 500	75 000	60 000
Water volume in m^3	700	1 000	-
COD in mg/l	25 000	40 000	25 000
Fresh water consumption in m^3/h	3-4	12.5	-
Waste water	0	0	0
H_2O_2 solution (30%), first 6 months	140 l/week	140 l/week	140 l/week
H_2O_2 solution (30%) after first 6 months	28 l / week	21 l/week	-

Catalytic disinfection is intermittently used in paper mills (example d)) with a paper output of 30 to 40 kt/yr and open water loops (water volume: 500 m^3, COD: 2 g/l, fresh water: 12 m^3/t product and waste water: 10 m^3/t product). During the usage of catalytic disinfection the paper production is interrupted for several days, the water volume is reduced by 250 m^3 and the water loop is closed. Several times a day the hydrogen peroxide solution (100 – 1 000 kg per dosage) is dosed near the catalyst. After the treatment the catalyst is removed from the water system and the water is changed. It is possible to use other biocides or other biocide methods during this temporary catalytic treatment.

> Cross-media effects:
> The dosage of 1 litre of solution requires 1 Wh. Side effects on air are not observed and not expected. As a result of the elimination of biolayers the redox potential increases in the water. Biotensides are adsorbed in the removed biolayer.
>
> Technical considerations relevant to applicability:
> Catalytic disinfection is applicable for treatment of fresh water, circulating water, cooling water and in paper slurry. It is possible to install this in new or existing plants.
>
> Economics:
> For a paper output of 10 kt/yr in a closed water loop, 5 000 – 10 000 EUR/yr are required (write-off and operating). In an open water loop the costs are higher depending on the waste water volume.
>
> By using the technique in an existing plant in the first year the consumption of the solution is considerably higher than in the following years. The costs for one temporary treatment are about 10 000 EUR.
>
> Driving force for implementation:
> Implementation of catalytic disinfection stops formation of toxic gases and odour, especially of hydrogen sulphide, and of microbiologically induced corrosion. Use of other biocides is not necessary. In some cases it was possible to reduce the consumption of flocculants.

Cross-media effects
Reduction of harmful additives in paper processing will result in less impact on water and waste compartments. It can also be beneficial from the perspective of life cycle management. By using environmentally sound product aids, harmful substances can be prevented from ending up in the product, which in turn might be used as a raw material in recovered fibre processing.

Economics
No data available.

Driving force for implementation
Some water authorities set requirements to minimise the contribution of additives to the COD load after treatment. Requirements for reduction of releases of biocides can also be found. Biodegradable, non-toxic and non-bioaccumulating chemicals should generally be favoured whenever possible. Chemicals suspected to pose a risk to humans or the environment should be avoided, especially those with ozone-depleting effects, suspected endocrine disruptors, and CMR substances. Directive 2008/105/EC of the European Parliament and the Council of 16 December 2008 on environmental quality standards in the field of water policy [263, Directive 2008/105/EC 2008] (Daughter Directive to Article 16 of the EU Water Framework Directive) includes in its Annex II 'List of priority substances in the field of water policy' and in Annex III 'Substances subject to review for possible identification as priority substances or priority hazardous substances'. For such substances the environmental objectives of Articles 1 and 4 of the EU Water Framework Directive [264, WFD 2000/60/EC 2000] apply.

Example plants
A limited number of plants in Europe, e.g. RCF NL 1, RCF DE 6, Papierfabrik Vreden GmbH, RCF DE 7 and Hakle-Kimberly Deutschland GmbH.

Reference literature
[11, Braunsperger et al. 1996], [68, IFP 1997], [89, RFC NL 1 2010], [165, ZELLCHEMING 2008], [263, Directive 2008/105/EC 2008], [264, WFD 2000/60/EC 2000].

2.9.3 Optimised water management

Description

Water reduction methods in paper and board machines are a complex issue and depend greatly on the desired degree of closure of the water circuits. A balance between the advantages and the drawbacks associated with the closing up of water systems should be established. The acceptable level of water system closure will depend on the paper grade produced, raw materials used, the water and pulp circuit management and the targets to be achieved [281, Project PaperBREF 2002].

When implementing the different measures mentioned briefly in the following text and, in more detail, in the pulp- and paper-specific Chapters 3 to 7, it is very important to assess the impact on the physico-chemical quality of the process water, the production process itself, the technical installations and the desired product quality.

To assess the potential environmental impacts of paper mills, it is necessary to have a complete overview of their processes. European paper research institutes and some specialised consultants provide simulation tools that can be adapted to each paper mill and can help identify the optimum arrangement of process circuits and to determine the equipment needed to reach specific objectives. They provide a detailed global view of the fresh water use and of the options for the best water circuit arrangement and possible equipment to be installed. A flow diagram of the in-mill stock and water systems can help give an overview of the pulp and water circuits. A decrease in fresh water consumption can modify the physico-chemical quality of process water so, therefore, analyses at important reference points in the water system are usually performed to measure the initial load situations and expected changes. All major instances of fresh water consumption are identified and measured.

This detailed process analysis, together with expert knowledge, enables:

I. Estimates to be made regarding the potential fresh water savings of a given mill. The detailed analysis of fresh water use allows potential 'losses' to be identified, i.e. the non-polluted raw water that goes to the effluent treatment plant or the environment without being reused.
II. Reorganisation of the system in order to improve water use in the papermaking process and to improve the quality of the process water used directly in the paper machine for sheet formation.

The modification needed to operate with minimum fresh water consumption concerns the reuse of non-polluted fresh water, the adequate internal treatment of process waters, the water circuit arrangements and management, the recycling of fresh and clarified water and the substitution of fresh water for clarified process water.

As a rule of thumb, the first methods to apply are those that have no effect on the organic and inorganic loading of the process water. These methods concern:

I. The cooling water network with the reuse of this non-polluted water (in terms of organic and inorganic load) as raw water for other process applications.
II. The decrease in the sealing water flow for liquid ring pumps (reduction of water losses by replacement and evaporation in the cooling tower). Vacuum systems using variable speed turbo blowers that do not need any sealing water and which are more energy-efficient than the conventional liquid ring pumps or fixed speed blowers are available [185, J.Zürcher 2009], [186, Lahtinen et al. 2009].
III. All other fresh water losses identified by a detailed and specific analysis of the fresh water used by the paper machine.

To minimise fresh water use and the possible drawbacks of reduced water consumption, a combination of further measures is required:

I. an adequate storage capacity and efficient broke system management is of prime importance with regard to the stability of the process water system;
II. efficient save-alls that produce clarified water with a low suspended solid content are essential for the use of process water instead of fresh water for applications such as paper machine showers;
III. reuse of process water in the systems counter-current to the fibre flow should also be applied.

For integrated pulp and paper mills and in particular paper for recycling-based mills (see Section 6.3.3), the strict separation of water loops together with counter-current flows is of major importance to restrict the organic load of the process water around the paper machine.

The measures adopted to reduce water consumption should be applied gradually. Figure 2.19 gives a schematic overview of the major steps, tools, techniques and the water consumption trend when this stepwise approach is implemented. The first item of each column of Figure 2.19 shows which substances are removed from the white water and mentions the most important step in reducing the waste water flow. Major measures are listed. Some of them are discussed in the process-related Chapters 3 to 7. It is clear that low water consumption is achieved by implementing several techniques. Reduced volumes and more concentrated flows result in benefits regarding subsequent treatment. Adapted and adequate techniques can be used at reduced costs and lower total emissions are achieved.

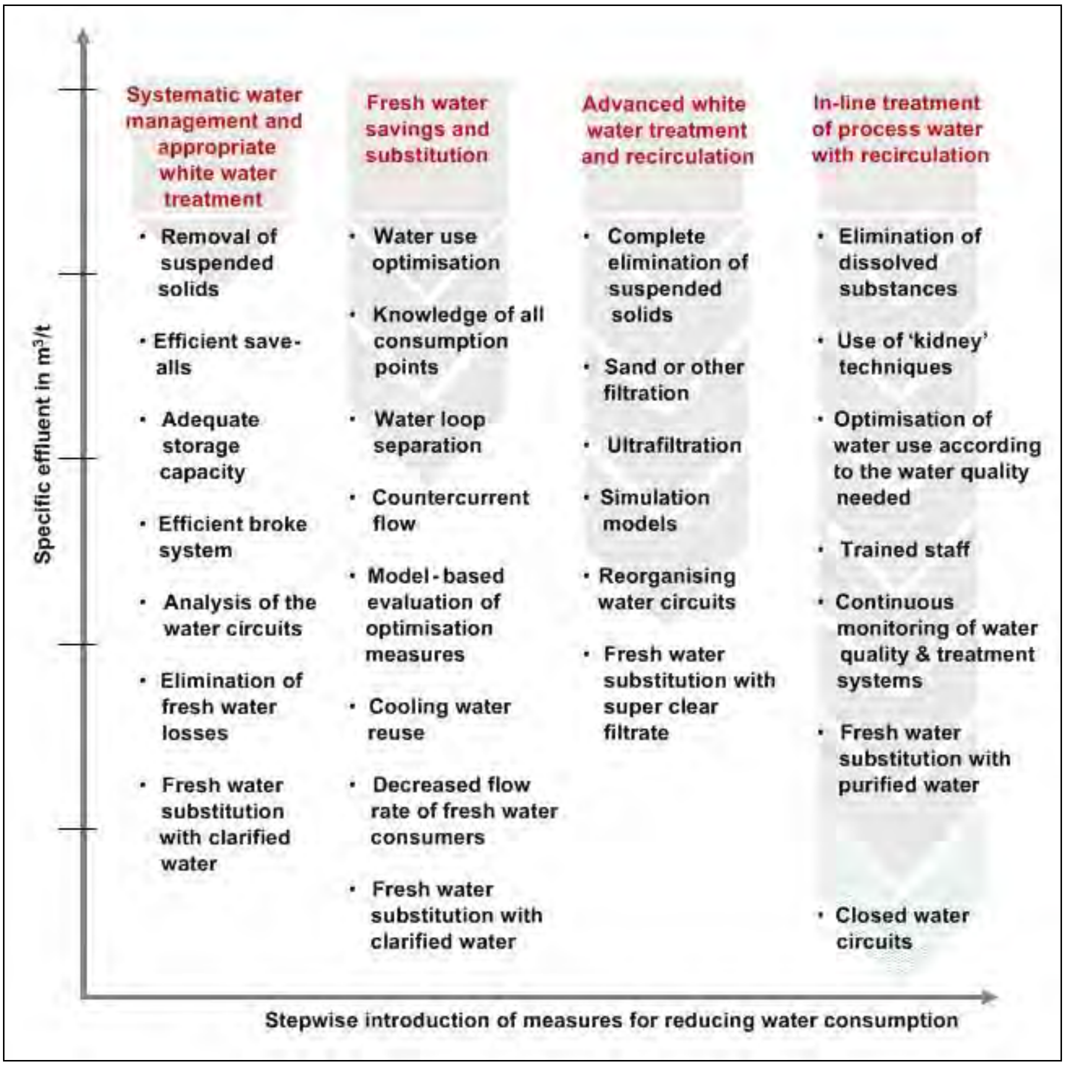


Figure 2.19: Steps towards lower water consumption and lower pollution load to the environment

The measures can be classified into four groups: systematic water management and appropriate white water treatment, fresh water savings and substitution, advanced white water treatment and recirculation, and in-line treatment of process water with recirculation.

The last steps for closing up the water circuits should only be applied if the preceding steps have already been implemented, e.g. 'knowledge of all consumption points' is an essential prerequisite for the subsequent actions (fresh water substitution). The model-based evaluation of optimisation measures is a powerful tool for effectively assessing and implementing fresh water reduction, water loop separation and counter-current flow. 'Decreased flow rate of fresh water consumers' refers to a number of common fresh water uses such as sealing water for vacuum pumps, shower water or water for the dilution of chemical additives. In-line treatment of process water with recirculation is still limited to some specific applications and depends on the local conditions and environmental objectives (see Section 7.3.3). However, all of them including the use of 'kidney' techniques and 'closed water circuits' are already in full-scale operation (see Section 6.3.4).

For specific water management issues on chemical pulping or integrated chemical pulp and paper mills, the reader is referred to Section 3.3.8 for kraft pulping and 4.3.8 for sulphite pulping; for mechanical pulping refer to Section 5.3.6 or 5.3.8, 6.3.2 – 6.3.5, and 7.3.1 – 7.3.3.

Achieved environmental benefits
Reduced water consumption and water discharge.

Environmental performance and operational data
Most European paper mills have implemented stepwise water-saving measures. Specific data for the different pulp and paper grades can be found in Chapters 3 to 7.

Cross-media effects
The enhanced recycling of process water in paper and board machines causes an increase in the concentration of colloidal and dissolved organic and inorganic constituents in these streams. Depending on the characteristics of the pulp in-feed and the chemicals used in papermaking, the process water management and the operation of the mill, the closed-up water systems can have an adverse effect on the operation of the machine, the quality of the end product and the production costs due to the increased use of chemicals. The build-up of organic and inorganic materials can be balanced to a certain degree by the use of specific chemicals to replace or complement the actual chemicals and a number of other measures specified in this document.

Technical considerations relevant to applicability
The technique is mainly discussed in reference to potential improvements in the paper manufacturing process and the paper machine. For fibre manufacturing and integrated mills, the reader should also refer to Chapters 3 to 6. Applicable to existing and new mills. Between 2001 and 2003 examinations were performed in 30 paper mills in the region of Tuscany, Italy [274, CTP 2002]. The grades produced in these mills are packaging paper and tissue made of virgin fibre or recovered fibre. The study confirmed the applicability and availability of the measures. Due to the complexity of paper production systems, in many cases expert know-how was needed for the analysis of the potential for improvement and for the selection of the most efficient BAT technologies and their correct application.

Economics
In the context of the EU-funded project 'PaperBREF' (see www.paperbref.info) the implementation costs of a more systematic water management plan in 30 paper mills in Italy were investigated. The results of the study carried out in the paper mills showed that with a very low investment a potential saving rate of 12.3 % of the water used could be reached; savings of 22 % are possible with an improved water usage and some important investments. With significant investments for the rebuild of numerous parts of the mill, it is possible to reach a savings rate of 40 %.

Driving force for implementation
The availability of technical options to save water is important for the paper industry since the cost of water and effluent treatment will probably increase in the future.

Example plants
To differing extents, all environmentally efficient pulp and paper mills have applied a systematic approach towards water management and aim at optimising their fibre/water/chemical additive system. The methods chosen by the operators and the degree to which measures are implemented are however different in each case.

Reference literature
[185, J.Zürcher 2009], [186, Lahtinen et al. 2009], [274, CTP 2002], [281, Project PaperBREF 2002].

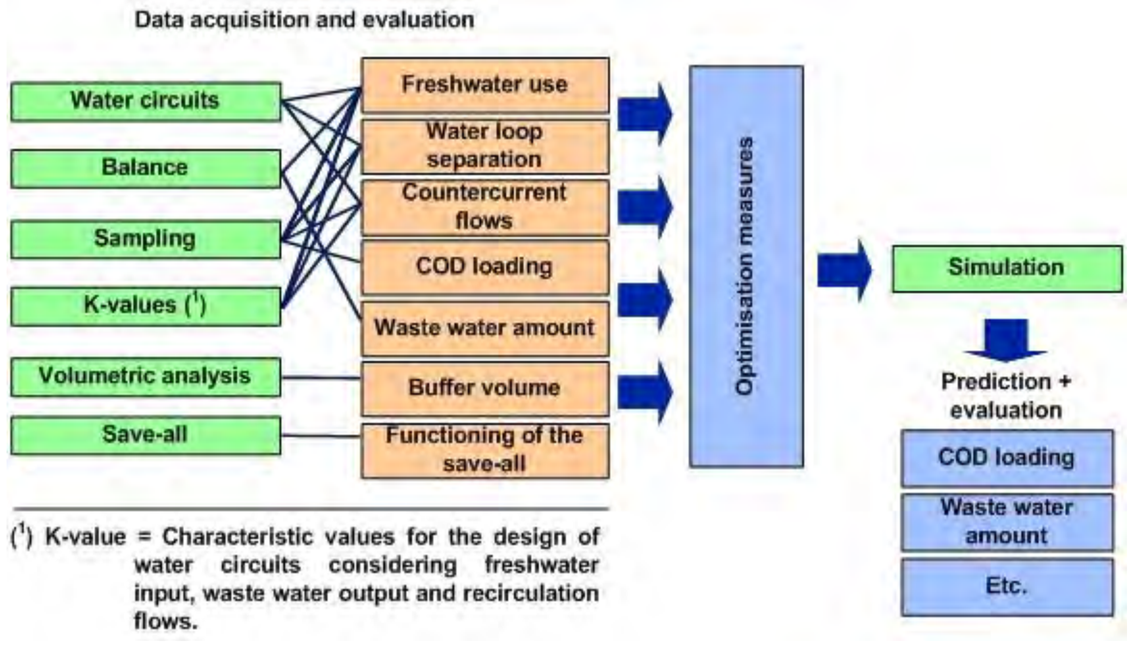
2.9.4 Model-based evaluation of optimisation measures for water circuits

Description
The papermaking process is characterised by a high degree of interaction between the various production processes, the raw materials used, the water and energy system, the product quality and the functionality of all technical units involved. An aid in mastering this complexity is the utilisation of mathematical modelling and simulation. Mathematical models and simulation are used in studies on phenomena like flow, mixing, reactions, heat and mass transfer to gain a thorough understanding of what is really going on inside production processes and how they can be improved. In process design, models and simulation are utilised to optimise the process operation and to help to find the best ways to utilise raw materials (fibre, water, chemical additives) and energy. Simulation is also an interesting tool for process operation. For example, it is employed in disturbance and alarm analysis, in start-up and shutdown planning, in real time control and optimisation and in operator training.

A survey on available software packages for process simulation in the pulp and paper industry [184, Alonso et al. 2006] confirmed that more than half a dozen well-suited software packages for practical use and application are available to the pulp and paper industry.

The first step of a model-based evaluation of process optimisation is to define the objective(s) to be reached by means of process optimisation. A systematic approach helps to develop, simulate and evaluate appropriate optimisation measures. The basis for evaluating optimising measures is to analyse the current state of the process. As shown in Figure 2.20, the analysis can be divided into several steps:

- data acquisition (e.g. circuit design, volume flows, volumes, reject volumes, sampling and analysis)
- data evaluation (with the help of water and heat balances, volumetric analysis, Sankey diagrams)
- assessment (e.g. key values, structure of the water circuits).



Source: J.Kappen, 2010

Figure 2.20: **Approach of data analysis and simulation**

Based on the data acquisition, a simulation model can be set up and calibrated to the real process. The level of detail of the simulation model depends on the objectives of the optimisation, for example:

- dimensioning of systems, finding rebuilds that can save water and energy;
- optimisation of level control in storage tanks;
- control optimisation of limited but complex processes.

The calibrated model serves as a basis scenario and represents the current situation. The prediction of the impact of individual optimisation measures is achieved by different simulation scenarios.

The concluding step of the simulation study is the evaluation. Evaluation of the different scenarios reveals the most suitable combination for maintaining or improving product quality (e.g. low system loadings in the paper machine circuits) under optimal economic conditions. The simulation results lead to a final action plan that describes the individual steps to achieve the desired objective.

Achieved environmental benefits

The main benefit of modelling and simulation techniques in pulp and paper manufacturing processes is a better understanding of the mechanisms of the processes and their control loops. This helps to find optimised solutions in a number of areas such as reducing emissions by improving process design, process monitoring and decision support during operation, improving paper quality, optimising wet-end chemistry and enhancing the runnability of the paper machine.

Environmental performance and operational data

As water systems in pulp and paper mills become more and more complex, the modelling and simulation of these systems are useful tools to optimise its design and operation. Simulation can make it possible to predict the consequences of process optimisation alternatives. This might minimise the risks associated with implementing an optimisation concept. It also provides the possibility to efficiently master dynamic aspects using simulation software. The integration of other elements such as energy and waste generation in such models allows a further step in the integrated analysis of water systems for a comparative analysis.

Typical applications for model-based evaluations of optimisation measures are:

- Reduction of fresh water consumption and effluent volume
- Recirculation of biologically treated water [180, A.Well 2006]
- Optimisation of water circuits
- Optimisation of dynamic water buffer volume
- Water management with fuzzy controller
- Reduction of effluent temperature [179, O.Blum 2006]
- Heat balance optimisation.

Example 2.9.4.1: Heat balance optimisation at MD Albbruck, DE
[182, J.Kappen et al. 2004]

The objective of the model-based evaluation of the process was to prepare a concept for optimising the heat balance. Improving the bleaching behaviour whilst reducing the bleaching cost was defined as a principal optimisation target. For this purpose, the mill water system had to be modified to install a counter-current circuit set-up. Another objective was the increase in system temperature of the paper machines to enhance the dewatering capacity of the wire and press sections. The combined effect of higher dry contents after the press and temperature increase ahead of the drying section leads to a reduced specific steam consumption.

With the help of the simulation results, a nearly complete separation of the water circuits of the groundwood mill, the oxidative bleaching plant and the paper machine was implemented in the mill, thus achieving a number of simultaneous benefits (no change in the temperature of the oxidative bleaching (70 °C), increased temperature in the reductive bleaching from 40 – 48 °C to 66 – 74 °C, increase in temperature in the paper machines by 10 °C on average, COD reduction in the paper machines (27 – 51 %) and no significant increase in the temperature and COD load of the effluent).

Example 2.9.4.2: Optimisation of fresh water use and water circuits

In the framework of a research project [181, Kappen et al. 2003] the potential for reducing the specific effluent volume by optimising the water circuits of various paper mills producing wood-free papers was investigated. Simulation models were used to quantify the impact of improvement measures and to identify optimisation potential. Various real mills were investigated. The simulation showed the effects of a reduction in fresh water use and predicted the effects of changes to the water systems and process design on the COD loading in the water cycles. For one example mill, three scenarios were calculated to improve water use by avoiding fresh water losses and by optimisation of the water circuit design. The avoidance of fresh water losses and optimisation of counter-current management resulted in a significant reduction of COD in the paper machine loop.

Cross-media effects
No negative effects reported. Modelling and simulation aim at finding solutions that simultaneously benefit different fields, e.g. optimising the heat balance and the system temperature in paper machines, improvement of processes and costs, modifying the mill's water system (e.g. installation of a counter-current water flow).

Technical considerations relevant to applicability
The objective-oriented simulation has proved to be an appropriate simulation tool for the paper industry, and simulation software is well-established. It is possible to forecast with relative accuracy the system load by simulating water cycles and to predict the temperature, COD, suspended solids and salt loads (except for calcium) both in water circuits and in the effluent.

The simulation models are readily available. However, objective-oriented simulation is based on empirical knowledge and every model has to be fed with real mill data. Therefore, a considerable effort is necessary to determine the material and heat balances. Data pre-processing is one of the most critical steps in any modelling and simulation project.

Economics
A model-based study for a medium-sized paper mill on optimisation measures related to the design and operation of the water circuits may cost around EUR 30 000 (rough estimate by an expert). However, for decision makers in the paper mills, the total cost of the system including training and working hours (when building or running the simulation) is said to be the most important aspect related to the implementation of simulation software.

Driving force for implementation
Optimising the manufacturing processes while maintaining or reducing energy consumption, water use and emission load.

Example plants
The validity of the software used and the degree to which software can be applied has been discussed extensively within the 'COST Action E36' by [183, J.Kappen et al. 2005]. Modelling and simulation is used in a number of European pulp and paper mills (e.g. Norske Skog Bruck, AU; MD Albbruck, DE) and is considered a proven technology.

Reference literature
[179, O.Blum 2006], [180, A.Well 2006], [181, Kappen et al. 2003], [182, J.Kappen et al. 2004], [183, J.Kappen et al. 2005], [184, Alonso et al. 2006].

2.9.5 Energy efficiency analysis, energy management and energy audits

Description
A systematic three-stage approach or similar for energy efficiency analysis is a useful tool for implementing the continuous improvement of energy consumption in paper mills [249, Blum et al. 2007]. Systematic energy efficiency analysis serves to aid paper mills to move towards or reach BAT levels for energy consumption. The three steps that are discussed further below are: a) the evaluation of the actual energy situation and the relevance of corrective actions (Step 1); b) the use of a method for locating, quantifying and optimising potential (Step 2); and c) the identification of a way of monitoring and safeguarding the optimised situation (Step 3). Typically, energy efficiency is measured by specific energy consumption (SEC), meaning secondary energy consumption per unit produced.

- **Step 1: Assessment of the initial energy situation of the mill and benchmarking**
  As a first step, the specific process energy consumption (for electric and heat-related power of shippable production) of the site has to be determined. A comparison of these figures with consumption levels from other mills within the same grade of paper produced (benchmarking) gives an indication of the potential for energy savings. The comparison can be done with the values in Table 2.9, the proposed BAT levels for energy-efficient mills of this document, or other appropriate reference documents (e.g. [193, Axegård et al. 2003] for kraft pulp mills). This initial benchmarking is also useful to classify the priority of an energy optimisation project within other activities at the mill.

  As a second stage, a breakdown of the specific energy consumption of the mill for the production lines helps to focus on the lines with the highest energy consumption and hence the greatest need for optimisation. In many mills, especially in older sites, the internal consumption measurement and monitoring system installed is insufficient to split the consumption for every line. If this is the case, a special energy analysis project may be needed.

- **Step 2: Detailed system analysis and improvement by optimisation**
  Because of the complexity of energy use in pulp and paper mills, which may include hundreds of energy-consuming units, a detailed and specified on-site energy analysis is essential in order to identify potential savings and to develop optimisation measures. This analysis assesses and evaluates the current energy use in the mill and investigates whether the currently installed machinery is working efficiently. The energy analysis can be performed both with internal staff and/or by external consultants. An example of a systematic evaluation and improvement of the energy use in paper mills [196, Blum 2006] is shown in Figure 2.21 (many other similar approaches are available).

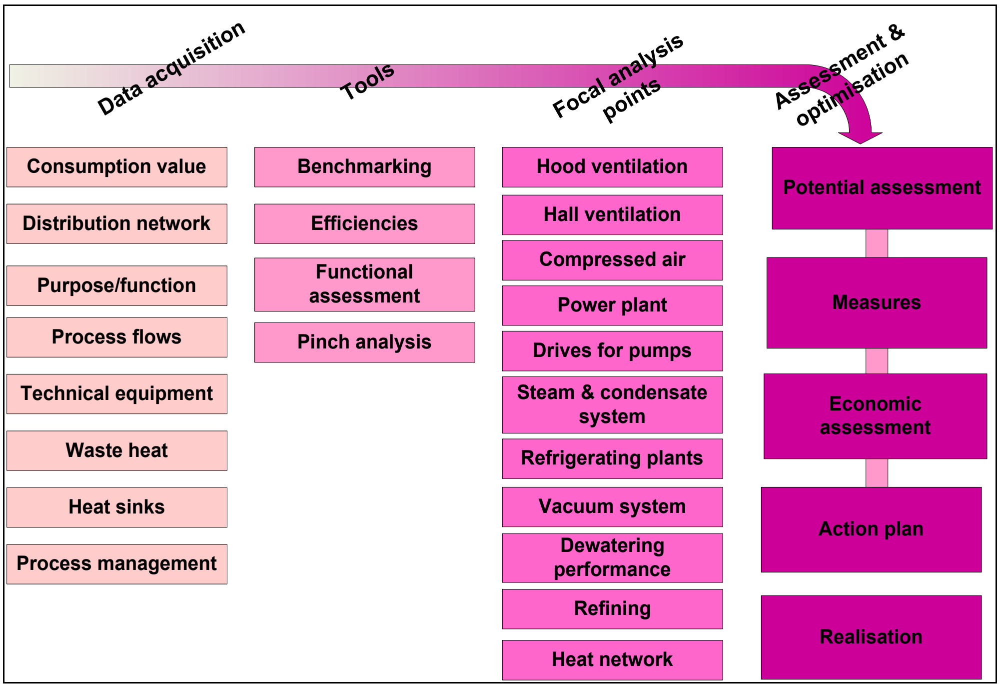


Figure 2.21: Systematic evaluation of and improvement of the energy use in paper mills

An energy efficiency analysis like the one proposed in Figure 2.21 normally contains the following steps:

- specific data acquisition in the areas of concern
- evaluation and assessment of the data using appropriate tools
- extensive investigation of focal points for the analysis where the highest energy savings potential is to be expected
- identification of potential and possibilities for optimisation (simulation-aided optimisation when needed)
- economic assessment that includes the calculation of achievable savings and investment required
- drawing up of an action plan and implementation of the identified and prioritised measures.

Depending on the individual case, it may not be appropriate to investigate all focal points shown in Figure 2.21. Because of the modular set-up of this procedure, a selection of the primary points of interest can be made.

- **Step 3: Monitoring and sustainable safeguarding of achieved savings**
  The outlined energy management scheme normally results in a continuous improvement of the energy use in the paper mill. To achieve satisfactory and sustainable results, gaps or weaknesses identified in the chain of analysis and action should be gradually closed or

dealt with. The following figure gives an example of an energy management method for continuous optimisation that is quite similar to the one discussed in Section 2.9.1.

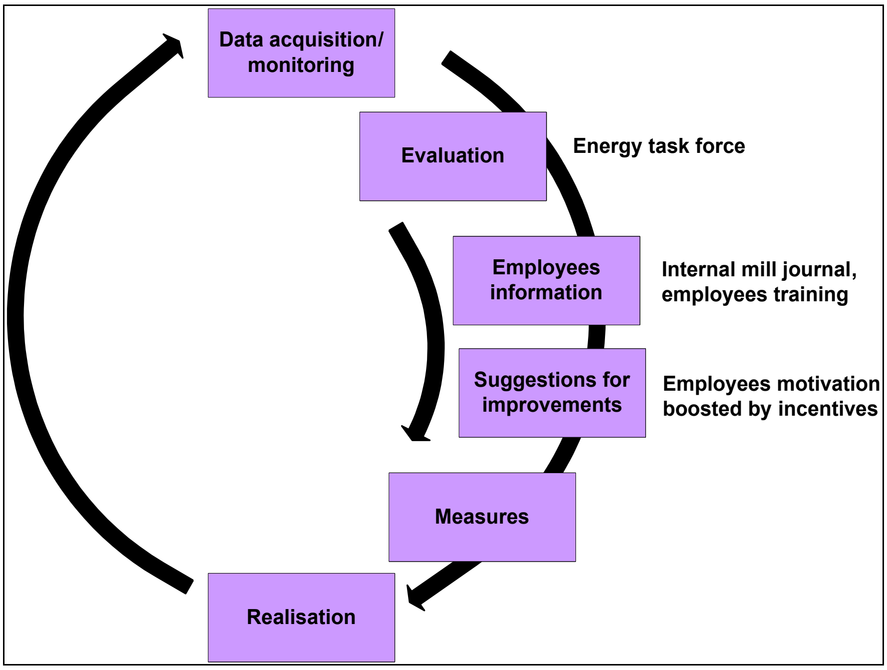


Figure 2.22: **Management method for continuous monitoring and optimisation of energy use**

A tool that is similar to 'energy efficiency analysis' and equally effective is an 'energy audit' [191, FFIF 2007], which is also a systematic procedure that leads to adequate knowledge of the existing energy consumption profile of the site and identifies the factors that have an effect on energy consumption. It also identifies and scales cost-effective energy-saving opportunities.

Achieved environmental benefits
By introducing new modes of operation or tools such as energy efficiency analysis, energy management systems or energy audits, significant energy efficiency improvement is possible.

Environmental performance and operational data
Energy efficiency analysis, energy management systems and energy audits have been a proven tool for the improvement of energy efficiency within the pulp and paper industry for many years. Many larger pulp and paper mills (e.g. SCA, Stora Enso, Holmen, etc.) apply a certain kind of energy management system but not necessarily to all of their mills. In Europe, there are still many paper mills that have not implemented an energy management system or energy audit; this applies especially to smaller mills. These mills may have greater potential for improvement with regard to energy efficiency.

In 2009, a new European standard on Energy Management Systems, EN 16001:2009 'Energy Management Systems- Requirements with guidance for use', was issued [195, CEN 2009] that may also support the application of a systematic evaluation and improvement of the energy use in paper mills. The new European standard provides organisations and companies with a single recognised framework and a tool to support them in establishing the systems and processes necessary to improve energy efficiency and to ensure that energy management becomes integrated into organisational business structures. The standard is also applicable for pulp and paper mills.

Cross-media effects
There are no negative cross-media effects.

Usually measures for energy saving are linked with investments to replace, rebuild or upgrade process equipment. However, these measures are mostly not just applied for energy saving. They attract special interest because they simultaneously increase production efficiency, improve product quality and reduce overall costs. It is therefore essential that energy-saving techniques be incorporated into all aspects and levels of papermaking. The connection between energy matters and processes (synergistic effects) should be borne in mind when discussing energy use and energy-efficient techniques.

Technical considerations relevant to applicability
This technique is applicable to both new and existing mills. Normally, for smaller mills it will be more difficult to implement because of their limited number of specially trained employees (e.g. no internal staff for energy analysis).

Economics
No information provided.

Driving force for implementation
Increasing energy costs and the reduction of greenhouse gas emissions are forcing the European pulp and paper industry to optimise their energy use.

The reliability of processes and high production efficiency are, together with cost-effectiveness, the primary objectives for industrial production. The purpose of improving energy efficiency is to support these goals. Often, an improvement in energy efficiency is followed by an enhancement of production efficiency. For example, the reduction of web breaks and the resulting shorter downtime improves energy efficiency too. In addition, energy conservation lowers energy costs and so improves cost-effectiveness.

Example plants
In Finland, all pulp and paper mills have committed themselves to the voluntary Agreement on Energy Conservation in Industry. The companies adhering to the agreement have undertaken to determine their possibilities for conserving energy by implementing an energy analysis at their production sites. Energy management systems are a part of environmental management systems. Similar agreements have been developed in Sweden and the Netherlands.

Reference literature
[191, FFIF 2007], [193, Axegård et al. 2003], [195, CEN 2009], [196, Blum 2006], [249, Blum et al. 2007].

2.9.6 Reduction of energy consumption applicable to all/most grades

For the purpose of this document, the measures for energy savings are divided into general techniques that can be applied to most types of pulp and paper mills and which are described in this section; and measures that are applicable to the manufacturing of specific types of pulp or paper and associated processes. They are discussed in the process-related Chapters 3 to 7. In order to assess the relevance of the various process units for total energy consumption, the reader is referred to Section 2.5 and Section 2.5.3 which point out the largest energy consumers of paper mills. However, there are a large number of other smaller consumers, some of which are discussed here, that together are also significant for the energy balance of the mill. The list of techniques is not exhaustive but only a selection of horizontally available techniques.

In this context, useful information can also be found in the Reference Document on Best Available Techniques for Energy Efficiency (ENE) [268, COM 2009].

2.9.6.1 Reduction of thermal energy use

2.9.6.1.1 Heat recovery from radial blowers used in vacuum systems

Description and achieved environmental benefits

Due to the compression process in the vacuum blower(s), the exhaust air from the blowers reaches temperatures of 130 – 160 °C. This hot air can be passed through air-to-air heat exchangers, enabling the recuperation of up to 75 % of the power absorbed by the vacuum blowers. Radial blowers are used for wire and felt dewatering across all grades and are normally installed in larger paper machines. By reusing the recovered heat, the steam demand in the drying section of the paper machine can be reduced. The waste heat from the exhaust air can be used to heat the supply air of the drying hood, resulting in savings of direct steam.

Environmental performance and operational data

Different types of heat exchangers are available and have to be designed for each application. In some cases, the humidity remaining in the blowers' exhaust air has a corrosive potential. Preventive maintenance contributes to avoiding unnecessary and expensive shutdowns due to blocking or corrosion damage.

Cross-media effects

No negative environmental impact associated.

Technical considerations relevant to applicability

Can be applied both in new and existing plants for all grades where axial blowers are installed for vacuum production. The pressure on the outlet of the vacuum blower needs to be high enough to overcome the pressure drop in the heat exchanger. Normally the distance between the heat source (the dewatering section of the paper machine where the blower is installed) and the heat sink (the drying section of the paper machine) is short. In older mills, there may be problems with the space available for the installation.

Economics

These kinds of installations usually have short payback times. The economic efficiency is case-specific. In an example plant, achieved steam savings are 26 kWh/t and the payback time was 1.5 years [249, Blum et al. 2007].

Driving force for implementation

Cost reduction due to steam savings or to increase in production rate because of higher drying capacity.

Example plants

There are numerous plants in Europe (at least two in Germany). For new mills, this measure becomes standard.

Reference literature

[249, Blum et al. 2007]

2.9.6.1.2 Use of thermo-compressors

Description and achieved environmental benefits

This technique leads to steam savings in the drying hood by reducing the condenser losses. The use of thermo-compressors increases the energy efficiency of the drying process because less steam has to be sent to the condenser. Thermo-compressors are used to increase the pressure of the exhaust vapours from separators. The exhaust vapours from the last separators in a cascaded steam and condensate system have a very low pressure level which is not directly useable for the drying process. With a steam jet thermo-compressor, this exhaust vapour is boosted with high-pressure steam to a pressure level which enables a recovery of the exhaust vapour to use it again for the drying process. Figure 2.23 gives a schematic view of the use of thermo-compressors.

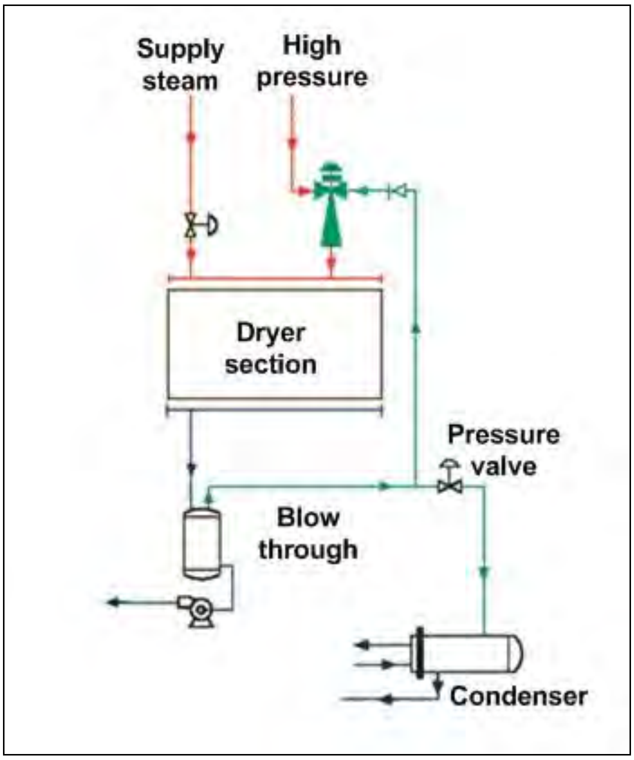


Figure 2.23: **Schematic of a thermo-compressor**

Environmental performance and operational data
Several suppliers offer thermo-compressors with varying performances that need to be adapted and designed for each application. For most applications, for the use of thermo-compressors, a steam pressure of 5 to 12 bar has to be available.

Cross-media effects
In many paper mills the cooling water from the condenser is used as warm water for showers. When optimising the steam and condensate system and hence reducing the condenser losses, the amount of cooling water will be reduced too and a shortage of warm water may occur. In this case it is possible to assess whether the amount of shower water can be reduced or another appropriate waste heat source can be found.

Technical considerations relevant to applicability
Can be applied to both new and existing plants for all grades of paper and for coating machines, as long as medium-pressure steam is available.

Economics
Economic efficiency is to be assessed for each situation. The payback times can be very short for some applications. In an example plant, achieved steam savings are 25 kWh/t and the payback time was 0.8 years [249, Blum et al. 2007].

Driving force for implementation
Energy savings for steam.

Example plants
The installation is common in all new paper mills and also in most of the latest rebuilds. There are numerous plants in Europe.

Reference literature
[249, Blum et al. 2007]

2.9.6.1.3 Insulation of steam and condensate pipe fittings

Description and achieved environmental benefits
Pipe insulation reduces the thermal radiation losses from pipes. Insulation is recommended both for pipes and fittings. Media concerned are hot water, condensate and steam, and in pulp mills the transport of hot liquors.

Environmental performance and operational data
Insulation of steam and condensate pipes is considered standard in Europe. The insulation of the fittings is not as common.

Cross-media effects
The measure has no negative effects. Improves work safety.

Technical considerations relevant to applicability
Can be applied to all mills.

Economics
Prices for pipe insulation works depend on the condition of the network. An example from a paper mill in southern Europe shows that the insulation of steam and condensate pipe fittings (calculated for 25 fittings on each medium) had a payback time of 1.1 years [249, Blum et al. 2007].

Driving force for implementation
Cost reduction because of energy savings for steam generation. Increased work safety.

Example plants
Numerous (mostly new) plants in Europe. The insulation of fittings is considered standard for new installations and later rebuilds.

Reference literature
[249, Blum et al. 2007].

2.9.6.1.4 Drying of biofuel and sludge utilising excess heat

Description
Many pulp and paper mills have both large amounts of biofuel and large sources of low grade heat (excess heat) available. However, this energy is mainly lost with exhaust air and effluents to water. The low grade heat can be utilised to dry biofuel and sludge. The drying of biofuel and sludge can generate added revenue (or reduced purchase costs for energy) and thereby also create incentives for further energy-saving modifications to the main process.

Due to the moisture content, in some mills additional fuels (such as oil) are added to combust bark in bark boilers. This is the case when the mechanical dewatering runs with lower performance levels. The drying of bark and sludge results in an added energy value, which makes it possible to combust the dried organic material without additional fuel.

An investigation of the available excess heat sources at the production site can determine the energy content in these heat sources and compare it to the energy needed for the drying process. A study analysing Swedish conditions [252, Johansson et al. 2004] made the conclusions listed below.

- There are large sources of excess heat available that could be used for drying purposes at pulp and paper mills.
- At pulp and paper mills, investment in a biofuel dryer utilising excess heat should be profitable but will have to be economically evaluated case by case. In chemical pulp mills, the most profitable option is to use flue-gases from the recovery boiler as drying gas (assuming that no flue-gas condenser is installed). Other types of pulp and paper mills would have to use other available excess heat sources.
- Bed drying seems to be the most suitable technology both from a technical and a commercial point of view.

The drying of biofuel and sludge is normally only economically viable if excess heat from other processes can be used for this purpose. Normally, excess heat such as hot air or hot process water flows can be used. Other more expensive options are steam heat exchangers or a gas-fired drying system. The minimum required temperature range is from 4 °C to 60 °C.

To run a dryer, hot air is produced with an air-to-air or water-to-air heat exchanger and is blown with fans into the dryer unit.

Achieved environmental benefits

Reducing the water content of bark, fibrous rejects, biosludge and other organic residues lowers the tonnage of waste to be transported for further treatment or disposal, which results in cost savings. Drying increases the calorific value of the biofuels and sludge and raises the thermal efficiency during combustion. The primary energy demand in the form of electricity and optional additional heating at load peaks is low when excess heat can be used for the drying process. The primary energy input to the drying process is essentially lower than the increased energy value of the fuel. Better energy and CO_2 balance.

Environmental performance and operational data

There is still little experience with the drying of biofuels and sludge in the pulp and paper industry. Preventive maintenance of the machinery contributes to avoiding unnecessary and expensive shutdowns due to blocking or corrosion damage.

a) The UPM-Kymmene biofuel drying plant in Rauma achieves a dry content of the wet biofuel of 60 % after the drying process. The energy needed in the drying plant (belt dryer) comes from the excess heat of the paper mill (warm waste water and exhaust air). The installation reduces the use of fossil fuels and increases the share of biofuels by 10 %.

In the case of the large Rauma mill, CO_2 emissions are reduced by 70 000 tonnes per year.

b) The Norske Skog Follum mill dries the secondary (biological) sludge in order to make incineration possible. The net effect on energy is slightly negative and some biofuel is purchased to supply heat for drying. Bark is only pressed. 43 % dryness is reached by using leading bark press technology. Drying of waste biofuels contributes positively to the energy balance only through usage of excess heat.

The secondary sludge could alternatively be used as soil fertiliser, if the level of impurities is maintained at an acceptable level.

In specific applications (e.g. the use of fibrous sludge in the cement and brick industry) and for a better handling of the dried sludge, a minimum humidity content may be required.

Cross-media effects

If excess heat can be used for drying, the energy balance of the process is positive. The extracted humidity may cause an odour problem and needs to be controlled.

Technical considerations relevant to applicability
The measure can generally be applied to both new and existing plants that have suitable excess heat sources for the drying of the biomass and sludge.

In particular, drying is applicable when combustion for energy production is the final use for these by-products and when the drying process cost (mainly investment and fuel) is lower than the benefits of increased energy production.

In southern Europe, during the dry season, biofuel (bark and wooden biomass; not the biosludge) arrives at the mill with a water content that allows energy production at the desired flame temperature for almost all year, which may affect the economic viability of the measure.

The use of secondary heat for drying may face the following restrictions:

- The investment costs of this solution increase with the use of low-temperature excess heat as a consequence of the need for larger dryers.
- The use of high-temperature excess heat, usually flue-gas, is associated with the problem of achieving the acid dew point of the gas with consequence of extended corrosion or increased cost. This can be prevented either by the choice of construction materials or by reducing the recovery temperature range.
- The implementation of this solution is also dependent on the layout of the mill, namely the distance between the secondary heat sources and the places where the sludges and biofuels are generated.
- Drying and burning of biomass and waste water treatment sludge is just one of the possible waste management options. Alternative usages of waste water sludge are available that also recover the value of this material.

Economics
No cost data submitted.

The economic feasibility depends on the technical characteristics of the mill, or climate in the case of use of heat from the environment. When assessing the costs, the savings for reduced weight transport have to be taken into account. Generally, the economic benefits will also depend on the regulations on the use of biofuels for energy generation.

Driving force for implementation
Drying of sludge and bark is done in some mills, basically for two reasons: to increase the calorific value prior to incineration or to ease the handling (reduce weight for lower transport and landfill costs).

Example plants
UPM-Kymmene, Rauma (FI), Norske Skog, Follum (NO).

Reference literature
[252, Johansson et al. 2004].

2.9.6.1.5 Further measures for reducing thermal energy use

As the techniques discussed in Section 2.9.6.1 are only a selection of the available horizontal techniques for which data were provided, some other measures for reducing thermal energy that are used in pulp and paper mills are outlined below:

- Balance of dryer hoods.
- Recovery of heat from infrared exhaust hot air (for drying of the applied coating colours).
- Optimisation of hall ventilations. Best practice is to use heat recovered from the drying hoods of the paper machine or the pulp dryer, control the humidity and temperature of the

fresh air supply and of the exhaust fans, avoid diffuse wet air input, close open doors and gates to avoid air leaks, guarantee good circulation and avoid short circuits between supply air and exhaust air.

Further information on possible energy savings can be found in the energy-related sections of the process-specific Chapters 3 to 7.

2.9.6.2 Reduction of electrical energy use

2.9.6.2.1 Energy-efficient vacuum systems for dewatering

Description and achieved environmental benefits
Energy-efficient vacuum systems achieve electrical power savings of approximately 20 – 45 % in the vacuum system and need no sealing water as water ring pumps (but some cooling water). Efficient systems have an automatic speed control to adapt to changes in speed, grammage and felt age (see Section 2.9.6.2.3).

Environmental performance and operational data
Modern speed-controlled vacuum blowers provide more vacuum flexibility at the paper machine in order to get a better runnability by increasing or reducing vacuum levels according to the reel's need.

Cross-media effects
Water savings of around 95 %. Recovery of a large share of the pumping energy by recuperation of the exhaust air heat energy

Technical considerations relevant to applicability
Can be applied to all plants. Normally new vacuum equipment is considered when rebuilding or optimising the vacuum system of the paper mill as a whole.

Economics
Stora Enso Kaukopää (FI), Clairefontaine (FR) and MM Baiersbronn (DE) achieved a 45 % energy savings; M-real Lielahti (FI) saved 46 % and Metsä Tissue Mäntä (FI) reduced energy consumption for its vacuum system by 40 %.

Example plants
SE Kaukopää, Clairefontaine paper mill, MM Baiersbronn, M-real Lielahti, Metsä Tissue Mäntä.

Reference literature
[163, J.Lahtinen et al. 2009].

2.9.6.2.2 Use of high efficiency electrical motors

Description and achieved environmental benefits
Almost all the electric power of a paper mill is consumed by electric motors. For asynchronous motors, which are the most commonly used type, different efficiency classes exist. Power savings can be achieved when using high efficiency electric motors. Until 2008, the level of efficiency for asynchronous motor drives was categorised by the association CEMEP into three levels: EFF1, EFF2 and EFF3, with EFF1 representing the most efficient motors. Since 2008 this labelling scheme has been replaced by a new standard relating to energy-efficient motors that were drawn up by the International Electrotechnical Commission, the IEC 60034-30:2008. It defines new efficiency classes for motors and harmonises efficiency levels around the world.

Now the efficiency classes for electrical motors are labelled IE1, IE2, IE3 (and IE4 is under consideration) where:

- IE4 – Super premium efficiency (under consideration)
- IE3 – Premium efficiency (equivalent to NEMA Premium)
- IE2 – High efficiency (equivalent to EFF1)
- IE1 – Standard efficiency (equivalent to EFF2)
- No designation – below standard efficiency – (equivalent to EFF3).

Motors pertaining to the highest energy efficiency class should preferably be used.

Environmental performance and operational data
There are no differences in operation between different EFF or IE classes.

Cross-media effects
No issues.

Technical considerations relevant to applicability
Can be applied to all plants.

Economics
For working times of more than 4 000 hours per year, it is recommended that the highest efficiency class be used (already standard in most mills). Considering the life cycle costs of an asynchronous motor, the initial price of a motor is approximately 2 % of the entire lifetime costs of operation [164, M.Kara 2007]. Therefore it usually pays back sooner to purchase the highest efficiency possible.

Example plants
Most mills use motors with the highest efficiency without problems.

Reference literature
[164, M.Kara 2007], [249, Blum et al. 2007].

2.9.6.2.3 Energy-efficient frequency inverter for pumps, fans and compressors

Description and achieved environmental benefits
In most paper mills the flow of pumps is controlled by a valve, while the pump is running at a constant speed. When adjusting the speed of the pump to the flow only the pumping power required for the purpose has to be served by the motor. Controlling the water flow by adjusting the speed of the pump is more efficient than using a throttling-type valve. With an inverter the power frequency provided by the grid can be modified to adjust the speed of the asynchronous motors (as the speed of an asynchronous motor is a function of the frequency).

Power savings for pumping applications result from the lower throttling losses and higher hydraulic yield of the pump. Typical savings range between 15 % and 25 % for each application.

Environmental performance and operational data
Some suppliers of mechanical seals require a minimum pump speed. Inverters need more capacity in the switch room. The motor has to be suitable for inverter control. Sufficient motor cooling needs to be guaranteed and, in some cases, forced air ventilation may be required.

Cross-media effects
No issues.

Technical considerations relevant to applicability
Can be applied to both new and existing plants using three-phase asynchronous motors. The applicability of a frequency inverter in a waste water treatment plant may be restricted when the waste water flow is discontinuous and characterised by sudden changes.

Economics
Prices for frequency inverters dropped significantly in recent years. Economic efficiency needs to be assessed for each situation. The payback period fluctuates between 0.5 and 4 years (Source: PTS market study, December 2006, for German situation).

Driving force for implementation
Cost reduction because of energy savings (power) and process control.

Example plants
Inverters are installed in almost all European mills. But in most mills, normally just some drives are equipped with inverters.

Reference literature
[249, Blum et al. 2007].

2.9.6.2.4 Further measures for reducing electrical energy

As the techniques discussed in Section 2.9.6.2 are only a selection of the available techniques for which data were provided, some other measures for reducing electrical energy that are used in pulp and paper mills are outlined below:

- Efficient agitators
- Efficient pumps
- Improvement of refiners (Chapters 5 and 7)

Further information on possible energy savings can be found in the energy-related sections of the process-specific Chapters 3 to 7 and especially in Section 7.3.15 (energy saving in papermaking).

2.9.6.3 Combined heat and power production

Description
Combined heat and power production is the simultaneous generation of heat energy and electrical and/or mechanical energy in a single process referred to as a combined heat and power plant (CHP). For more information, see Section 2.6.1.2.2.

Achieved environmental benefits
Increased energy efficiency, and consequently reduced emissions per kWh produced or per MJ fuel input. The installation of CHP can reduce the consumption of primary energy from 10 % to 15%, resulting in a decrease in CO_2 emissions. Waste in the electricity distribution system is reduced to 5%.

Environmental performance and operational data
Cogeneration power plants based on gas turbines in combined cycle application are an important measure for reducing fuel consumption and CO_2 emissions because of their comparatively high overall fuel efficiency, even for relatively small capacity units (from some MW_{th} upwards). The high electricity/heat ratio and the high conversion rate of fuels used significantly reduce the specific CO_2 and also the total emissions per kWh produced compared to condensing type steam power plants. Lower CO and NO_X emissions are achieved.

Energy losses from power generation and from heat production can be reduced by combining the generation of heat and power (CHP). Cogeneration plants raise the conversion rate of fuel use (fuel efficiency level) from around a third in conventional power stations to around 80 – 93 %. The characteristics of the paper manufacturing process are favourable for the use of CHP plants: high electricity and heat demand at a relatively stable power to heat ratio over the whole year.

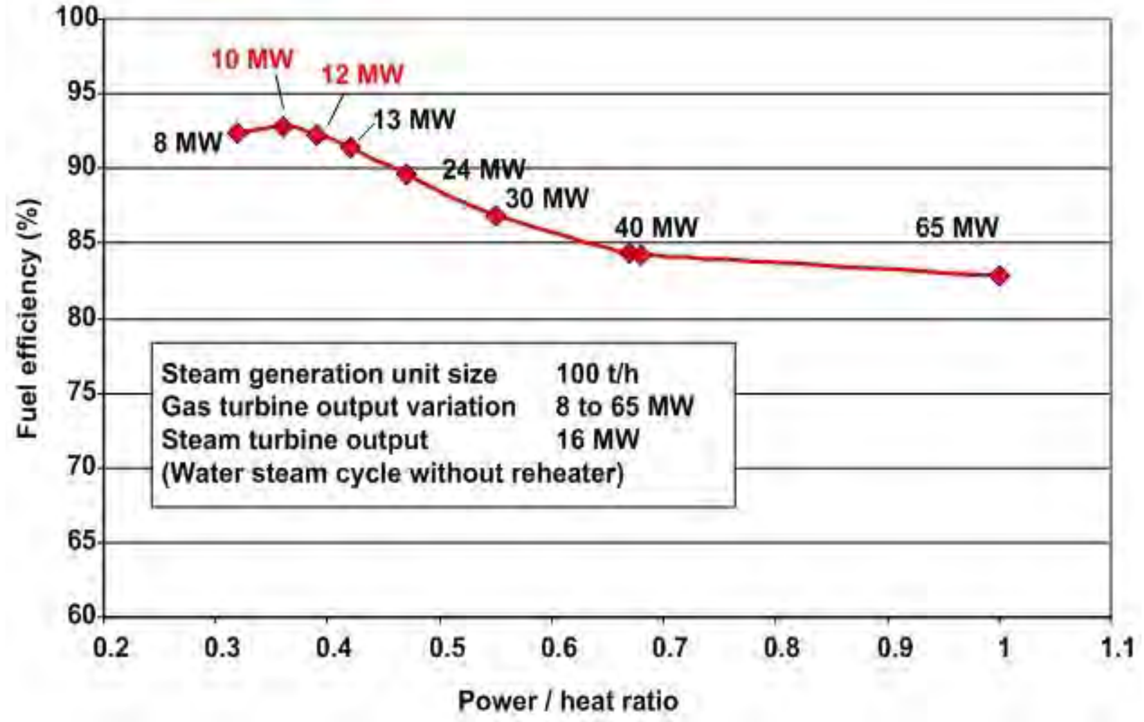
In paper mills different kinds of cogeneration processes are used. Besides the classic back-pressure type steam power plants, since 1980 combined cycle utilities have been on the market. The back-pressure type steam power plant can reach a power to heat ratio of about 0.2 which is not sufficient for covering the electricity demand of modern paper production facilities. State-of-the-art paper machines need a power to heat ratio between 0.3 and 0.65 depending on the paper type, quality and pulp production facilities (for mechanical pulp mills, even higher). Traditional steam power plants may increase the power output by retrofitting the steam cycle and arranging a gas turbine upstream of the boiler, which is then called a combined cycle gas turbine. For boiler houses fired with gas, one or several gas turbines prior to the existing supplementary fired steam boiler can be installed to reach a higher output of electricity from the plant. If a steam turbine is already in operation, a gas turbine can be installed before the steam generator to produce a higher yield of power.

As an example, a modern and efficient combined cycle gas turbine (CCGT) was installed in 2008 at a paper and cartonboard mill in Germany. This system for the internal generation of electricity and heat is characterised by a fuel efficiency of 92 %, a reduction of CO_2 emissions and low emissions of CO and NO_X. Where it is practicable, this system should be considered the preferable option.

As in normal gas turbine technology, air is drawn from the atmosphere and compressed. In the combustion chamber, fuel and air from the gas turbine compressor are mixed and combustion takes place. After combustion, the flue-gas is expanded into a turbine, which drives a generator. In combined cycle power plants, the thermal energy contained in the gas turbine exhaust gas is utilised in a heat recovery steam boiler to produce steam that is used to generate additional electricity via a steam turbine (see also Section 2.6.1.2.2).

Plants for the cogeneration of heat and power convert 80 – 93 % of the energy input into 50 – 80 % heat and 20 – 50 % electricity depending on the specific need of the mills for power and steam and the CHP plant system applied.

The ratio of electricity output to process heat produced is named Heat to Power Ratio (HPR). When selecting an appropriate HPR for a specific paper mill, basic physical limits with regard to fuel efficiencies have to be taken into account. Figure 2.24 uses an example to show the interrelationship between fuel efficiency and the chosen HPR.



Source: [105, F.Hutter 2007]

Figure 2.24: Interrelationship between fuel efficiency and the chosen heat to power ratio for CCGT utilities

Figure 2.24 shows the results of thermodynamic calculations: from a technical point of view, the best possible fuel efficiencies can be reached within a HPR range of 0.3 – 0.5. A Heat/Power Ratio of more than 0.5 leads to a reduction in fuel efficiency values. The graph is plotted for a common process steam utility that generates 100 tonnes of steam/hour. The power output of the steam turbine is kept constant at 16 MW. The points in the graph are the results of thermodynamic calculations for the boiler with varying sizes of gas turbines (from 8 to 65 MW) arranged upstream of the steam boiler. Some relevant gas turbine power classes are also indicated in the graph.

The economic optimum may differ from the technical optimum and does not necessarily coincide with the former. Dependent on the electricity/fuel price ratio the economic calculations can lead to higher or lower HPRs. For example, high electricity/fuel price ratios of about 4 allow higher Power to Heat Ratios and result in cogeneration utilities which achieve higher HPRs but have lower fuel efficiencies, of e.g. only 75 %. When the electricity/fuel price ratio drops down to around 3, cogeneration utilities with higher fuel efficiencies but lower power to heat ratios are economically viable.

Table 2.23 gives an example of the emissions reduction achieved by substituting a combined cycle gas turbine utility (CCGT) for mid-load operating public utility supply. The CCGT example represents a cogeneration process with the best possible thermal efficiency. The combined cogeneration of steam and power (CCGT with 92 % fuel efficiency) is compared with purchased electricity that is generated by a state-of-the-art coal-fired utility (42 % electrical efficiency, in the German example) and an on-site steam block (88 % boiler efficiency). A special flap system makes sure that exactly the right amount of oxygen is metered into the firing equipment. Fuel-oxygen regulated facilities which operate in accordance with a specified computer control system guarantee combustion that is almost CO-free. The low NO_X emission levels may have another advantage: the competent authorities decided in this case that the continuous NO_X measurement specified by the relevant regulations was no longer required.

Table 2.23: Comparison of the environmental performance of a combined cycle gas turbine plant and a public utility supply in Germany

Example of a combined cogeneration plant designed for 95 t steam/h; production of approximately 90 t steam/h; 24 MW_e output [1]					mg/MJ (2)
	Unit			**Value**	NA
Power output combined	MW			24.0	NA
Process heat combined	MW			60.0	NA
Power to heat ratio	MW/MW			0.40	NA
Total generated energy	MJ/h			302 400	NA
		Utility			
	Unit	**Gas turbine**	**Supplemental firing**	**Total**	**mg/MJ** (2)
Rated thermal input	MW	37.9	53.6	91.5	NA
Gas flow (dry gas, normal conditions)	m^3/h	NA	NA	109 000	NA
Emission NO_X (1)	mg/m^3	NA	NA	70	NA
Emission CO (1)	mg/m^3	NA	NA	5	NA
Emission SO_2 (1)	mg/m^3	NA	NA	0	NA
Mass flow NO_X	kg/h	NA	NA	10.9	36.0
Mass flow CO	kg/h	NA	NA	0.5	1.8
Mass flow SO_2	kg/h	NA	NA	0	0
Mass flow CO_2	t/h	NA	NA	19.0	62 830
Purchased electricity: 24 MW from coal-fired mid-load operating public utility - process steam is generated by a steam block 90 t/h [2]					
	Unit			**Value**	**mg/MJ** (2)
Purchased power	MW			24	NA
Heat generation	MW			60	NA
Total generated energy	MJ/h			302 400	NA
		Utility			
	Unit	**Electricity generation**	**Steam generation**	**Total**	**mg/MJ** (2)
Rated thermal input	MW	59.4	67.6	127	NA
Gas flow (dry, normal)	m^3/h	73 070	69 030	142 100	NA
Emission NO_X	mg/m^3	200	100	NA	NA
Emission CO	mg/m^3	200	50	NA	NA
Emission SO_2	mg/m^3	200	0	NA	NA
Mass flow NO_X	kg/h	14.6	6.90	21.5	71.1
Mass flow CO	kg/h	14.6	3.45	18	59.7
Mass flow SO_2	kg/h	14.6	0	14.6	48.3
Mass flow CO_2	t/h	19.6	13.9	33.6	110 950

NB: NA = not available

(1) Oxygen content in the waste gas is 3 %.

(2) Calculation for conversion of the figures into specific values: 1 MW × 3 600 = MJ/h; e.g. (24.0 + 60.0) × 3 600 = 302 400 MJ/h; For example, the specific NO_X emissions can be calculated as 10 900g/h divided by 302 400 MJ/h = 36 mg/MJ.

Sources:

[1] Data from CCGT Power Utility Paper Mill (DE) commissioned 2008, reported data from 2008 [106, F.Hutter 2010].

[2] Data from Research Report BMFT-FB-T85-065, F. Hutter et al.; therein: Fichtner: Design of a Coal Fired Power Station with Environmental Protecting Components published by Ministry of Research and Technology, Germany, 1985.
Example calculated by F.Hutter GmbH Biberach, Germany, 2010. It is assumed that cogeneration substitutes base load electricity generation for public utilities. In Germany, the upper base load is generated by coal-fired utilities. The comparison is made with a 42 % efficiency power plant with modern desulphurisation and denitrification and 2 % transmission losses.

Compared with the conventional electricity generation of a state-of-the-art coal-fired power plant and an on-site steam boiler, the CCGT described in Table 2.23 achieves the following reduction rates:

- fuel consumption: 28 % reduction
- NO_X: 49 % reduction (instead of 21.5 kg NO_X/h, the CHP plant generates 10.9 kg NO_X/h)
- CO: 97 % reduction (instead of 18 kg CO/h, the CHP plant generates 0.5 kg CO/h)
- SO_2: 100 % reduction
- CO_2: 43 % reduction (instead of 33.6 t CO_2/h, the CHP plant generates 19 t CO_2/h).

It should be noted that achievable emission reduction rates depend on the energy generation systems being compared.

Cross-media effects
The installation of CHP results in the creation of new sources of emissions into the atmosphere. The emission point of CHP is usually the boiler (HRSG).

Technical considerations relevant to applicability
CHP is applicable to both new and existing mills. In existing plants cogeneration can be implemented for instance by repowering existing steam back-pressure units by transforming them into combined cycle cogeneration plants. CHP can be used in a wide range of capacities. The capacities for CHP production ranges from ≤1 MWth for a small paper mill up to ≥500 MWth for recovery boilers in large pulp mills. Obstacles to implementing CHP may be administrative procedures involved in obtaining the permits required to build the plant and connect it to the national grid or to build a high-voltage power line to connect it to the grid, if required.

The relatively small size of most tissue mills can make CHP less viable than for larger mills.

Economics
The achievable savings and the payback time depend mainly on the price of electricity and fuels within the country. Investment and costs for depreciation and maintenance have to be considered. For the mills that have applied cogeneration of heat and power, this measure was a cost-effective measure (under the given energy prices).

Investment costs for CHP depend on the size of the plant. Capital investments per MW installed decrease with plant size and depend on the CHP technology installed. The following capital investments required in 2010 according to size and technology were reported [ASPAPEL, 2011]:

Simple cycle with gas turbine:

- 1 MW and production of 3 t/hr of saturated low-pressure steam: € 1.5 million
- 4.5 MW and production of 6 t/hr of saturated low-pressure steam: € 5 million

Simple cycle with engine:

- 1 MW with steam or cold production: € 1.3–1.5 million

Combined cycle with gas turbine (CCGT):

- 25 MW and production of 40 t/hr of saturated low-pressure steam: € 30 million
- 48 MW and production of 90 t/hr of saturated low-pressure steam: € 54 million

Driving force for implementation
The estimated increase in energy efficiency of the plant and the reduction in its power costs.

If the whole cogeneration potential of a site is realised, the power generation of the plant may exceed the electricity demand of the mill. A certain amount of electricity generated is then sold to the grid, if the market conditions are favourable.

Example plants
Use of combined heat and power generation is a common technique and is applied in numerous paper mills in Europe (see also Table 1.4). In the pulp and paper sector in Spain, 50 CHP plants were in operation in 2010. There are different schemes for combined cycle gas turbines and other types of CHP plants in use. Which system is finally applied depends mainly on the existing power plants already in operation and on local and market conditions.

Reference literature
[9, Directive 2004/8/EC 2004], [12, Directive 2010/75/EU 2010], [105, F.Hutter 2007], [106, F.Hutter 2010].

2.9.7 Reduction of emissions of multifuel, biomass and auxiliary boilers to air

In pulp and paper mills different types of biomass, fossil fuels (coal, lignite, oil or natural gas), process residues and waste may be used for steam production, typically coupled with turbines for electric power production. In relation to the scope, the reader is referred to the first paragraphs of Section 2.6. Stationary internal combustion engines are outside the scope.

Pure biomass boilers (fuels include bark, wood residues and screening rejects) are typical in chemical or mechanical pulp and paper mills that operate a wood yard. Multifuel boilers are also commonly used. The bark is readily used as fuel in the mill's auxiliary boiler. If dewatered sludge (lower calorific value) is incinerated in these boilers, certain features of the preparation and burning of sludge have to be considered (adding of high heat value support fuel, adequate design of the furnace, mixing, preheating of combustion air, etc.).

In burning these mixed fuels, environmentally sound incineration techniques as well as secondary flue-gas cleaning techniques are called for to minimise dust, NO_X and SO_2 and other gaseous pollutants, if present.

For more details on the techniques available to control emissions from reject and sludge incinerators from mills processing paper for recycling, the reader is also referred to Section 6.3.14 where four examples are discussed.

Conventional gas- or oil-fired steam boilers (steam blocks) with a rated thermal input exceeding 50 MW for meeting the process heat demand in pulp and paper mills do not differ from the steam generators in other industrial sectors and the emission control measures are not discussed here in detail (only some data on the reduction of NO_X emissions are discussed). The reader is referred to the BAT Reference Document on Large Combustion Plants [271, COM 2006]. The LCP BREF contains extensive information related to applied techniques and abatement measures for combustion plants that use commercial fuels such as natural gas, coal or lignite and others.

Emissions from CHP plants in the pulp and paper industry are exactly the same as for pure steam boilers using the same fuel. The emission point for the CHP applications is normally the boiler. For the gas turbine, however, the combustion process does not occur in the boiler but originates in the combustion chamber. For a CCGT process the NO_X and CO levels should be controlled in the gas turbine. The emissions are also monitored after the boilers.

2.9.7.1 Reduction of dust emissions

Description
Pulp and paper mills run different types of combustion plants for steam and power production. In terms of fuels utilised, the combustion plants may be charged with wood residues only (from bark and wood waste), fossil fuels only (lignite and coal, fuel oil, natural gas) and mixtures of

fuels such as biogas, biomass and fossil fuels, other internal production residues and various types of sludge (e.g. sludge from biological waste water treatment).

Techniques which are commonly used to control the emissions of particulate matter (dust) from these plants are fabric filters (FFs) and electrostatic precipitators (ESPs).

Electrostatic precipitators use electrostatic forces to separate and retain particulates from the flue-gas of boilers. In fabric filters, dust is separated by passing the flue-gas through a filter of fabric material.

Both ESPs and FFs are highly efficient particulate removal devices with design efficiencies in excess of 99.5 %. The choice between an ESP and a FF generally depends on the fuel type, plant size, boiler type and configuration, and the particulate removal target to be achieved. Fabric filters can reach slightly lower emissions of dust than ESPs. A detailed description of ESPs and fabric filters can be found in the LCP BREF [271, COM 2006].

Achieved environmental benefits
Reduction of dust and fine dust. Fine dust is generally referred to as PM_{10}, $PM_{2.5}$ which denotes particulate matter (PM) with an aerodynamic equivalent diameter of 10 microns or less and 2.5 microns or less, respectively. Fabric filters are more efficient at removing very fine particulates than ESPs.

Environmental performance and operational data
Both techniques give a very high removal efficiency of particulates, in excess of 99 % and have a proven track record in the industry. The particulate content of the flue-gas after cleaning is between 5 and 20 mg/Nm^3 for properly designed equipment functioning under normal operating conditions for ESPs and between 1 and 10 mg/Nm^3 for fabric filters as a daily average value. In Table 2.24 some example data for fluidised bed boilers equipped with electrostatic precipitators or fabric filters are compiled.

Table 2.24: Dust emission data of example boilers of paper mills using different fuels and equipped with an ESP or FF

Rated thermal input (MW)	Year of commissioning	Fuels	Flue-gas cleaning system	Dust (mg/Nm^3)	O_2 (%)	Type of measurement
48	1994	Bark, sludge, paper, waste wood	Dry adsorption + FF	0 – 10 (DAV) 3 – 7 (MAV) 4 (YAV)	11	Continuous
4.8	2003	Waste wood, rejects, sludge	Dry adsorption + FF, SNCR	0.1 – 0.3 (YAV)	11	Continuous
15	1984	Bark, sludge, coal, biogas	ESP+FF	1 – 4	11	Discontinuous (every year)
25	1982	Bark, sludge, biogas	ESP	15-16	11	Discontinuous (every year)
40	Not indicated	Bark	FF	1.1 – 4.4 (DAV) 2 (YAV)	11	Continuous
32	Not indicated	Bark, biosludge	ESP	7 (YAV)	11	Continuous
35	2006	Biomass (89%), rejects from waste paper (11 %)	ESP	14 – 23 (DAV) 19 (YAV)	8	2/year

NB: DAV = daily average value; MAV = monthly average value; YAV = yearly average value.
Example plants are from AT, DE, FR and PT (the names of the mills were declared confidential).
Sources: filled-in questionnaires 2007 and 2009; [229, Stubenvoll et al. 2007]

Cross-media effects

ESPs need a supply of electric power. Fabric filters normally cause a larger pressure drop than ESPs and may therefore require more energy to the flue-gas fans. Removed ashes require environmentally sound treatment and disposal.

Technical considerations relevant to applicability

Common technique at combustion plants of various sizes and purposes. Both techniques can be applied in new installations and as retrofits to existing plants.

Economics

An investment cost estimate for an ESP or bag filter installation is about EUR 1 million for a 40 MW_{th} plant, EUR 1.4 million for a 60 MW_{th} plant, and EUR 2.1 million for a 100 MW_{th} plant. The investment costs for ESPs and fabric filters are about the same for a boiler of the same capacity [229, Stubenvoll et al. 2007].

In Table 2.25 additional cost data for dust removal devices for smaller combustion plants (2 – 20 MW) are shown.

Table 2.25: Cost data for dust removal devices for smaller combustion plants

Costs for dust removal (1)	Rated thermal input: 2 MW	Rated thermal input: 5 MW	Rated thermal input: 20 MW	Remarks
Investment costs – ESP in €	11 000 – 140 000	155 000 – 190 000	410 000 – 510 000	Including erection, insulation, heating, ash discharge, electronic equipment
Investment costs – FF in €	110 000 – 135 000	180 000 – 230 000	590 000 – 710 000	Including erection, insulation, heating, ash discharge, electronic equipment
Yearly operating costs – ESP in €	5 500	7 800	15 000	8 000 operating hours; including costs for electrical power and pressure loss
Yearly operating costs – FF in €	7 200	16 000	62 000	8 000 operating hours; including costs for replacing filter tubes, electrical power, pressure loss and pressurised air

Source: Fa. Scheuch (2006)

(1) In both cases, ESP and FF, a multicyclone has to be installed for security reasons (removal of large ash particles and sparks). Multicyclones increase the investment costs of PM removal devices by 5 – 10 %.

NB:
For new plants, even those with a one-field ESP, it is possible to maintain levels around 20 mg/Nm^3 (as daily average value).
For existing plants: If the ESP has been designed to keep the PM concentration below 50 mg/Nm^3, retrofitting may be difficult and replacement of the whole ESP may be required.

An example of the relation between investment costs and the dust removal efficiency of an ESP for a combustion plant with a rated thermal input of 1.2 MW (*Source:* Scheuch, 2006) is:

- ESP <50 mg/Nm^3; EUR 72 000 – 75 000
- ESP <20 mg/Nm^3; EUR 82 000 – 85 000.

Driving force for implementation

IED (Directive 2010/75/EU on industrial emissions) and LCP Directive (Directive 2001/80/EC) as well as national legislation.

Example plants
Numerous plants in Europe.

Reference literature
[229, Stubenvoll et al. 2007], [189, Norrström 2010], [Questionnaires 2007 and 2009].

2.9.7.2 Reduction of NO_X emissions

In principle, to reduce NO_X emissions, primary (process-integrated) measures and secondary measures that remove NO_X after the combustion can be used. The secondary measures have an influence on both thermal and fuel NO_X.

2.9.7.2.1 Primary measures for NO_X reduction

Description and achieved environmental benefits
The formation of NO_X in the furnace depends essentially on three parameters: temperature, oxygen supply and the N content in the fuel. The primary measures for NO_X reduction include measures like burner firing optimisation, use of fuels with low N content, low excess air, low-NO_X burners (for liquid and gaseous fuels only), air staging (over fire air) and flue-gas circulation. This section gives only the general principles of NO_X formation and the techniques used for reduction. For a detailed description, the reader is referred to the LCP BREF [271, COM 2006].

Low-NO_X burners for liquid and gaseous fuels are designed to control fuel and air mixing to create larger and more branched flames. Peak flame temperature is thereby reduced and results in less formation of thermal NO_X. The improved flame structure also reduces the amount of oxygen available in the hottest part of the flame thus improving burner efficiency.

In conventional oil- or natural gas-fired boilers, the burners feeding the fuel-air mixture are usually designed to maintain low-NO_X burning conditions. Also, coal or peat is often burnt as finely ground dust in conventional boilers, fed through burners whose designs ensures low-NO_X burning. In low-NO_X burners the primary burning air is brought through the burner in the fuel-air mix. Secondary and tertiary air is fed in separately to ensure an appropriate primary/secondary/tertiary air balance in the flame area in order to maintain low-NO_X combustion. Some air may still be fed, if necessary, above the main flame area to complete the fuel combustion.

The purpose of the multi-phase air feed is to burn the fuel without excess air and actually even under reducing conditions, meaning that there is not enough oxygen to promote strong NO_X formation and that the flame temperature is lower than in conventional burners, which further decreases NO_X formation.

Low-NO_X burners can be combined with other primary measures such as over fire air or flue-gas recirculation. The combination of low-NO_X burners and other primary measures may achieve a NO_X reduction of up to about 70 %.

Air staging is the introduction of over fire air into the boiler or furnace. Staging the air in the burner (internal air staging) is generally one of the design features of low-NO_X burners. Furnace over fire air (OFA) requires combustion air to be separated into primary and secondary air to achieve complete burnout and the formation of N_2 rather than NO_X. The primary air (70 – 90 %) is mixed with the fuel producing a relatively low-temperature, oxygen-deficient, fuel-rich zone and moderate amounts of fuel NO_X are formed. The secondary (10 – 30 %) combustion air is injected above the combustion zone. The relatively low-temperature second stage limits the production of thermal NO_X. The location of the injection ports and mixing of over fire air are critical to maintain efficient combustion.

Flue-gas recirculation includes gas recirculation into the furnace or into the burner. In this technology, part of the flue-gas (e.g. 20 – 30 %) is recirculated (at 350 – 400 °C) and mixed with the combustion air. The resulting dilution in the flame decreases the temperature and availability of oxygen therefore reducing thermal NO_X formation. Retrofitting boilers with flue-gas recirculation involves installation of a system to extract the flue-gas from the boiler unit, additional ductwork, fan and a fly ash collecting device. The fly ash collecting device is necessary in order to clean the flue-gas of dust prior to recirculation. Heat distribution in the furnace may be affected due to the increase in throughput. Excessive flue-gas recirculation can also result in flame instability problems and increased steam temperatures. Flue-gas recirculation alone achieves only a low-NO_X reduction efficiency or less than 20 % but may be combined with other control measures.

A specific type of low-NO_X burner is the 'dry low-NO_X (DLN)' technology which is mainly applied at gas turbines. The dry low-NO_X (DLN) combustion system yields low emissions while operating in the dry premixed mode on natural gas fuel, i.e. no water or steam injection on gas fuel units is applied. The dry low-NO_X combustion system reduces NO_X emissions through lean premixed burning in multi-zone combustion liners, and by control equipment which directs fuel to the different liner zones depending upon the mode of operation. The low-NO_X burners, like other techniques to control NO_X, are not specific to the pulp and paper industry but are generally applicable to boilers and gas turbines.

Low-NO_X technology applied to the burning of solid fuels and pulp and paper mill residues (bark, wood waste, sludge) with fluidised bed boilers is discussed in Section 2.6.1.2.3. Coal and lignite are well-suited to be burnt as the main or support fuel in fluidised bed systems which, by applying air staging and/or flue-gas recirculation, promote low NO_X formation.

Cross-media effects

Cross-media effects from the primary measures are in general small. Optimised furnaces prevent excess oxygen and high temperatures, which both promote NO_X formation. Unduly low excess oxygen, however, increases the risk of incomplete combustion with higher CO (carbon monoxide) and TOC emissions. The right balance is needed when trying to achieve very low NO_X emission levels by reducing airflow. In some cases, recirculation of flue-gases can enhance the control of combustion and consequently result in a reduction of CO emissions. Due to the lower temperature, a decrease in energy efficiency may be observed at some plants.

In fluidised bed reactors, injection of secondary air may lead to a decrease in energy consumption since secondary air is injected at a lower pressure than primary air.

Environmental performance and operational data

The NO_X emissions from a biomass auxiliary boiler depend on the fuel used and the combustion conditions. The nitrogen content of biomass varies between different species, and for specific biomass species the N content varies between different plant fractions. Higher emissions caused by the use of more polluting raw materials (higher N content) or processes can be compensated for by greater efforts in pollution prevention and control (primary or secondary measures).

Emission monitoring with on-line NO_X meters and oxygen meters help to ensure that low-NO_X burning conditions are maintained and emission targets are achieved. Effective reduction of NO_X by primary measures requires the installation of a good firing rate control system in fluidised bed boilers.

The primary techniques give a NO_X removal efficiency ranging from about 20 % for individual primary measures (low-NO_X burner, air staging, flue-gas circulation) up to 70 % when combining primary measures with each other.

Emissions from modern fluidised bed boilers burning pulping and reject sludge with support fuels can be efficiently controlled and optimised. The variety of fuels, the add-on emission control techniques applied in the boilers and the emission targets set influence the achieved emission levels. Examples of achieved emissions for different fuels and boilers are given below.

I. In fluidised bed boilers that mainly burn solid fuels and sludge, low-NO_X burners are not used during normal operating conditions. They may be used during start-up and shutdown. Air staging and flue-gas recirculation can reduce NO_X emissions to a value of 200 mg/Nm^3 (6 % O_2) independent of the fuel mix used.

Table 2.26 shows the emission control techniques applied and the achieved emission levels for NO_X and CO for some combustion plants running in European pulp and paper mills (AT, DE, FR) for different fuel mixes. At some of the example installations, primary and secondary measures (see Section 2.9.7.2.2) are applied.

Table 2.26: NO_X emission data for example fluidised bed boilers of paper mills applying primary and/or secondary measures for NO_X reduction

Rated thermal input (MW)	Year of commissioning	Fuels	Flue-gas cleaning system	NO_X (mg/Nm^3)	CO (mg/Nm^3)	O_2 (%)	Observation
48	1994	Bark, sludge, paper, waste wood	Primary measures	90 – 220 (DAV) 142 – 187 (MAV) 165 (YAV)	3 – 20 (DAV) 4 – 9 (MAV) 6.4 (YAV)	11	C_{org} <2 mg/Nm^3
4.8	2003	Waste wood, rejects, sludge	Primary measures, SNCR	161 – 171 (YAV)	2.3 – 2.8 (YAV)	11	Corg <1 mg/Nm^3
40	Not indicated	Bark	Over fire air	80 – 150 (DAV) 116 (YAV)	70 – 170 (DAV) 95 (YAV)	11	C_{org} 4 mg/Nm^3
32	Not indicated	Bark, biosludge	Primary measures	148 (YAV)	54 (YAV)	11	NA

NB:
The figures are all based on continuous measuring.
NA = not available; DAV = daily average value; MAV = monthly average value; YAV = yearly average value
Source: questionnaires 2007 and 2009

II. In gas-fired steam generators or boilers, low-NO_X burners achieve a NO_X concentration of 60 mg/Nm^3 to close to 100 mg/Nm^3 (at 3 % O_2), as shown for some examples in Table 2.27. CO emissions are generally below 20 mg/Nm^3 (at 3 % O_2). Emission values are given as daily average values and are measured at gas-fired boilers with a capacity of 17 MW to >50 MW. At some boilers, continuous measurement systems for NO_X and CO are in use.

Table 2.27: NO_X emission data for example gas-fired boilers of paper mills in Austria applying low-NO_X techniques

Rated thermal input (MW)	Year of commissioning	Flue-gas cleaning system	NO_X (mg/Nm^3)	CO (mg/Nm^3)	O_2 (%)	Type of measurement
17	NA	Low-NO_X burner	95 (YAV)	19 (YAV)	3	Discontinuous
45	2002	Low-NO_X burner	56 – 72 (DAV) 61 (MAV) 60 (YAV)	3 – 5 (DAV) 4 (MAV) 4 (YAV)	3	Continuous
48	1977	Low-NO_X burner (retrofitted), flue-gas recirculation	86 – 96 (DAV) 92 (MAV) 88 (YAV)	4 – 13 (DAV) 7 (MAV) 7 (YAV)	3	Continuous

NB
NA = Data not available. Gas is the fuel for all boilers. DAV = daily average value; MAV = monthly average value; YAV = yearly average value.
Source: Questionnaires 2007, 2009.

III. Low-NO_X techniques in combined cycle gas turbines (CCGT) achieve a NO_X concentration of 40 mg/Nm^3 (at 15 % O_2) for new installations and of 60 – 90 mg/Nm^3 (at 15 % O_2) as shown for the example plants in

Table 2.28. CO emissions are generally below 40 mg/Nm^3 (at 15 % O_2). Emission values are given as daily average values and are measured at newer and older plants with different capacities. At most CCGT boilers continuous measurement systems for NO_X and CO are in use.

Table 2.28: NO_X emission data for an example CCGT plant of paper mills in Austria applying low-NO_X techniques

Rated thermal input (MW)	Year of commissioning	Flue-gas cleaning system	NO_X (mg/Nm^3)	CO (mg/Nm^3)	Type of measurement
23	1997	DLN	70 – 90 (DAV)	0 – 40 (YAV)	Continuous

NB: The figures are all based on continuous measuring and on an O_2 content of 15 % with gas used as fuel.
DAV = daily average value; MAV = monthly average value; YAV = yearly average value.
Source: Questionnaires 2006 and 2008.

IV. For oil-fired steam generators no data on NO_X emissions achieved with primary measures were provided during the information exchange on BAT.

Technical considerations relevant to applicability
Low-NO_X burners, air staging and flue-gas recirculation (for fluidised bed boilers) have been applied successfully in the retrofit of existing boilers and the construction of new ones. The primary measures have a proven track record in the industry.

Primary measures as described here are common techniques for new plants and have been applied for many years. Retrofitting of existing plants with primary measures is, in principle, possible. At some boilers retrofitting may be difficult for the following reasons:

- Fluidised bed reactors: Geometric restraints and the necessity to install an efficient firing rate control may result in higher costs at some plants.
- CCGT: Installation of DLN may be impossible if this was not foreseen in the original construction concept. However, applying steam or water injection is possible in every case.
- Oil- and gas-fired boilers: Low-NO_X burners can be installed at every plant; difficulties may arise at very old plants with geometric restrictions.

Economics

An investment cost estimate for low-NO_X burners is EUR 1 – 2 million for boilers in the range 50 – 100 MW (ÅF Engineering file data, 2009). No major increase in the operating costs is anticipated.

Driving force for implementation

IED (Directive 2010/75/EU on industrial emissions) and LCP Directive (Directive 2001/80/EC) as well as national legislation. Driving forces include legal requirements and European air quality objectives such as the national emission ceilings that have been set for acidifying and eutrophying pollutants in order to provide greater protection for the environment and human health against their adverse effects (Directive 2001/81/EC of the European Parliament and of the Council on national emission ceilings for certain atmospheric pollutants).

Example plants

Numerous mills in and outside Europe.

Reference literature

[1, Finnish BAT Report 1997], [229, Stubenvoll et al. 2007], [Questionnaires 2007 and 2009].

2.9.7.2.2 Selective non-catalytic reduction (SNCR)

Description and achieved environmental benefits

In SNCR systems, ammonia or urea is injected into the furnace within a suitable temperature window. Emissions of NO_X can be reduced by 30 % to 70 % by the reaction between NO and the reducing agent to form nitrogen and water. The most common reagents used in SNCR processes are anhydrous ammonia, aqueous ammonia and urea solution. In the SNCR process, it is the ammonia molecule that is the active reducing agent. When using urea solution in such a deNO_X process, the urea will be first converted into ammonia prior to the deNO_X process. The dominating reaction in the SNCR processes in combustion processes where NO is the main NO_X species is:

$$4\ NO + 4\ NH_3 + O_2 \rightarrow 4\ N_2 + 6\ H_2O.$$

In the more efficient SCR process about 1 mole of ammonia is required per mole of NO_X reduced or about 0.5 mole of urea per mole of NO_X reduced. The SNCR process is not as efficient as SCR when it comes to reagent utilisation. In this process, the reagents need to be dosed in an over-stoichiometric ratio. For SNCR it can be in the range of 1.5 – 2 mole (or even higher in some cases). The approximate reagent consumption for SCR and SNCR processes is:

SCR: 1 kg NO_X reduction requires 0.37 kg NH_3 or 0.653 kg urea.
SNCR: 1 kg NO_X reduction requires 1.2 – 1.9 kg NH_3 or 2.2 -3.3 kg urea.

The temperature window for efficient SNCR operation is typically between 800 and 1 050 °C. When the reaction temperature increases to over 1 000 °C, the NO_X removal rate decreases due to the thermal decomposition of ammonia. Below 800 °C, the NO_X reduction rate decreases and ammonia slip may increase. The longer the reagent is in the optimum temperature window, the better the NO_X reduction. Residence times in excess of one second yield optimum NO_X reductions.

Ammonia slip from the SNCR systems occurs either from injection at temperatures too low for effective reaction with NO_X or from over-injection of the reagent. Controlling ammonia slip in SNCR systems is difficult since there is no opportunity for effective feedback to control the reagent injection. Another difficulty is that the reagent should be placed where it is most effective and the NO_X distribution varies within the boiler cross-section.

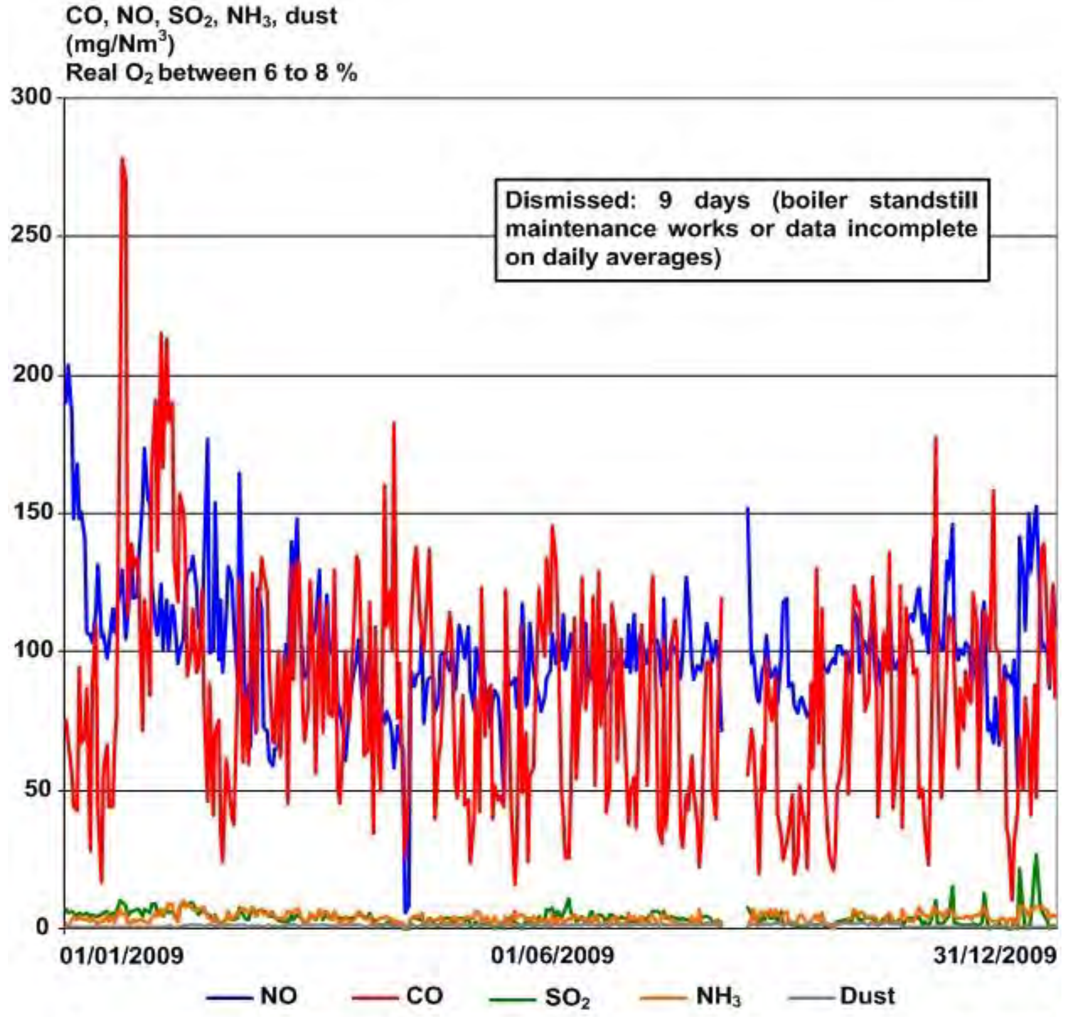
Distribution of the reagent needs to be particularly controlled in larger boilers because of the long distance required to cover the cross-section of the boiler. Multiple points of injection are commonly used to follow the temperature changes caused by boiler load changes. In well-controlled SNCR systems, NH_3 emissions are in the range of 1 – 10 mg/Nm^3 (see 'Environmental performance and operational data' and the LCP BREF).

Environmental performance and operational data

For SNCR, a reduction of 30 % to 70 % is reported (ÅF Engineering file data, 2009). The result of the application of SNCR is very sensitive to variations in the operational conditions of the boiler and the urea/ammonia dosing needs to be controlled permanently. Continuous NO_X measurement should be carried out and experience shows reliable results.

The highest NO_X reduction possible in a bark boiler is about 30 – 50 % and is achieved by changing the combustion techniques and/or by applying a SNCR process. The NO_X emissions would then amount to 40 – 60 mg/MJ, equal to about 100 – 200 mg/Nm^3. Achieved emission data for SNCR applications in fluidised bed boilers can also be seen in Table 2.26.

Figure 2.25 shows the measured daily average emission data (2009) of the bubbling fluidised bed boiler from KRAFT SE 1. The biomass boiler has a rated thermal input of 132 MW_{th}. Fuels used are (expressed as energy input): 0.16 % light fuel oil; 2.07 % peat; 1.92 % waste from internal processing paper for recycling; 91.56 % bark, forest residuals and sawdust, and 4.29 % waste wood. The boiler is equipped with over fire air, SNCR for NO_X reduction and a bag filter with lime injection for the precoat layer for dust removal. Urea is injected in different sections and amounts into the boiler depending on the boiler load. The lime is only used as a precoat layer when new filters are introduced. Alkaline particles from the bark that is used as fuel have the same effect as injected lime. NO is measured on-line (additionally NO_2 is measured once a year; for 2009 the share of NO_2 in the total NO_X ($NO + NO_2$) was 7.4 %, i.e. 100 mg NO/Nm^3 equals 108 mg NO_X/Nm^3). HCl was <1 mg HCl/Nm^3 over the whole year. TOC emissions varied between <1 mg/Nm^3 and 5 mg/Nm^3 over the year.



Statistics	NO (mg/Nm^3)	CO (mg/Nm^3)	SO_2 (mg/Nm^3)	NH_3 (mg/Nm^3)	Dust (mg/Nm^3)
Yearly average	101.0	83.3	3.9	4.0	1.1
1st decile	78.2	36.1	1.1	1.7	0.6
Daily maximum	203.7	278.2	26.6	10.0	2.6
Standard deviation	23.1	40.8	2.9	1.9	0.4
95th percentile	147.5	139.1	8.0	7.6	1.9

Source: [166, KRAFT SE 1 mill 2010]

Figure 2.25: Daily average emission data for the bubbling fluidised bed boiler equipped with SNCR from the KRAFT SE 1 pulp mill

SNCR on bark boilers is sometimes difficult to control because relatively fast changes of load can happen in bark boilers. This results in variations in the NO_X reductions achieved by these techniques. Therefore, sometimes it is difficult to obtain a stable NO_X reduction with SNCR in boilers with rapidly changing operational conditions.

Cross-media effects

Injected urea or ammonia does not react completely but a small share of the reagent escapes in the flue-gas. The benefit of reduced NO should be weighed up against increased NH_3 emissions and the ammonia slip controlled and kept as low as possible (see 'Environmental performance and operational data' below). Depending on the stoichiometry the urea is added, and a slight increase of ammonia (slip) may be detected but measurements demonstrate the risk to be marginal.

A potential danger is unreacted ammonia combining with SO_3 to form ammonium bisulphate. Ammonium bisulphate will precipitate at air heater operating temperatures and can ultimately lead to air heater fouling and plugging. If not properly controlled, there is a certain risk that a SNCR process may produce nitrous oxide (N_2O), which contributes to the greenhouse effect. However, N_2O emissions are more likely to occur at coal-fired boilers than at biomass-fired ones (see the LCP BREF).

CO_2 emissions associated with the use of urea and ammonia for NO_X reduction are relatively small to negligible compared to the overall generation of CO_2 in pulp and paper production. However, reduction of NO_X emissions is required for health reasons and to protect the environment from adverse effects (such as eutrophication, acidification and ozone formation).

Technical considerations relevant to applicability
SNCR systems are widely applied in different plants of different sectors and are a cost-effective measure to reduce NO_X emissions to low levels. Installation in new plants is a common technique, and many existing fluidised bed reactors have been retrofitted with SNCR. The optimal reaction conditions might be difficult to obtain in some existing boilers, thus limiting the potential NO_X reduction to about 40 %.

Economics
The investment costs for installing the SNCR technique in boilers depending on the rated thermal input are reported as follows: 40 MW_{th}: EUR 0.7 million; 60 MW_{th}: EUR 0.8 million; 100 MW_{th}: EUR 1 million [229, Stubenvoll et al. 2007]. The investment includes injection equipment, pipes, pumps, tanks and rebuilding/adoption of the boiler. The operating costs mainly include the purchase of urea. About 1 – 2 kg urea is required per kg NO_X removed.

Another estimation (ÅF Engineering file data, 2009) assumes the investment for SNCR for boilers in the range of 50 – 100 MW_{th} to be around EUR 0.2 – 0.3 million. In addition the operational costs, mainly for ammonia, should be considered.

Driving force for implementation
IED (Directive 2010/75/EU on industrial emissions) and LCP Directive (Directive 2001/80/EC) as well as national legislation. NO_X has an acidifying potential and may increase eutrophication. In some sensitive lake areas in Europe a further reduction of NO_X emissions by secondary measures such as SNCR is therefore regarded as necessary. Another driving force might be to meet the air quality objective and whether or not the national critical NO_X loads according to the NEC Directive (Directive 2001/81/EC) are exceeded and additional measures for NO_X removal required. A fee for NO_X emissions in Sweden may also give an incentive for further NO_X reduction.

Example plants
A number of facilities apply the SNCR technique on bark boilers, incinerators for deinking sludge and various types of fluidised bed boilers in SE, AT and DE. In Sweden SNCR on bark boilers is an established technique.

Reference literature
[166, KRAFT SE 1 mill 2010], [189, Norrström 2010], [229, Stubenvoll et al. 2007], [SEPA-Report 4008], [SEPA-Report 4713-2, 1997].

2.9.7.3 Reduction of SO_2 and other gaseous pollutants

Description and achieved environmental benefits
Emissions of SO_2 and other gaseous pollutants depend on the fuels utilised, the design and operation of the furnace and the emission control techniques applied. The need for an abatement technique and, if so, which type is usually determined according to the pollution potential of the fuel and the combustion process. For instance, emissions of gaseous sulphur are low when only bark is burnt. In this case, no measure for SO_2 reduction will be applied.

If mixtures of fuels including fossil fuels with variable pollution potential are burnt, the following measures to prevent and/or reduce SO_2 emissions are available:

- Use of a low-sulphur fuel.
- Use of control techniques such as:
    - injection of lime or limestone for desulphurisation into the boiler (fluidised bed boilers);
    - spray dry scrubbers;
    - wet scrubbers (rarely used in the sector);
    - other sorbent injection processes (e.g. active carbon).

The most common and often the most economical way to control SO_2 in the pulp and paper industry is by using a low-sulphur fuel. Low-sulphur fuels contain from about 0.02 – 0.05 % weight sulphur (e.g. forest biomass, low-sulphur oil). Low-sulphur fuel oil with 0.05 % weight sulphur is available in many areas from several suppliers. The low-sulphur oil is also low in nitrogen (about 0.05 % by weight) and in ash (about 0.005 %) thus providing for low NO_X and particulate emissions [189, Norrström 2010].

In fluidised bed boilers, the boiler ash already contains some calcium that binds sulphur present in the fuel. Additional SO_2 reduction is obtained by lime injection into the boiler, by providing a calcium to sulphur ratio in the range of 1 – 3. A high calcium surplus provides up to 80 – 95 % sulphur removal to boiler ash, the higher removal being with CFB. Optimum sulphur capture takes place at around 850 °C burning temperature. The drawback of lime injection is the increased ash amount. In grate-fired boilers there is no efficient internal means of controlling SO_2 emissions.

External sulphur and SO_2 removal methods can also be applied. Either wet or semi-wet methods, which both apply alkaline washing liquid to bind sulphur, or dry methods are available. Dry methods are less efficient than the enhanced control of fluidised bed burning, lime injection into the boiler or the external wet methods. Wet scrubbers are however only used in very few cases.

Dry and semi-dry processes are mainly used to separate minor pollutant loads. They mostly serve as waste gas cleaning plants for a variety of pollutants such as SO_2, HCl, HF, TOC, heavy metals, PCDDs/PCDFs (the latter two groups of pollutants normally do not occur in significant concentrations in the pulp and paper sector). The facilities mainly consist of a dry reactor or spray absorber followed by an efficient particulate control device such as an ESP or fabric filter and some accessory facilities to manipulate adsorbents and separate dust.

The sorbent usually used is lime or calcium oxide. The lime slurry is sprayed into the flue-gas in a reactor vessel and water is evaporated by the heat of the flue-gas. The residence time (about 10 seconds) in the reactor is sufficient to allow for the SO_2 and other acid gases such as SO_3 and HCl to react with the hydrated lime to form a dry mixture of calcium sulphate/sulphite. Waste water treatment is not required in spray dry scrubbers because the water is completely evaporated in the spray dry absorber. The by-product also contains unreacted lime which may be recycled and mixed with fresh lime slurry to improve sorbent utilisation.

Spray dry scrubbers in commercial use have achieved a removal efficiency of up to 90 % with some suppliers claiming >95 % SO_2 removal efficiency is achievable. Apart from reducing the SO_2 content of the flue-gas, the scrubber system also removes other acidic components such as HCl and HF.

Active carbon can be added to the system and will remove mercury and organic compounds such as dioxins and furans. Active carbon may be required for co-incineration boilers.

Environmental performance and operational data

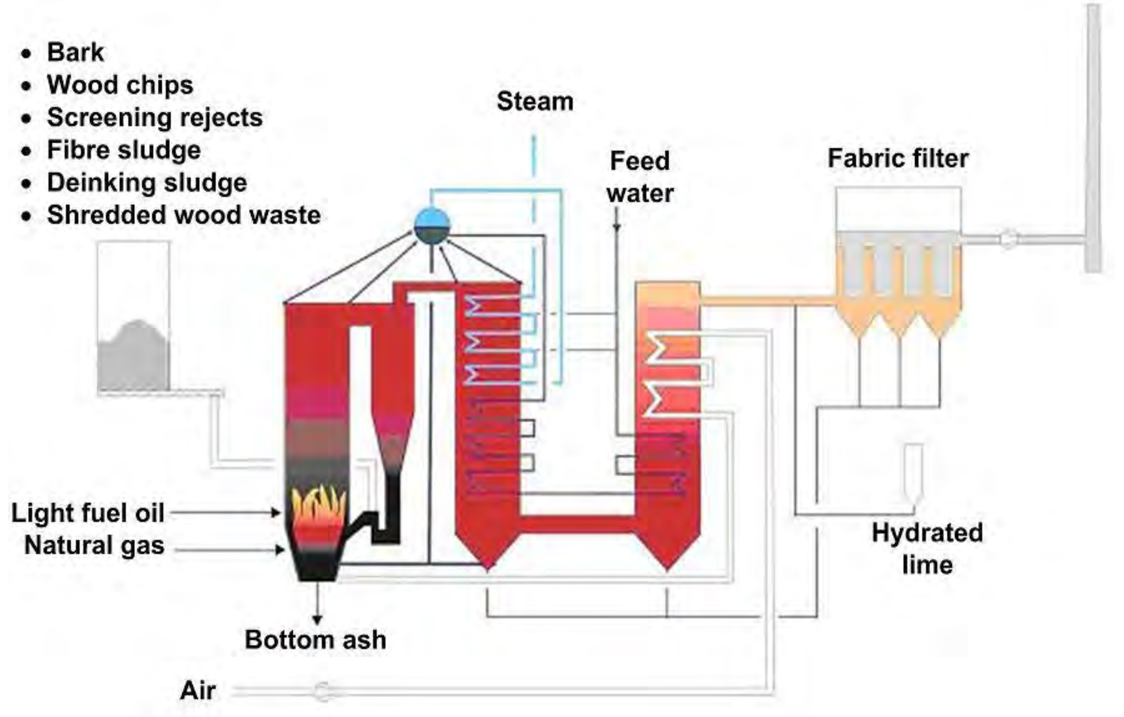
The removal efficiency of using low-sulphur fuels depends on the previously used fuel. The secondary measures give reduction efficiencies in the range of 50 % to over 90 % depending on the method applied and operational conditions (ÅF Engineering file data, 2009). Both the primary and the secondary measures have a proven track record in the pulp and paper industry. In Table 2.29 the achieved SO_2 emissions for different fuels and emission control techniques are shown. Bark-fired boilers achieve emission levels of below 20 mg SO_2/Nm^3 (at 6 % O_2), in installations where SO_2 emission levels are controlled by using dry adsorption plus an efficient particulate control device.

Table 2.29: SO_2 emission data for example fluidised bed boilers of paper mills using (a mix of) different fuels (AT, DE, FR, FI)

Rated thermal input (MW)	Year of commissioning	Fuel	Flue-gas cleaning system	SO_2 (mg/Nm^3)	O_2 (%)	Type of measurement
48	1994	Bark, sludge, paper, waste wood	Dry adsorption + FF	0 – 10 (DAV) 1 – 2 (MAV) 1.8 (YAV)	11	Continuous
4.8	2003	Waste wood, rejects, sludge	Dry adsorption + FF	2.5 – 3.9 (YAV)	11	Continuous
15	1984	Bark, sludge, coal, biogas	ESP + FF	2 – 6	11	Discontinuous
25	1982	Bark, sludge, biogas	ESP	1.7 – 13 (YAV)	11	Discontinuous
40	Not indicated	Bark	FF	1.8 (YAV)	11	Discontinuous
24	Not indicated	Bark	NA	5 (YAV)	6	Continuous

NB: NA = not available; DAV = daily average value; MAV = monthly average value; YAV = yearly average value.
Source: Questionnaires 2006 and 2008.

Figure 2.26 shows an example of an external circulating fluidised bed boiler that utilises a fuel mix for combustion; process residues from a mechanical pulp and paper mill (bark, fibre residues) and from a RCF-based paper mill (deinking sludge) and some external shredded wood waste are used as fuels.



Source: [229, Stubenvoll et al. 2007]

Figure 2.26: Flow diagram of the circulating fluidised bed boiler of UPM-Kymmene Austria

For the reduction of NO_X emissions, air staging and flue-gas recirculation are applied. For the removal of SO_2 and other acidic components such as HCl, a hydrated lime slurry is sprayed into the flue-gas and water is evaporated by the heat of the flue-gas. The spray dry scrubber is followed by a fabric filter to remove dust. If necessary, hydrated lime can also be dosed into the furnace. Table 2.30 compiles the achieved emission levels by the use of the emission control measures applied.

Table 2.30: Emission data of the UPM-Kymmene Austria

Pollutant	Emission concentration [mg/Nm^3, at 11 % O_2,] half-hourly values	Emission control measures applied
NO_X	165 (yearly average)	Air staging and flue-gas recirculation
SO_2	0 – 5	Spray dry scrubber with hydrated lime
HCl	0 – 2	Spray dry scrubber with hydrated lime
C_{org}	0 – 2	Circulating fluidised bed with proper control of oxygen supply, furnace temperature, mixing of fuel and combustion air and residence time
CO	3 – 10	Circulating fluidised bed with proper control of oxygen supply, furnace temperature, mixing of fuel and combustion air and residence time
Dust	0 – 5	Fabric filter

Source: [229, Stubenvoll et al. 2007]

Other boilers using other fuels will need only an efficient particulate control device such as an ESP or fabric filter if emissions of SO_2 and other acidic components do not exceed tolerable levels. This is the case if bark and fibre residues are the main fuels, natural or low-sulphur fossil fuel is used as a support fuel and some sludge from biological waste water treatment is added.

Cross-media effects

Apart from reducing the SO_2 content of the flue-gas, the scrubber systems also remove other acidic components such as HCl and HF. The secondary measures produce some solid waste (ash) which will have to be dealt with.

Technical considerations relevant to applicability

All techniques have been applied to boilers in the pulp and paper industry with good results. Apart from biomass which has a low-sulphur content, low-sulphur fuels are available although at additional costs.

Economics

The additional cost of purchasing low-sulphur oil compared to oil with a higher sulphur content varies but can be estimated to an average of about 20 %. An estimate of the investment required for a wet scrubber system is EUR 3 – 5 million for boilers in the range 50 – 100 MW_{th}. The additional cost of equipment for adding calcium carbonate or sorbent injection for new boilers is in the order of EUR 0.5 million [189, Norrström 2010].

Driving force for implementation

Both primary and secondary techniques reduce the emission of SO_2 and thus the acidifying potential of boilers. National and European regulations are also driving forces.

Example plants

Numerous installations in Europe and globally.

Reference literature

[189, Norrström 2010], [229, Stubenvoll et al. 2007].

2.9.8 Prevention, minimisation, recycling and treatment of process residues – minimising solid waste to landfill

Description

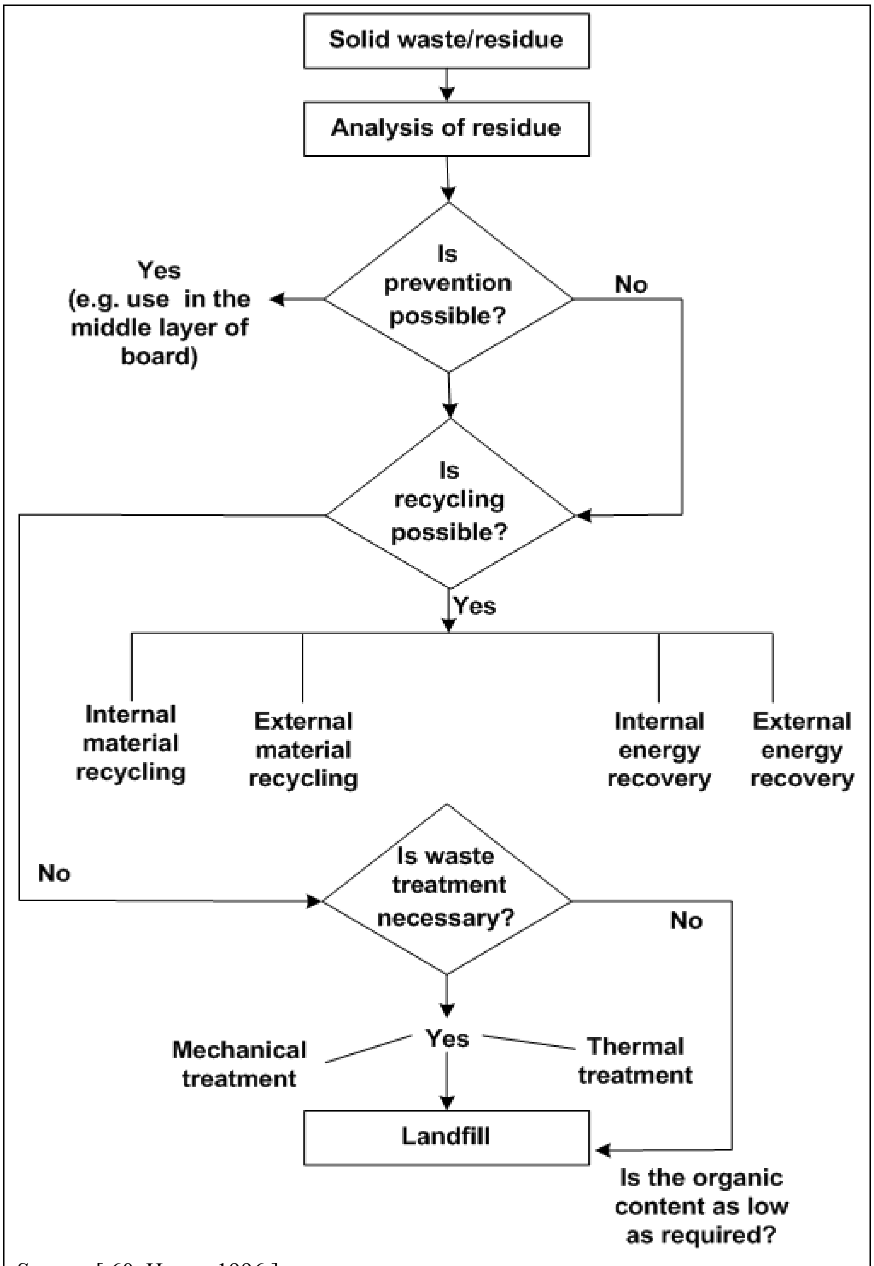
The majority of the process-related residues (see also Section 2.8) can be extensively reused, recycled and/or recovered. The waste hierarchy of the Directive on waste [205, WFD 98/EC 2008] provides guidance in planning for a minimum of residues to be disposed of.

Some of the waste/residues that result from the production process may be regarded as not being waste according to point (1) of Article 3 of the Waste Framework Directive (WFD) but as being a by-product if the conditions listed in Article 5 of the WFD [205, WFD 98/EC 2008] are met.

In order to prevent or minimise waste generation, all processes should be reviewed to identify areas where there is potential for improvement. Waste inventories allow for identifying and classifying the type, characteristics and amount of each waste fraction and show where waste originates. After collecting the waste/residue fractions at the points of origin, the waste/residue fractions are kept separate or are merged depending on the preferred options for reuse/recycling and further treatment and disposal.

Waste assessment and waste management schemes/concepts are useful tools to identify feasible options for prevention, preparing for reuse, recovery, recycling and the safe disposal of waste and residues. These waste management schemes may also contribute to a high resource utilisation and improved operating economy.

The decision-making tree for waste management of paper mills shown in Figure 2.27 outlines the general approach that the waste hierarchy follows and helps identify the possibilities for material recycling or energy recovery.



Source: [60, Hamm 1996]

Figure 2.27: Possible decision-making tree for waste management of paper mill waste

The residues of paper mills are mostly characterised by a relatively high amount of organic material. General possible management options to minimise waste and progressively eliminate landfilling include energy recovery in on-site incinerators or biomass power plants, energy and material recovery in other industries, such as cement, bricks, land construction, and in some cases also agricultural use providing that the composition fulfils the criteria for such use.

a) Prevention

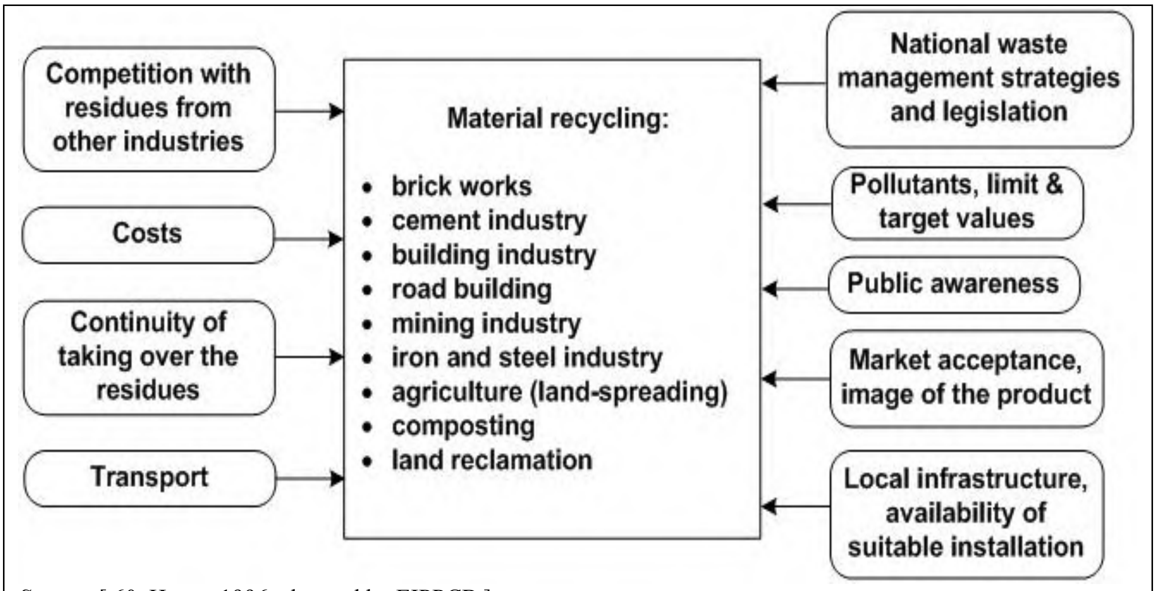
Prevention of waste primarily applies to the production process where suitable techniques should be used where possible. Examples are to minimise the amount of fibre rejects having to be removed from the process (see Section 5.3.3), suitable handling and recovery (see Section 7.3.5) to avoid having to discard coating chemicals, or using good quality make-up chemicals to reduce the amount of material having to be bled out from a kraft or sulphite recovery system.

In many cases it is not possible to prevent residues, e.g. bark and wood residues from wood handling, bale thread from pulp or recycled paper bales, biosludge or chemical sludge from effluent treatment. The amount of primary sludge, often mainly consisting of fibres and fibre fragments, can however be minimised by preventing fibre losses and fibre rejects from entering the effluent as much as possible (see Section 7.3.4).

Direct reuse is most commonly applied to process equipment in the pulp and paper industry. Equipment in good condition can be reused after reconditioning and/or repair and sometimes entire paper machines, boilers, etc. are dismantled, reconditioned and brought to use in new locations.

Paper trim, cuttings, off-grade pulp and other production paper residues are recycled making new products most common in the mill producing the residue or in another paper mill that uses recycled fibres.

b) Material recycling
An overview of the main treatment options for material recycling and the factors governing the treatment options choice are shown in Figure 2.28. Concerning transport, the principle of proximity reduces environmental impact and costs.



Source: [60, Hamm 1996, changed by EIPPCB]

Figure 2.28: Options for material recycling of paper mill residues and factors governing treatment options choice

Recycling possibilities depend on the papermaking process considered, the raw materials used and consequently the type and physico-chemical properties of the generated production residues. In some countries, composting of paper sludge or land spreading in agriculture is practised when the waste fractions are suitable for this option, e.g. composting only makes sense when the sludge is biodegradable (high amount of organic matter (fibres) compared to inorganic matter-like pigments), and spreading in agriculture depends on the amount of nutrients in the sludge and its pH-adjusting capability (pigments/fillers).

For spreading in agriculture the control of the potential pollutants is of crucial importance. Sludge from paper mills usually does not contain more pollutants than sludge from municipal treatment works and restricted application can have some positive effects on the soil ($CaCO_3$ is a neutralising agent for acidic soils, moisture retention by fibres and fines on dry soils, low nitrogen content). The possible benefits vary according to the soil type. The periods of land spreading are restricted to certain months of the year. It is therefore necessary to ensure sufficient storage capacity for the sludge.

The feasibility of land spreading is strongly dependent on the acceptance in Member States to apply sludge to agricultural land. In some Member States this practice is authorised applying specific legal requirements for its application and especially considering soil protection; in other Member States land spreading of paper sludge is banned. The major concerns are possible contamination of soils with low concentrations of heavy metals and organic micro-pollutants, and local opposition because of nuisance problems or image problems for agricultural products from land-spreading areas.

For composting, the quality demands of the compost are most important to get a marketable product. Composts made from organic waste mixed with different quantities of paper for recycling and residues from the paper industry fulfil these requirements such as degree of maturity or suitability for plant growth. Furthermore, parameters such as salt and organic substance content and the process-specific leachate emission are positively influenced. The concentration of harmful substances, especially those containing heavy metals, must be considered a limiting factor.

Another option for material recycling of sludge from paper mills is the utilisation in the cement and brick industry (to improve porosity) or as another building material. In the cement industry both the material and energy content of the paper residues can be recovered. For use in the cement industry, sludge from primary clarifiers (or mixed with excess sludge from biological treatment) that contains fibres, fines and inorganic compounds (e.g. fillers, coating pigments) is especially suitable. The sludge (about 50 % moisture content) is dried with waste heat from the pre-dryer of the cement kiln so that no additional thermal energy is needed to reduce the moisture of the sludge down to 10 – 15 %. Thus, when burning the dried sludge in the cement rotary kiln the calorific value of the organic substances is used and the ash from incineration of the sludge (mainly) remains in the product (cement). The inorganic substance of the ash of the incinerated sludge is also a compound of the cement clinker. If cement (or brick) manufacturing industries are close to the mill and are able to use the sludge it is a viable option. It has also been reported that fibrous sludges mixed with fly ash have been used for construction purposes, e.g. roads and storage fields.

The inorganic waste fractions (sand, stones, grit, ashes, lime) can often be used for construction like paving, roads, covering layers, etc. Using best available techniques, only a small fraction of the original amount of the residues have no economic use and will have to be brought to waste disposal. Before disposal, in some cases, the given waste fraction requires pretreatment in order to achieve the legal limits of the organic content of the material to be disposed of.

c) Energy recovery

The majority of the organic waste and residues from the production of pulp and paper (bark, wood residues, residual fibres) can be recovered and incinerated on site to generate heat. Energy recovery off site (e.g. dried bark) or in other industries such as the cement and bricks industry are other possible treatment options. Bark and wood residues from wood handling are a carbon-neutral fuel. In order to obtain a high level of energy efficiency the bark should be as dry as possible before incineration, which can be achieved by drying the bark (in hot climates in wet seasons). Wood ash from bark boilers contains nutrients from the forest. This ash can be suitable as a fertiliser if transportation and spreading can be efficiently arranged and if the ash is not contaminated, e.g. by high metals content.

Usually fluidised bed boilers or multiple-hearth furnaces are used to burn the organic residues from the paper industry. These installations achieve the legal requirements for incineration when appropriate air emission abatement is applied (see Section 2.9.7). For further information regarding incineration of rejects and sludge from processing paper for recycling the reader is referred to Section 6.3.14 of this document.

Co-incineration of paper industry waste and residues in other industries is practised in cement kilns, incinerators for municipal waste, blast furnaces (iron and steel industry) and cupola furnaces (foundries). For this option, waste and residues with a high calorific value are especially suitable to replace fossil fuel (e.g. coal, fuel oil). The paper mill residues are usually mixed with other fuels burnt in these installations. Before incineration, they have to be dewatered and sometimes also dried (e.g. for cement, and iron and steel industry). The homogeneity of secondary fuel and uniform and constant composition of the residues are also important.

The combustion behaviour of paper mill waste and residues such as deinking sludge, rejects from cleaning and screening, or sludge from waste water treatment is shown in Figure 2.29. It illustrates the connection between combustible/organic content, ash content and water content.

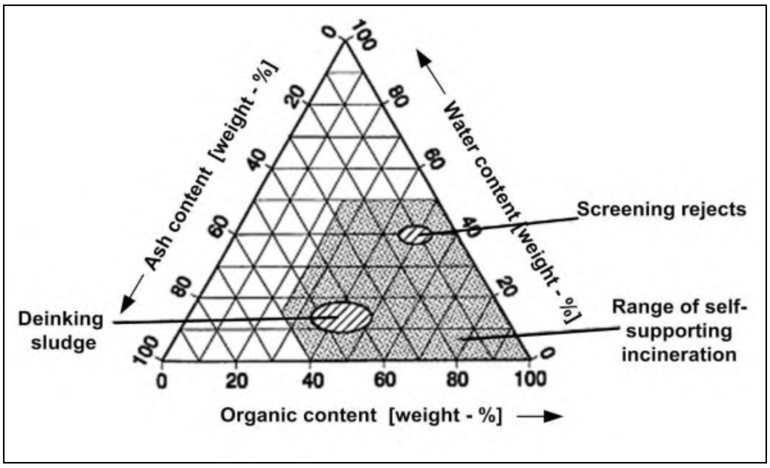


Figure 2.29: Fuel triangle for waste and residues from the paper industry (provided by IFP)

The area where dewatered deinking sludge and dewatered rejects from mechanical cleaning and screening are located is plotted hatched. It shows that self-supporting combustion where no additional fuels are necessary can be achieved for both: (i) rejects with relatively high calorific values and (ii) deinking sludge with a relatively high ash content. Sludge from effluent treatment can also be burnt but the net energy production is zero or negative if the dry solids (DS) content in the sludge is below about 40 % and/or the sludge contains a high amount of inorganic material. Under such conditions, the use of auxiliary fuel is necessary, preferably bark and other wood waste material. Burning reduces the volume of waste and the inorganic content remains as ash which is landfilled or further used in the building industry.

Sludge from chemical precipitation cannot be burnt alone without the use of auxiliary fuel due to the high content of inorganic matter and water. Still, such sludge is sometimes burnt to minimise the volume sent to landfill. Methods to recover precipitation chemicals are being explored but must still be considered under development. Sludge from flocculation with only synthetic organic polyelectrolytes is suitable for incineration.

The effect of co-incineration of paper mill waste and residues and sludge on air emissions depends on the composition of the burnt material. Co-incineration of fibre and paper sludge - especially those with high alkali content - in coal- or lignite-fired power plants has either no effect on air emissions or leads to a slight reduction of pollutants. Emissions of SO_2, HCl and HF are reduced by co-incineration of sludge with high alkali content (deinking sludge, fibre sludge containing coating pigments and filler). The content of heavy metals in fibre and paper sludge is also low compared to coal and lignite. Rejects from stock preparation of paper for recycling in mills manufacturing corrugating material have a higher chlorine content (1 – 3 % mass). Experience shows that co-incineration of rejects, e.g. in lignite-fired power plants, is feasible without increasing dioxin emissions (see Section 6.3.14).

Achieved environmental benefits

The measures protect the environment and human health by preventing or reducing the adverse effects of the generation and management of waste and by reducing the overall impacts of resource use and improving the efficiency of such use.

Environmental performance and operational data

Typical ranges for the amount of residue that is brought to solid waste disposal are compiled in Table 2.31 for different types of pulp and paper production. The table represents the situation in 2009 in Swedish mills which have taken ambitious measures to minimise residues.

Table 2.31: Typical ranges of solid residues (wet weight) sent to disposal from different types of pulp and paper production

Production type	Waste to disposal (kg/tonne (1))
Non-integrated kraft mill	0 – 50
Kraftliner	0.5 – 5
Integrated kraft paper	0 – 20
Integrated sulphite paper	0.5 – 5
Integrated board	0 – 15
Wood-containing printing paper	0 – 5
Non-integrated paper mill	0 – 10

(1) The specific amount of residue is calculated per tonne of total production, i.e. in the case of integrated manufacturing, on the total amount of pulp and paper produced on the site.

Source: The table is based on statistics for the Swedish industry compiled by the Swedish Forest Industry Federation.

The table shows that, for all types of production, very low amounts of residues being sent to disposal can be achieved.

The ranges also indicate that mills producing kraft pulp tend to have higher amounts of residues being sent to disposal than those based on sulphite or mechanical pulp. This is because of the necessary purge of impurities from the recovery area of kraft mills (green liquor sludge, grits and other inorganic material). Non-integrated production of paper normally results in very low amounts of solid residues being sent to disposal. Further examples are presented in the process-specific Chapters 3 to 7.

It may not be possible for mills to always reach the low amounts of residues sent to disposal indicated by the lower end of the ranges shown in the Table 2.31. Important prerequisites are well-functioning systems to minimise process residues and sorting residues according to the intended further treatment. Another prerequisite is that there must be a use for the residue either in the mill or externally.

Residues which are typically difficult to eliminate and find uses for include green liquor sludge from the kraft recovery process, ash from boilers, and the mix of sand, stones, bark and wood fragments that originate from the wood handling. In many cases, such materials can be used as construction material in finalising landfills or in road construction. The mix of sand, bark and wood fragments may be used in soil improvement after adding nutrients for example. Trials have been under way for some time to use ash to recycle nutrients and trace metals to forests. There are also companies specialised in handling and upgrading such material for more diverse uses.

Mills reporting zero or almost no residues sent to disposal have been able to develop these end-users, at least for periods of time. Since the demand from the end-users may vary, this may not be possible at all times and thus it is important for almost all types of pulp and paper mills to have a safe and sufficient disposal site available.

Table 2.32 shows two examples of mills that have been able to reduce the amount of residues sent to disposal to low levels. Mill A is a non-integrated paper mill and Mill B is an integrated kraft mill producing printing and writing papers and market pulp.

Table 2.32: Two examples of mills with low levels of residues sent to final disposal

Residue types and handling	Residue/Handling	Mill A (kg/tonne) (1)	Mill B (kg/tonne) (1)
Residue type	Paper industry-specific	25	306
	General	4	2
	Hazardous	0.8	0.5
	Total	30	309
Handling	Material recycling	28	31
	Energy recovery	1	255
	Other recycling/safe disposal	0.8	0.5
	To disposal	0.3	22

(1) The amount of residue is given as wet weight. The specific amount of residue is calculated per tonne of total production, i.e. in the case of integrated manufacturing (mill B), on the total amount of pulp and paper produced on the site. The examples, Mill A and Mill B, have been taken from statistics for the Swedish industry compiled by the Swedish Forest Industry Federation.

Industry-specific residue is bark, wood residue, ash, green liquor sludge, etc. and is used for material recycling or energy recovery. In the case of the kraft pulp and paper mill, virtually all of the bark and wood residues are used in the bark boiler. The hazardous waste is in both cases handled by certified organisations ('other recycling') and developed for other uses or safe disposal. As a result of the waste management applied, the amount of residue sent to disposal from the paper mill is close to zero. The residue sent to disposal from the kraft mill is mainly green liquor sludge which might be used as a covering layer on a solid waste disposal.

Cross-media effects
Reduced quantity of residues and consequently raw material consumption and associated costs. Waste is used and its pollution potential reduced. Furthermore, the process efficiency and process economy are improved.

Technical considerations relevant to applicability
Applicable to all mills. Potential for recycling may depend on the papermaking process and the raw materials used (depending on which paper product is produced). For example, the option of composting paper sludge depends on the biodegradation of the sludge (the amount of organic matter-like fibre versus inorganic matter-like pigments). Spreading in agriculture depends on the amount of nutrients in the sludge (raw materials) and its pH-adjusting capability (pigments/fillers).

Economics
The application of the waste hierarchy provides for use of resources with high economic efficiency, particularly to prevent the formation of residues by applying cleaner technologies.

Driving force for implementation
Prevention of or preparation for reuse, recycling and recovery of process residues have economic benefits as they allow better use of resources and higher economic efficiency. The recovery of energy by incineration of residual material is vital to increase value and minimise final volumes sent to disposal. EU and national waste legislation are other driving forces. There

are two EU Directives of prime importance for the handling of residues from the pulp and paper industry: the Waste Framework Directive and the Waste Incineration Directive.

The Waste Framework Directive 2008/98/EC [205, WFD 98/EC 2008] provides definitions, encourages waste management plans and promotes the waste hierarchy which shall apply in order of priority in waste prevention and waste management: prevention, preparing for reuse, recycling, other recovery, e.g. energy recovery, and finally disposal. When this course of action is fully applied, any residual waste should be recycled, recovered as a raw material, a source of energy or, as a last possibility, should be safely disposed of.

The Waste Incineration Directive [203, Directive 2000/76/EC 2000] regulates the permit requirements for incineration and co-incineration plants, and sets emission limits and monitoring requirements for certain pollutants released to air or to water. The Directive also applies to 'co-incineration' plants (facilities whose main purpose is to produce energy or material products and which use waste as a regular or additional fuel, this waste being thermally treated for the purpose of disposal). According to Article 2 (2) of the Directive, combustion plants treating only 'fibrous vegetable waste from virgin pulp production and from production of paper from pulp' or 'wood waste' are not covered. For the description of best available techniques for waste incineration, the reader is also referred to the Reference Document on Best Available Techniques for Waste Incineration [273, COM 2006].

Example plants
Many pulp and paper mills in Europe have implemented waste management plans or integrated waste management concepts. All mills try to minimise the amount of solid waste to be disposed of.

Reference literature
[60, Hamm 1996], [139, ASPAPEL 2008], [203, Directive 2000/76/EC 2000], [205, WFD 98/EC 2008], [273, COM 2006], [Swedish Forest Industry Federation, 2008].

2.9.9 Reduction of emissions from the use of chelating agents in peroxide-based bleaching technologies

Description
In chemical or mechanical pulp mills, complexing agents are used to protect oxygen-based bleaching chemicals against catalytic degradation prior to or during the bleaching stages. The complexing agents are used in neutral, slightly acidic or slightly alkaline (depending on the formulation and the process requirements) washing and pulp bleaching steps to eliminate transition metals (mainly Mn and Fe, and Cu). The most widely used chelating agents are EDTA (initialism for the chemical compound ethylenediaminetetraacetic acid) and DTPA, a polyamino carboxylic acid, in different product formulations.

- DTPA and EDTA are powerful chelants, but are poorly biodegradable and are emitted to receiving water bodies at the end of the process. Even though EDTA and DTPA are considered stable molecules, some studies suggest that they are degraded substantially in the harsh conditions of bleaching [208, Langi et al. 2007]. The bleaching agents ozone, chlorine dioxide and peracetic acid may degrade to a certain extent both EDTA and DTPA that are introduced into the bleaching of chemical pulp. Others observed a significant reduction of EDTA in biological waste water treatment plants under slightly alkaline conditions (pH between 7 and 8) [206, Akso Nobel 2007]. This removal is either the result of degradation or transformation of EDTA into unknown degradation products. By contrast, other studies [209, Aschacher et al. 2007] and mill operators found that the used EDTA can be almost completely detected in the effluents of their biological waste water treatment (less than 10 % biodegradation). DTPA is more degradable than EDTA in an aquatic environment, but it is probable that DTPA decomposes to EDTA during the bleaching process or in the waste water treatment. [Sillanpää M, 1997], [Remberger M, 2001].

The following stepwise approach can be implemented in order to reduce the emissions from the use of chelating agents efficiently:

1. Carrying out a simplified 'mass balance' that provides information about the fate of complexing agents in the process and the biological waste water treatment plant (use, retention or degradation in bleaching and washing steps, elimination or degradation during waste water treatment). Thus, the quantity of chelates that is released to the environment is determined. From an environmental point of view, the quality and bonding form of the discharged complexes may be distinguished.

2. Periodic measurements by qualified/certified laboratories and documentation of the chelating agents in the effluents.

3. Investigation and documentation of the possibilities for:
(i) reducing the use of not readily biodegradable chelating agents in the process by for example optimising pH, dosing and retention time, recovery and retention of the chelating agents in the process);
(ii) recovery and retention of the chemicals in the process;
(iii) their reduction in the waste water treatment system (an extension of residence times, e.g. sludge age > 28 d and a slightly alkaline pH seem to enhance the biodegradation of chelating agents in some waste water treatment plants). This also includes the follow-up of the development of biodegradable or eliminable substitutes that match bleaching requirements.

4. Preferential usage of biodegradable or eliminable products and phasing out of non-biodegradable products as much as possible taking into account their technical and economic suitability and viability. Alternative chelating agents should reach biodegradation levels of above 70 – 80 % according to the biodegradation test standard EN ISO 7827 or similar methods.

A stepwise introduction of these new chemical additives is normally most promising. To achieve the effectiveness of new complexing agents, they need to be first tested, the correct formulations determined and the operational conditions of the bleaching process adapted (pH, temperatures, other chemicals used, dosing points).

Achieved environmental benefits

This technique should result in a reduction in emissions of the poorly biodegradable EDTA/DTPA by reducing their use. This should reduce the concentration of chelating agents in river waters downstream of mills. EDTA/DTPA have the ability to remobilise heavy metals (lead, mercury, cadmium) from natural water sediments, which may accumulate in water bodies or reach the drinking water supply via waste water input.

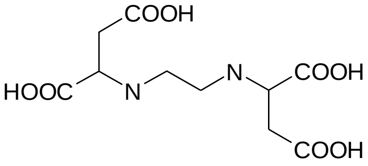
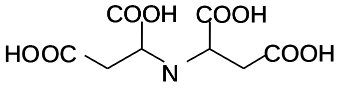
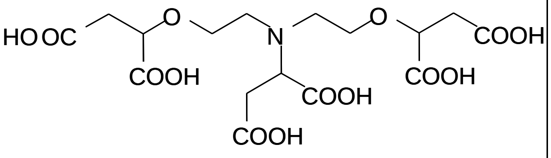
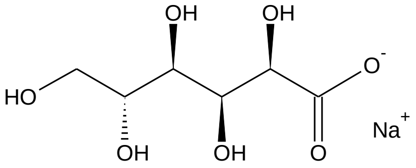
Environmental performance and operational data

The use of chelating agents is only relevant for peroxide-based bleaching technologies. The quantity of chelating agents needed depends on a number of factors: the quality and heavy metal content of the wood logs/chips used, the final brightness to be achieved, and for chemical pulp mills: the quality of the base used (impurities). There are significant differences with regard to the heavy metal content of the wood and the cooking base used (in the case of sulphite pulping, the make-up magnesium oxide). Mills that use wood with higher alkaline earth metal content have failed to reach the desired qualities of the pulp after bleaching without using DTPA or EDTA. A few others could operate the peroxide bleaching stages without using a chelating agent. Also, the seasons may have an influence on the need for chelating agents in bleaching. In the summer, stored wood achieves less brightness with the same treatment. And wood that is stored over longer time periods loses brightness.

Some new complexing agents reach biodegradation levels above 70 % or 80 % according to the biodegradation test standard EN ISO 7827 [262, ISO 7827 1994]. Some chemical suppliers report that biodegradable chelant systems have been developed that match the performance of the traditional chelants in the chemical pulping processes. For example, the sodium salt of iminodi-succinic acid (IDS) is a readily biodegradable chelating agent [223, H. Hyvönen et al. 2003]. The biodegradability of N-bis-dicarboxyethoxy-ethyl aspartic acid (AES) is reported to be 20 – 70 %, depending on the sludge used [222, S. Metsärinne et al. 2007]. This novel complexing agent (AES) is not readily biodegradable but shows slight biodegradation.

The following substances were positively tested, i.e. meet 80 % biodegradability, by Holzforschung Austria. With regard to functionality, the substances shown in Table 2.33 nearly meet the performance of EDTA/DTPA, but in some cases not completely.

Table 2.33: Biodegradable chelating agents with nearly full functionality

Name of the active ingredient	Chemical compound	Chemical structure
EDDS	N,N'-ethylene-di-amine-di-succinic acid	
IDS	Iminodi-succinic acid (e.g. as sodium salt)	
AES	N-bis-dicarboxyethoxy-ethyl N-hydroxyethyl aspartic acid	
Sodium gluconate (large amounts are needed; cannot be used exclusively)	NA	
NB: NA = not available Source: [224, Aschacher 2009]		

It is difficult to assess the effectiveness of biodegradable chelating agents in full-scale trials as most of the results are treated confidentially. Research institutes like Holzforschung Austria report that in full-scale trials there is no clear evidence yet that the alternative bleaching additives match the performance of the traditional chelants. The results obtained with the most promising products do not yet completely equal the technological performance of DTPA or EDTA. This is especially worth remembering when the highest brightness levels have to be achieved (where a brightness loss of 1 percentage point is already unacceptable for the mills). Therefore, research is continuing with modifications of complexing agents and variations of usage [209, Aschacher et al. 2007]. By contrast, others report that full-scale mill trial results and experience from regular customers show that biodegradable chelating agents may replace DTPA/EDTA without the loss of process efficiency [221, Sankari 2009].

Distinguishing between the major pulp grades, some operational experience regarding reduced emissions of chelating agents are summarised below.

I. **Kraft pulping:**

There are cases where the biological waste water treatment (see Section 3.3.13) leads to a reduction of approximately 90 % of the EDTA [159, Steube et al. 2005]. For example, at the Stendal pulp mill, DE, the inflow concentration of 34 – 63 mg EDTA/l is reduced to effluent concentrations between 0.4 and 7 mg EDTA/l (average 2008: 1.8 mg/l; measured 12 times a year in 24-hour composite samples; method of analysis: DIN 38413-3). In the inflow on average 50 mg EDTA/l (24-hour mixed sample) was measured [160, LVSA 2009].

No further evidence from real mills has been provided, be they a single case or at other kraft pulp mills.

II. **Sulphite pulping:**

In nearly all mills in the bleach plant, DTPA is used (1 – 2 kg DTPA/ADt). Depending on the closure of the bleach plant 10 – 90 % of this ends up in the waste water. Normally, no significant biodegradation of DTPA in the waste water treatment plant can be expected. So, pulp mills that do not possess a MgO-based first bleaching step that allows parts of the washing liquids to be recirculated back to the recovery island (see Section 4.3.8) will virtually release 90 – 100 % of the used DTPA or 1 – 2 kg DTPA/ADt.

A German pulp mill with the bleaching sequence P_{MgO}-A-P_{NaOH} recirculates 80 – 90 % of the used DTPA to the chemical recovery plant and thus prevents the release of DTPA to the water body in an effective way. Manufacturing 500 – 600 tonnes of pulp/day, the mill uses around 1 000 kg DTPA/day, of which only 50 – 60 kg DTPA/day are actually released to the environment.

The effectiveness of the substitutes for EDTA or DTPA seems to depend on a number of factors such as the type of pulping and bleaching, the wood species used and their metal content, the alkaline earth and heavy metal content (impurities) of the bleaching base (e.g. make-up MgO for sulphite pulp mills) and the final objectives for brightness or dirt spots. One German pulp mill uses a mixture of DTPA and DTMPA, a phosphonate that is also not readily biodegradable but more adsorbable to the biosludge. As DTMPA accumulates on the biomass of the waste water treatment plant, it can be eliminated from the waste water and less chelating agents are released to the water body [216, Patt 2009].

The sulphite pulp mill Nordic Paper, SE, uses 0.7 – 1.0 kg EDTA/ADt, the majority of which ends up in the waste water treatment plant. By using a three-step bioreactor process with MBBR technology 40 % degradation of EDTA is observed.

III. **Groundwood**

Several mill trials from Holzforschung Austria in oxidative bleaching of groundwood pulp have clearly shown that an elimination of DTPA leads to a brightness drop of 5 – 6 points in ISO brightness. Trials with the substitution of DTPA for other chemicals (sold by the suppliers as biodegradable) have shown that a reduction (e.g. from 0.3 % to 0.05 %) of DTPA is possible though with brightness losses of 1 – 2 points. Phosphonate-based substitutes showed results similar to DTPA in some cases. If the alternative contains phosphonates, it may create operational problems in the clarification plant. There are mills that have not observed these problems while applying phosphonates as eliminable alternative chelating agents achieving complexing properties close to DTPA [161, C.Hoelger et al. 2008]. A pulp and paper mill in Germany has considerably reduced the amount of DTPA used in its groundwood line from 2 kg DTPA/t down to 0.4 kg DTPA/tonne of pulp (*source:* German EPA, 2010).

IV. **Deinked pulp from processing paper for recycling**
In most cases, chelating agents are not required to produce bleached deinked grades based on paper for recycling. The stabilisation of the peroxide required for oxidative bleaching occurs mainly through natural or modified types of sodium silicate (Na/K silicates). Due to the high calcium content in the process waters, the effect of EDTA or DTPA is greatly reduced so their use is normally not effective. As an exception, DTPA is used as a chelating agent in the production of very high-quality paper such as SC-B-qualities based on 100 % deinked pulp (DIP) or SC-A-quality with 25 % DIP use (example mill in Germany). An additional washing stage is established before the peroxide stage. The DTPA amounts used in these cases are comparatively small.

Cross-media effects
If biodegradable complexing agents are used, no negative cross-media effects are to be expected (as long as the alternatives match the performance of the traditional chelants).

When the major feature of the substitutes is the better adsorption capacity (e.g. some phosphonates), the metal complexes are not biologically degraded. However, they are not released with the discharged waste water but adsorbed into the bleached fibres or the biosludge, which is burnt in most cases.

Studies that were carried out at Holzforschung Austria (HFA) on the elimination of phosphonates (tests according to EN ISO 7827) showed that the phosphonates are not biodegradable; they also showed that phosphonates do not adsorb to biosludge to the extent communicated elsewhere; and that they are only detectable with great effort and may increase the phosphorus content of the waste water.

However, for a full-scale application of phosphonate-based chelating agents e.g. in the paper mill Albbruck (DE), a removal rate of approximately 90 % of the phosphonates after passing the biological treatment plant has been shown [161, C.Hoelger et al. 2008].

Technical considerations relevant to applicability
The stepwise approach for reducing the emissions from the use of chelating agents is applicable to new and existing mills. Depending on the substitutes used, minor or more significant process adjustments may be required to guarantee the performance of the complexing agents. For example, some adjustment to the process usually in terms of altering the pH or dosing point of the chelant has been found to be necessary to optimise the process for the new blend.

Often the biodegradable alternatives to EDTA/DTPA are highly specific, i.e. different chelating agents have to be used for different pulping and bleaching processes. There is no one-size-fits-all chelating agent like EDTA/DTPA. Before application, there is a need for process adjustments and for the identification of the most appropriate bleaching additive substances.

Economics
The mass balance of the use and fate of the chelating agents used (EDTA or DTPA) involves calculating costs for the sampling, chemical analysis and the drafting of a report. If more biodegradable substitutes are investigated on a full scale, normally chemical suppliers take care of sampling, analysis, etc. in the test phase, i.e. it should not cause any extra costs for the pulp mill. The economics of the mass balance calculation and tests of conventional products or substitutes does not differ as the same procedure is needed for both products.

When an operator decides to use a more readily biodegradable substitute, a dosage pump and pipes are needed. However, when the biodegradable chelating agents are used on a regular basis, the mill uses the same dosing pumps/tanks and pipes as with DTPA/EDTA, so no extra costs should occur. It is unlikely that significant modifications to the plant will be required, so there is very little investment required for the substitution of the bleaching additives.

The main cost implication is in the price of the biodegradable alternative chelant. The unit price per 100 % active ingredient was in 2010 higher for biodegradable or eliminable substitutes than for DTPA or EDTA. One chemical supplier reported that the unit prices of biodegradable substitutes are ~10 – 15 % higher than the unit price of DTPA. In contrast, a paper mill (SCA Laakirchen, AT) reported that the bleaching costs would rise considerably (up to 200 %) if a tested alternative chelating agent was used exclusively [162, U.Hamm 2009].

Driving force for implementation

The Commission Recommendation on risk measures for substances such as EDTA [260, COM Recommendation 2006/283/EC 2006] proposes in its Section 6 a number of measures for the reduction of EDTA emissions, which are also applicable to other poorly biodegradable chelants like DTPA:

- to establish Environmental Quality Standards (EQS) and national pollution reduction measures;
- to consider the usage of EDTA in permits issued under Directive 2010/75/EU;
- to monitor the implementation of BAT regarding EDTA and report any important developments to the Commission in the framework of the exchange of information on BAT.

Also, in the Commission Communication on the results of the risk evaluation and the risk reduction strategies for different substances, one of which is EDTA [259, COM Communication 2006/C90/04 2006], it is recommended that the updated BREF develop guidance on BAT in terms of EDTA use. Directive 2008/105/EC of the European Parliament and the Council of 16 December 2008 on environmental quality standards in the field of water policy [263, Directive 208/105/EC 2008] (Daughter Directive to Article 16 of the EU Water Framework Directive) also includes EDTA in its Annex III, 'Substances subject to review for possible identification as priority substances or priority hazardous substances'.

Some national regulations and regional competent authorities ask pulp mills within the area of their responsibility to reduce emissions of EDTA or DTPA to the receiving waters (e.g. in Austria or Germany), assessing the availability of substitutes case by case. If recipient rivers or lakes are used to provide drinking water, environmental officials set increasingly strict limits on permissible EDTA and DTPA concentrations.

Example plants

A few sulphite pulp mills use no chelating agents for metal management, although most of them do. Others are seeking to reduce the release of chelating agents from the mill to receiving water bodies. According to confidential information, a mechanical pulp mill in Central Europe has used a biodegradable chelating agent in their process successfully since January 2009. A RCF mill in Central Europe uses a biodegradable chelating agent regularly.

Due to the confidentiality of the full-scale experiences, it is not possible to present more detailed information.

Reference literature

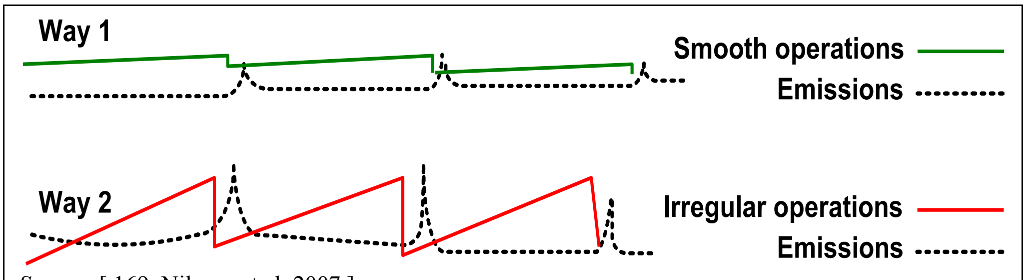
[161, C.Hoelger et al. 2008], [162, U.Hamm 2009], [206, Akso Nobel 2007], [208, Langi et al. 2007], [209, Aschacher et al. 2007], [216, Patt 2009], [221, Sankari 2009], [222, S. Metsärinne et al. 2007], [223, H. Hyvönen et al. 2003], [224, Aschacher 2009], [259, COM Communication 2006/C90/04 2006], [260, COM Recommendation 2006/283/EC 2006], [263, Directive 2008/105/EC 2008], [264, WFD 2000/60/EC 2000].

2.9.10 Ensuring smooth running and minimising accidental releases

Description and achieved environmental benefits

In many cases, ensuring smooth running and minimising accidental releases has a significant impact on the achieved performance of the 'techniques to consider in the determination of BAT' discussed in Chapters 3 to 7. A smooth running of processes improves material efficiency, cuts pollution, decreases energy consumption and reduces costs [169, Nilsson et al. 2007]. On the other hand, repetitive production breaks, technical shutdowns and incidental releases increase emissions and cause wasteful processes. The smooth and safe running of machines and processes guarantees low emission levels without further end-of-pipe investments. However, there are periods in the pulp and paper business when the utilisation rates of pulp and paper mills are rather low – this can be the case for market reasons or due to labour market unrest or other disturbances beyond the control of the mill. This increases specific consumption and emission figures (expressed as kg pollutant per tonne of pulp or paper). Thus, from an environmental point of view, it is best to run continuous series of production without interruptions. However, different market conditions demand changes in furnish content and products. This means that there is no best practice on what to produce but only on how to produce grade changes well using best practices and measures.

Figure 2.30 shows the correlations between smooth and bumpy running and emissions. Smooth running avoids production peaks/valleys and starts/stops and extraordinary high/low loads resulting in reduced emissions and decreased energy consumption. This also affects product quality.



Source: [169, Nilsson et al. 2007]

Figure 2.30: Emissions levels according to how the mill is operated

Aiming at smooth running is to use the available information to be aware of disturbing conditions and to act in time if necessary. The following list describes measures for reducing accidental releases, which should be considered on a case-by-case basis.

- Modern information, automation and computer-based control systems with on-line measurements especially in the monitoring of atmospheric emissions reduces the need for separate emission control and makes statistical follow-up possible.
- Continuous measurements and monitoring of process parameters demonstrating the process stability for both manufacturing processes and emission control techniques, thus providing the necessary data to operate close to the optimum process parameters and trying to stabilise critical process parameters.
- Determining N and P levels over long-term intervals does not provide the operator with the necessary information for action in due time in the event of inadequate dosage of nutrients or malfunctioning of the biological treatment plant. As part of the self-monitoring, on-line measurement of nitrogen and phosphorus for controlling the dosage of the nutrients can be used. The on-line analysis of samples allows for continuous assessment of the nutrient situation in the treatment plant and, in the case of poor performance of the treatment plant or inadequate dosage of nutrients, for taking prompt action. In many cases, using on-line measurements to get additional information on the

levels and variation of nutrients completes the self-monitoring activities that are based on laboratory analysis.
- Optimum volumes of tanks and basins to manage exceptional releases.
- Optimum level of production in relation to the maximum capacity. Full capacity production rate exposes the plant to process disturbances and uncertainty in emission control.
- Shared information facilitates the ability to take the right actions in a timely manner. Communication requires commitment at all levels and regular meetings between all departments. Also process workers should be involved.
- Active reporting of exceptional conditions. All environmental information should be transmitted to the control room of the mill using the mill information system. The waste water treatment plant should be controlled from the mill control room, not separately.
- Careful planning of shutdowns and related actions – preparing for disturbances.

Abatement techniques for emissions to air and water can be designed and operated in such a way that unexpected peak loads and accidental releases can be considerably reduced (see also Section 10.2.2).

Environmental performance and operational data
No information provided.

Cross-media effects
The technique has positive effects, preventing pollution of all media.

Technical considerations relevant to applicability
Measures/techniques can be applied to new and existing mills.

Economics
No information provided.

Driving force for implementation
Smooth running of processes and less incidental releases improves material efficiency, cuts pollution (waste, emissions) and also costs in most cases. Smooth and safe running of machines and processes guarantees lower emission levels.

Example plants
Many pulp and paper mills in Europe have implemented measures to ensure the smooth running of processes and emission control techniques for emissions to water and air, thus reducing incidental releases to the environment.

Reference literature
[169, Nilsson et al. 2007].

2.9.11 Reduction of pollution load of waste water

2.9.11.1 Primary waste water treatment

Description
Primary waste water treatment consists of physico-chemical treatment such as equalisation, neutralisation or sedimentation.

Primary treatment aims at avoiding peaks in the pollution load, flow or temperature of the influent of a waste water treatment plant, thus protecting the subsequent biological treatment, and at initially reducing the pollution load allowing for a more efficient biological treatment with less sludge generation. Primary treatment in pulp and paper mills may comprise equalisation, neutralisation and sedimentation, flotation, filtration etc. In equalisation (e.g.

equalising basins or large buffer tanks) the inflow is collected, mixed and intermediately stored and thus peaks are levelled. Suspended solids (fibres, bark particles, and organic material such as fillers) are removed by mechanical means (sedimentation, flotation and filtration). To enhance clarification and separation of some suspended solids, colloids and certain dissolved coagulants or flocculants can be added.

Achieved environmental benefits
Reduction of pollution load, especially TSS.

Environmental performance and operational data
Normally primary treatment is not applied as a stand-alone treatment, but rather as a pretreatment. Therefore environmental performance and operational data are included in the sector-specific information provided on secondary treatment in Sections 3 to 7.

Cross-media effects
Primary waste water treatment requires energy for pumping etc. and generates sludge.

Technical considerations relevant to applicability
Applicable to new and existing plants.

Information on cross-media effects, applicability, economics, driving force for implementation, example plants and reference literature for this technique is given in the sector-specific Sections 6.3.6 and 7.3.10.

2.9.11.2 Secondary waste water treatment

2.9.11.2.1 Aerobic biological waste water treatment

Description
In aerobic biological waste water treatment, the biologically degradable load is reduced in the presence of oxygen by digestion by microorganisms, generating biomass, carbon dioxide and water.

After primary treatment, usually done to protect the biological treatment plant from excessive loads and pollutant peaks, the biodegradable dissolved and colloidal material in the waste water is transformed by microorganisms in the presence of air into solid cell substance (biomass) and into carbon dioxide and water. After biodegradation, biomass and water are separated normally using sedimentation tanks (clarification may be enhanced by flocculation etc.). Different process designs are available, which can be classified in two main categories: activated sludge systems (such as one- or two-stage activated sludge plants or aerated lagoons) and biofilm systems (such as moving bed biofilm reactors (MBBR) or membrane bioreactors (MBR)). A combination of biofilm and activated sludge systems is also used.

a) *Activated sludge process*
The activated sludge plant consists of two main units, the aeration basin and the secondary clarifier (sedimentation basin). In the aeration basin, the effluent is treated with a culture of microorganisms (the activated sludge), which are present in a high concentration. The sludge is separated from the water in the clarifier. Most of the sludge is recycled to the aeration basin, which is necessary for keeping the sludge concentration high. A small part of the sludge, corresponding to the net growth, is removed from the system as the excess sludge.

Oxygen mixing is provided to the aeration basin by mechanical aeration equipment. Various types of aerators are in use, such as surface aerators, submerged turbine aerators, fine-bubble aerators and jet aerators. The last three types require compressed air from blowers or compressors. A large number of process and plant designs exist for the activated sludge process.

These alternatives may vary in terms of the design of the aeration basin, the number of stages, the clarifier, and the aeration equipment, as well as the sludge recycling.

b) *Aerated lagoon*

An aerated lagoon has a large volume with residence times for the effluent of 3 – 20 days. The microorganisms grow in suspension in the bulk of liquid, reaching in the lagoon a relatively low solids concentration, 100 – 300 mg/l. The growth of microbes requires oxygen, which is provided almost exclusively by mechanical aeration equipment. Surface turbine aerators are the most common aeration units, but in deep lagoons bottom aerators with self-induced or compressed air feeds are also used. Aeration equipment also provides the mixing required to keep solids in suspension and enhance microbial action. Aerated lagoons require a large area and volume and are constructed as earth basins and can be constructed with or without a settling zone. In the first case, the end of the lagoon is left without aeration and mixing, thus allowing solids to settle. In the latter case, this settling is carried out in a separate pond. The biological process does not involve the recirculation of biomass from the beginning to the end of the basin. The settled sludge is seldom removed, once every 1 – 10 years.

The use of aerated lagoons has become less common for many reasons: its lower removal efficiency of effluent contaminants in comparison with the activated sludge process, the need for a large land area and basin volume and the high energy requirement for and poor energy efficiency in aeration and mixing. More ambitious effluent requirements contributed to many of the existing lagoons in the industry closing down or being retrofitted to high efficiency activated sludge processes or supplementary effluent treatment basins.

c) *Moving bed biofilm reactor*

The basis of the moving bed biofilm reactor (MBBR) process is the biofilm carrier elements that are made from polyethylene. The elements provide a large protected surface area for the biofilm and optimal conditions for the bacterial culture to grow. The bacterial cultures digest the soluble organics, gradually mature, and slough off from the media. The cultures form a natural floc which can be easily separated from the water.

d) BAS – Biofilm-activated sludge treatment

In order to reduce volumes and decrease energy consumption, compact biological effluent treatment plants were developed during the last ten years which combine moving bed carriers with activated sludge (BAS).

The advantage of the biofilm carrier is that a large amount of biomass stays on the carrier and does not have to be circulated via a sedimentation chamber. Movable biofilm carriers' advantage compared with fixed beds is that there is no risk of plugging.

The usage of this technology reduces the retention time by at least 50 % compared with traditional activated sludge plants. The smaller volume makes it possible to build the biological treatment plants closer to the production line thus saving energy and costs. The reduction of COD is similar in all different types of treatment plants with activated sludge, but the sludge production is lower than in activated sludge plants when sludge is decomposed in the last stage of the BAS plant (e.g. BAS 0.15 kg suspended solids (SS)/kg reduced COD, compared to long-term activated sludge treatment plant (LAS) 0.3 kg SS/kg reduced COD (reference: Södra mills). Reduction of chlorate is high, 95 -100 %, due to the anoxic conditions in the growing biomass. BAS treatment plants use less energy than other treatment plants due to the compact volume (BAS 23 kWh/ADt, compared to LAS 33 kWh/ADt (reference: Södra mills). However, these compact systems are sensitive to lack of nutrients as the retention time is short. Therefore, these systems are operated with a nutrient surplus, leading to higher emissions of phosphorus and nitrogen.

e) *Membrane bioreactor*

A membrane bioreactor (MBR) usually consists of an aerated bioreactor, similar to in the activated sludge process, combined with a membrane process to separate the biomass from the effluent. Two basic MBR configurations exist: one where the membranes are immersed in the reactor and are an integral part of the biological reactor (internal/submerged) and one where the membranes are a separate unit process following the biological reactor (external/sidestream). The cleared filtrate from the membrane stage can be reused in the process while the separated biomass is recirculated to the bioreactor. The high quality of the filtrate makes the MBR technology ideally suited for use as an internal water circuit treatment. To avoid accumulation of solids on the membrane surface, the membrane system requires mechanical or chemical cleaning at defined time intervals. This is normally done fully automatically and carried out directly in the MBR basin (no removal of membranes is necessary).

Achieved environmental benefits
Reduction of emissions of organic matter (COD, BOD), AOX, phosphorus, nitrogen and chelating agents to water.

Environmental performance and operational data
Activated sludge plants are widely used in the pulp and paper industry. As a rough estimate, the activated sludge process is used in 60 – 75 % of all the biological effluent treatment plants in this industry and is also the most common waste water treatment used in recently built plants. Generally, the activated sludge process – or comparable techniques such as moving bed biofilm reactors – achieves high treatment efficiencies. However, the biomass is vulnerable to disturbances and operational instability. Therefore, operators usually make provisions that peak loads or flows or some toxic waste water streams be kept away from the biomass of the aerated basin. Measures include controlling the stability of the manufacturing process (see Section 2.9.10), avoiding the influent of spillages of concentrated liquor (see Section 3.3.9) and using emergency tanks (see Section 3.3.12) and equalisation basins. The most common reasons for poorer performing plants are the chosen design and dimensioning, too high a load or insufficient maintenance and operation of the system.

The temperature of the waste water influences the functioning of the biology. The temperature must not exceed 30 – 35 °C in aerobic processes and cooling can become necessary.

Further information on the specific environmental performance and operational data for application in individual pulp and paper subsectors is given in the sector-specific sections on waste water treatment in Sections 3 to 7.

Cross-media effects
Aerobic biological waste water treatment consumes energy (e.g. for aerators and pumps) and generates sludge that normally requires treatment before utilisation or disposal.

Some biological treatment plants in the pulp industry have detected *Legionella* bacteria. The issue should be taken care of by operators in cooperation with the competent authorities in order to minimise and control the dispersion of these bacteria.

For compact biological treatment plants, the use of a nutrient surplus may lead to higher emissions of phosphorus and nitrogen.

Technical considerations relevant to applicability
Applicable to new and existing plants. For specific information on applicability, economics, etc. see the sector-specific information provided on secondary treatment in Sections 3 to 7.

Information on economics, driving force for implementation, example plants and reference literature for this technique is given in the sector-specific sections on aerobic treatment (see sections 3.3.13, 4.3.16, 5.3.12, 6.3.8 and 7.3.11).

2.9.11.2.2 Anaerobic biological waste water pretreatment

Description

In anaerobic biological waste water treatment, the biologically degradable load is reduced in the absence of oxygen by digestion by microorganisms, mainly generating methane and carbon dioxide.

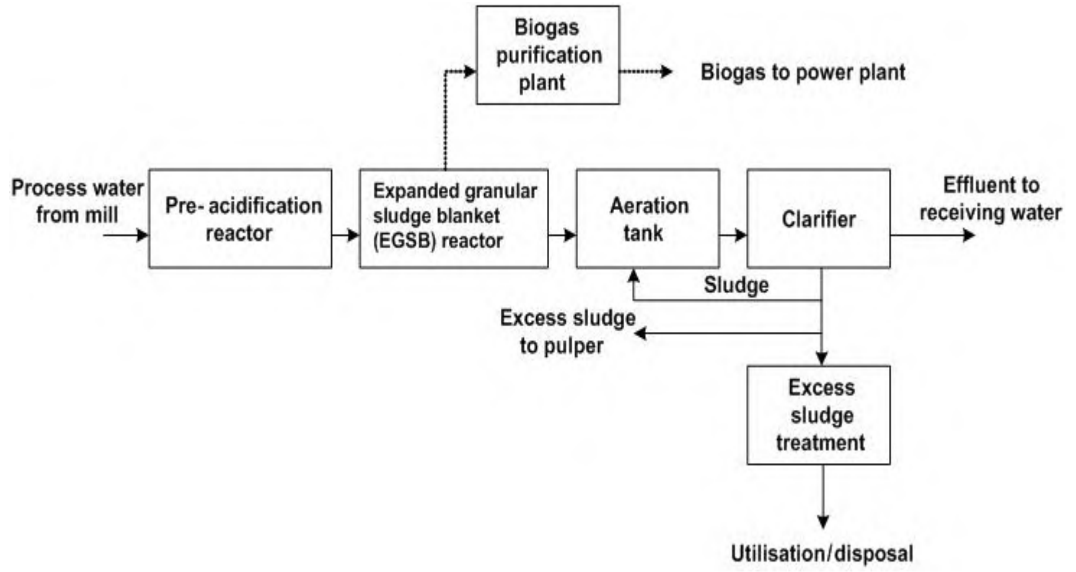
The biogas produced can, after desulphurisation, be used for the production of energy. Normally for emergency situations, the option to burn the biogas by flare is available.

Different process designs are available. The main reactor types applied are: fixed bed reactor, sludge contact process, anaerobic upflow sludge blanket (UASB), expanded granular sludge blanket (EGSB) and, more recently, internal circulation (IC) reactors. In UASB and EGSB reactors sludge particles are kept fluidised by the upflowing influent. In IC reactors, the gas produced in the system drives the circulation and mixing of liquid and solids in the reactor.

The main purpose of the different reactor concepts is to ensure a high concentration of biomass within the reactors. This is achieved either by recycling washed out biomass after settling in an external separator (contact reactor system), or by attaching the biomass to a supporting media within the reactor (fixed bed reactor) or through auto-immobilisation producing granular biomass (UASB and EGSB reactor). The reactors can be operated as single units or as modular combined units.

Anaerobically treated waste water does not comply with requirements for the final COD and BOD concentration of the treated effluent. Therefore, anaerobic treatment is not normally used as a stand-alone treatment. The effluents of anaerobic systems are always post-treated by an aerobic biological stage.

A simplified scheme of a combined anaerobic-aerobic waste water treatment plant is shown in Figure 2.31 (for RCF-based graphic paper and tissue production, excess sludge cannot be fed back to the pulper or the mixing chest).



Source: [69, IFP 1998]

Figure 2.31: Simplified scheme of a combined anaerobic-aerobic waste water treatment plant

Achieved environmental benefits

Anaerobic pretreatment reduces the organic pollution load of waste water, reduces the excess sludge generated in comparison to stand-alone aerobic treatment and utilises the energetic content inherent in the organic pollution load (biogas production).

Environmental performance and operational data

Compared to stand-alone aerobic treatment plants, combined anaerobic-aerobic treatment plants have proved themselves to be more stable systems with respect to changing COD loads and toxic or inhibiting substances in the process water. The availability of the plants is close to 100 %.

For an economically viable application of anaerobic techniques as a first stage of biological waste water treatment, the COD concentration of the process water should not be less than 1 000 – 2 000 mg/l.

Depending on the design of the anaerobic reactor suspended solids in concentrations above 200 – 500 mg/l could cause problems in anaerobic systems, especially in fixed bed reactors. In some UASB reactors a slow disintegration of the biomass pellets was observed. In this case, the biomass can be replaced with new pellets from other UASB reactors in order to keep the reactor in effective operation. The anaerobic pretreatment considerably reduces the likelihood of bulky sludge developing in the subsequent aerobic stage.

In combined anaerobic-aerobic treatment plants, the energy demand related to the removal of 1 tonne of COD (mainly used for pumping and aeration) is about 200 – 300 kWh, whereas in stand-alone and well-designed aerobic plants, the energy demand for the removal of 1 tonne of COD amounts to 500 – 600 kWh. The volume of biogas produced during anaerobic degradation ranges from 400 to 600 m^3/tonne COD removed and consists of methane (60 – 75 %), CO_2 (20 – 35 %) and small amounts of hydrogen sulphide. Before being used as fuel in mills' internal power plants as a substitution for fossil fuels, the biogas is desulphurised. Otherwise, corrosion problems and higher SO_2 emission in the power plant occur.

Since the calorific value of methane is 35.7 MJ/m^3, the energy resulting from the thermal utilisation of biogas in a combined heat and power plant is in the range of 1 900 – 2 900 kWh/tonne COD removed, assuming the efficiency of the power plant is 75 %. Energetic utilisation of biogas covers the total energy demand of the anaerobic-aerobic treatment plant. Part of the energy produced (about 70 – 80 %) can be used in other areas of the plant, e.g. for the paper production process.

The main parameter used to control the performance of anaerobic and aerobic waste water treatment techniques is the COD, which is mostly analysed on a daily basis. For anaerobic systems, the biogas production rate, continuously measured by a gas meter, is another important control parameter, as well as the continuous measurement of the CO_2, CH_4, and H_2S content of the biogas.

Cross-media effects

None reported.

Technical considerations relevant to applicability

Applicable to new and existing plants. Upgrading an existing aerobic waste water treatment plant with an anaerobic pretreatment stage is normally feasible when the process water composition, the COD load and the sulphate content are suitable for anaerobic treatment. The retrofitting of an anaerobic pretreatment stage is a convenient measure when the aerobic stage has reached its maximum capacity and is probably overloaded.

Anaerobic waste water treatment may require more attention and possibly changes with regard to the application of chemical additives (e.g. cleaning agents, defoamers, and slimicides) because anaerobic microorganisms are more sensitive to these chemical additives and toxic effects.

Information on cross-media effects, applicability, economics, driving force for implementation, example plants and reference literature for this technique is given in the sector-specific sections on anaerobic pretreatment (see sections 4.3.15 and 6.3.7).

2.9.11.2.3 Control of biological waste water treatment plants and optimised nutrient supply

Description

Emissions of nutrients are reduced by control of the functionality of the biological waste water treatment and by adjustment and optimisation of the nutrient dosage to avoid overdosage.

The microorganisms used in biological waste water treatment need nitrogen and phosphorus for proper growth. In pulp and paper mill effluents, the amount of nutrients is normally low compared with the amount of organic substances. It is therefore often necessary to add phosphorus and nitrogen to the waste water to achieve efficient treatment. However, it is recommendable to assess whether the initial nutrient supply in the waste water is sufficient. In some cases, e.g. if eucalyptus is used as a raw material, enough phosphorus is present in the waste water and no or only little additional nitrogen is needed. In controlling the functionality of the biological waste water treatment the following aspects are of importance.

Technique I. Sufficient nutrient supply of the microorganisms

Microorganisms in biological waste water treatment plants need a sufficient N and P supply to break down the dissolved organic substances in the waste water. Effluents from pulp and paper mills mostly contain only low concentrations of N and P so, for the effective operation of the biological waste water treatment plant, nutrients e.g. in the form of urea and phosphoric acid are added. An exception are mills pulping wood from Iberian eucalyptus, from which higher amounts of phosphorus are released during pulping. No phosphorus is added to the biological treatment plants treating effluents from eucalyptus pulp mills.

The addition of nutrients is carried out with readily available nutrient compounds, preferably ammonium (NH_4^+) and phosphate (PO_4^{3-}). In some cases, higher concentrations of nutrients are carried with the process water (sometimes with varying concentration and composition). In these cases and also when water flows vary, excess nutrients are measured after the biological treatment plant if the dosage is not adjusted accordingly. The operator of the biological treatment plant has to find the right balance between insufficient supply of N and P to the biological system and undesired overdose. Insufficient nutrient supply may damage the biocoenosis (see paragraph on 'bulking sludge' below) and may subsequently reduce the removal rate of the plant. An overdose is undesired because released excess nutrients increase eutrophication in water bodies.

Many mills do not consider the content of N and P in the inflowing process water or the variation of hydraulic loading and time-proportionally add the same amount of nutrients to the waste water continuously. However, in some cases organic nitrogen compounds are introduced into the waste water by the used chemical additives that are hydrolysed in the biological system and converted into ammonium. This can result in a situation where the concentration of biologically useable nitrogen exceeds the need of the biological system. The need for nutrients varies between mills. As a maximum theoretical demand, a ratio of BOD:N:P of 100:5:1 is required [146, Möbius 2008]. In practice, ratios of 100:2.3 – 2.5:0.5 are also successfully applied in a number of treatment plants.

Technique II. Nutrient dosage

The nutrient requirements of the different aerobic and anaerobic biological treatment systems vary within certain limits. The appropriate nutrient supply can be controlled from three different sides.

(a) From the inlet into the biological waste water treatment plant. It should initially be based on a ratio of BOD:N:P in the influent to the aerobic biological stage of about 100:3.0:0.5 and then be optimised according to the real needs. Since it has proved very difficult to reliably determine the BOD of waste water in due time (analysis is too slow) some mills use (on-line) COD as a parameter, applying an initial ratio of reduced COD:N:P of 100:1:0.2. Others continuously measure the TOC and TN_b for the regulation of the nutrient dosage.

(b) From the treated effluents. For sufficient nutrient supply the yearly average values after the biological treatment should be: 0.5 – 1 mg/l NH_4-N and 0.5 – 1 mg/l PO_4-P [100, M.Cordes-Tolle 2000] or referring to all measured values, e.g. over a complete year, single measurement values between 0 and 2 mg/l.

Treatment plants with very stable operational conditions and few load fluctuations may need lower average concentrations as indicated under point (b), especially with regard to P. The given target values are derived from experience and are intended to give only a rough orientation. Every biological system needs to be optimised and fine-tuned case by case.

(c) By analysing the biomass itself. The control of the effluent concentration in activated sludge systems often does not provide clear evidence for an optimised nutrient supply of the biomass. The composition of the biomass should be monitored by an analysis of the ash content, Kjeldahl nitrogen (TKN) and total P of the activated sludge samplings, especially if the sludge characteristics are unfavourable, or the degradation capacity of the treatment plant does not meet expectations. The target values for the analysed activated sludge sampling are (based on dry solids):

P: >10 mg Total P/g DS)
N: 50 – 60 mg TKN/g DS).

The P supply in particular has a very strong influence on the sludge properties (sludge volume index). The sludge volume index should be determined daily or weekly. It is one of the most important parameters for controlling an activated sludge process. The microorganisms ought to be checked by microscopy weekly.

For combined anaerobic-aerobic waste water treatment plants, it should be noted that the anaerobic bacteria have lower nutrient requirements than the aerobic. The optimal ratio of N and P for the organic load must be determined in each case. Experience has shown that a ratio of COD:N:P:S of 350:5:1:1 gives good results [101, G.Weinberger 2004]. It was found that reducing the dosage of nutrients to the lower needs of anaerobic biomass results in operating conditions that are too unstable for the following aerobic stage. It is therefore necessary to dose in the inlet of the anaerobic stage the N and P necessary for the subsequent aerobic treatment.

Technique III. Control of the nutrient dosing
For an optimised dosing of nutrients, the most appropriate control parameter has to be chosen for every plant. When measuring N and P concentrations in the inlet, especially for nitrogen the bioavailability of the nitrogen species should be taken into account. The measurement of NH_4-N is not always sufficient, e.g. when significant quantities of organic compounds (measured as Kjeldahl nitrogen) that are present in the waste water are transformed into bioavailable ammonium compounds. In turn, not all organic N compounds (TKN) are useable by the microorganisms and will partially pass unchanged the biological treatment. Excess ammonia and dissolved total P or PO_4^{3-}-P in the effluent after the WWTP, together with N % and P % of sludge and its settleability, are the key parameters to be monitored for nutrient dosing. On-line COD or TOC measurement may complete the control.

A suitable control of the nutrients dosing is essential for economic and environmental reasons. The control of the N- and P-dosing as a function of the TOC load is a suitable approach for the control of the nutrient dosing. For the dosing, empirically determined ratios of TOC:N:P can be used taking into account the continuously measured concentrations of N and P in the untreated waste water. On-line TOC measurements and on-line measurement of N and P especially for larger plants are appropriate tools for nutrient control. In many waste water treatment plants nutrient dosing is carried out without taking into account the fluctuations in the organic load or the hydraulic loading. This is appropriate in systems that show few variations. When large fluctuations of the organic or hydraulic load occur, overdosing may take place if the dosing is not adjusted. For these systems, on-line control and dosing of nutrients according to the volumetric flow is a feasible option.

Technique IV. On-line measurements
On-line analysers for nutrients offer the operator the possibility of real-time recording of data curves for the chosen sampling points. Considering these data, operators can react in due time if target values are exceeded in the effluents or peak loads in the inflow or if larger variations of the process stability of the waste water treatment plant occur. Low targets for nutrient emission levels, control of the removal efficiency and requirements regarding process stability and control of the waste water treatment result in an increased use of on-line measurement devices. The greater time and staff requirements of the conventional methods and their lack of flexibility are other reasons for their use. However, on-line measurements are more expensive and still require frequent calibration and maintenance to be reliable. For smaller mills on-line measurements may be too expensive.

Technique V. TSS reduction and prevention of bulking sludge
For separation of the solid biomass from the purified process water, sedimentation tanks are mostly used. Maintaining a good settleability of the activated sludge and avoiding formation of bulking sludge is therefore crucial. Apart from the appropriate dimensioning and operation of clarifiers (surface load of the secondary clarifier or hydraulic load), monitoring and control of the microbial composition of the biomass is essential. A massive growth of certain microorganism species, especially of filamentous bacteria, often indicates a degeneration of the activated sludge and leads to increased losses of TSS.

Sludge bulking in activated sludge treatment generally appears when there is a disturbance in the biological system, e.g. caused by variations in pollution load, variations in dissolved oxygen in the activated sludge basin, lack or excess of nitrogen and phosphorus or variation in the amount of recycling sludge fed back to the aeration basin.

Appropriate measures to prevent and control the (massive) formation of bulking sludge in biological waste water treatment plants are:

- Monitoring of the incoming waste water. Anaerobic zones should be avoided (e.g. by short retention times in the primary clarifier or intermediate aeration) and sufficient nutrient supply guaranteed. In some cases, it appeared that lower carboxylic acids, like acetic acids, were the main cause for prevalent growth of filamentous bacteria, which are responsible for sludge bulking. Filamentous bacteria can also appear when sulphur is present in the effluents.
- Appropriate design of the treatment plant [111, Möbius 2009]. The food to mass ratio has to be in a certain range in order to avoid bulking sludge and ensure good COD elimination. For one-stage activated sludge reactors, cascades, plug flow or selector tanks reduce the risk of bulking sludge formation; aeration, oxygen concentration range and the gradient of oxygen concentration are relevant for process efficiency and the prevention of bulking sludge. Two-stage biological treatment better prevents the risk of sludge bulking in the final stage and offers the possibility to operate at a relatively low BOD sludge load. The first stage is often a high-load stage with biofilm carrier material (moving bed biofilm reactor). When the effluent is suitable for anaerobic treatment, a high-loaded anaerobic first biological stage can be built, today generally an expanded granular sludge blanket (EGSB).
- Daily control of the functioning of the treatment plant.
- Microscopic examination of the activated sludge.

Achieved environmental benefits
Reduction of emissions of nitrogen, phosphorus and TSS.

Environmental performance and operational data
Techniques I to IV

Table 2.34 shows examples of N_{inorg} and tot-P levels achieved by optimised dosing of nutrients and control measurements.

Table 2.34: Example of nutrient control measures and achieved emissions of nine pulp and paper mills

Paper mill and [data source]	N_{inorg} average in mg/l			Tot-P average in mg/l			Remark
	Daily	Monthly	Yearly	Daily	Monthly	Yearly	
MD Paper Plattling Myllykoski (<50 % RCP), [4] (1)	2.8	NA	2.1	1	NA	0.77	Daily averages 80th percentile
Lang paper mill Ettringen (RCP, GW) [1] (1)	0.3	NA	NA	0.5	NA	NA	Average from 2-hour mixed samples
UPM Schongau (> 50% RCP), newsprint, magazine paper, [1] (2)	0.1 – 10.0(3)	1.3 – 2.6	1.8	0.2 – 3.0	NA	0.8	NA
Hans Kolb, Paper mill Kaufbeuren, corrugated medium, [1]	NA	1.1 – 7.5	4.8	NA	0.6 – 1.3	1.0	NA
Paper mill Rieger Trostberg (100 % RCP board), [1] (4)	NA	3.1 – 6.2	4.4	NA	0.7 – 2.2	1.2	NA
Palm paper mill, Eltmann, newsprint 100 % RCP, [1]	NA	0.6 – 1.6	1.2	NA	0.2 – 0.3	0.2	NA
Water treatment plant Südwasser, for Carl Macher paper mill (100 % RCP)	Nges: 0.4 – 4.9	3.8	NA	0.2 – 1.0	0.6	NA	Monthly average 05/2001
Wepa Giershagen, Tissue: virgin and recycled fibres, [3]	TN_b: 6.1 – 9.4	NA	NA	0.08 – 0.5	NA	NA	Half-hour averages
Deli Tissue Stendal, virgin fibres, [2]	0.0 – 1.31(5) Average N_{inorg}: 3.08 TN_b: 3.7 – 10(6) Average TN_b: 8.4	NA	NA	0.08 – 1.9 Average Tot-P: 0.44	NA	NA	2-hour mixed samples

NB: NA = not available, Nges. = the sum of ammonium, nitrate, nitrite nitrogen
(1) One control measurement per day.
(2) On-line measurement of nutrients and TOC.
(3) In 2009 only two daily averages were above 10 mg/l: 15.6 and 10.4 mg/l.
(4) Additional techniques: activated sludge with upstream denitrification.
(5) One value above 10 mg/l: 19 on 26/11/2009.
(6) One value above 10 mg/l: 29 on 26/11/2009.

Sources:
[1] Data from the Bavarian competent authority (Rörig, 2009, yearly reports).
[2] Data from the Saxony-Anhalt competent authority (Ziem, Analysis report 2006 – 2010).
[3] Data from the North Rhine-Westphalia competent authority (Dreher, Analysis report 2010).
[4] MD Plattling, data are taken from German filled-in questionnaire 2006.

Technique IV (On-line measurements)

In a few German paper mills, on-line measurement devices are used for the determination of TOC (EN 1484:1997), rapid-BOD, PO_4 (EN 1189:1996), total P (EN 1189:1996), NH_4 (DIN 38 406, Part 5) and TN_b (DIN 38 409, Part 27). TOC is the most frequently measured parameter to determine the load of the inflow (process control) or for monitoring the effluent limits. Other mills use on-line measurements for the monitoring of N and P concentrations in the effluents or for control of the N- and P-dosing; dosing of flocculants in the case of P removal is another application. In German paper mills, the application of on-line measurements for process control of waste water treatment plants is still limited to about 10 mills (5 % of the total number) although on-line devices are readily available, because results for TOC, NH_4, PO_4 and total P are largely reliable (proper maintenance and trained staff provided) [94, F.Schmid et al. 2002], [95, M.Cordes-Tolle et al. 2000], [98, G.Weinberger et al. 2002]. On-line measurement devices have a shorter payback time for larger mills since the costs for possible inappropriate dosing of nutrients are relatively higher for them. To assess the economic viability of on-line measurements, the costs (investment, expenses for chemicals, replacement parts and maintenance contracts) and benefits have to be assessed on a case-by-case basis

Cross-media effects
None reported.

Technical considerations relevant to applicability
Applicable to all mills.

Economics
No information provided.

Driving force for implementation
Requirements of the competent authorities. Cost reductions for nutrients dosing. Quality objectives for N and P in water bodies. As the purpose of biological waste water treatment is mainly to reduce the organic load to receiving water bodies, the emission of excessive N, P and suspended solids would undermine the success of the treatment.

Example plants
See Table 2.34.

Reference literature
[87, Jouttijärvi et al. 2006], [94, F.Schmid et al. 2002], [95, M.Cordes-Tolle et al. 2000], [98, G.Weinberger et al. 2002], [100, M.Cordes-Tolle 2000], [101, G.Weinberger 2004], [111, Möbius 2009], [146, Möbius 2008].

2.9.11.2.4 Techniques for P and N reduction

Assessment of the N and P content of the used chemical additives and substitution by additives with a lower N and P content can reduce the load of nutrients in the influent of the waste water treatment plant and subsequently in the discharged waste water. Additional techniques for the reduction of phosphorus and nitrogen are described in Section 2.9.11.3

2.9.11.3 Tertiary waste water treatment

Tertiary treatment is normally applied to remove contaminants that preceding treatment steps (e.g. biological treatment) could not remove or could not sufficiently remove, like TSS, COD, nitrogen or phosphorus. The advanced treatment can comprise techniques such as flocculation/precipitation, biofiltration, membranes for advanced filtration, ozonation etc.

2.9.11.3.1 Chemical precipitation

Description
Chemical flocculation of dissolved and suspended matter generates flocs that are separated by subsequent filtration or clarification.

Chemical precipitation involves the addition of chemicals to alter the physical state of dissolved and suspended solids and to create larger particles/flocs to facilitate their removal by sedimentation, or flotation. Different substances have been used as precipitants. The most common ones are aluminium salts ($Al_2(SO_4)_3$ and $Al_n(OH)_mCl_{3n-m}$), ferric chloride ($FeCl_3$), ferric sulphate ($Fe_2(SO_4)_3$), ferrous sulphate ($FeSO_4$) or lime ($Ca(OH)_2$). To optimise the flocculation, polyelectrolytes are used in the mixing phase.

The metal coagulants used for precipitation/flocculation are usually the following:

- aluminium salts: $Al_2(SO_4)_3$ and $Al_n(OH)_mCl_{3n-m}$;
- ferric salts (Fe(III)): $FeCl_3$ and $Fe_2(SO_4)_3$;
- ferro salts (Fe(II)): $FeSO_4$;
- lime.

Achieved environmental benefits
Reduction of emissions of phosphorus and TSS.

Environmental performance and operational data
Chemical precipitation is normally applied as an additional measure in combination with biological treatment. In some exceptional cases chemical precipitation may be sufficient as a stand-alone treatment, substituting a biological treatment (e.g. for the waste water of some paper mills (see Section 7.3.12)).

Information on cross-media effects, applicability, economics, driving force for implementation, example plants and reference literature for this technique is given in the sector-specific sections on tertiary treatment (Sections 3.3.14, 4.3.17 and 7.3.12).

Cross-media effects
Additional sludges are generated.

2.9.11.3.2 Nitrification and denitrification

Description
In nitrification and denitrification for N removal, parts of the organically bound nitrogen compounds (TKN) are transformed into ammonium.

Ammonium is used as the main nutrient source for the microorganisms and is nearly completely transformed to nitrate in the course of low-loaded biological treatment (prerequisite: low sludge load, high sludge age). The nitrification increases the concentration of the nitrate and nitrite content of the waste water. Nitrate in turn can be removed by denitrification. In this process, under poor oxygen conditions microorganisms use nitrate as an oxygen source. In some paper mills denitrification is carried out by intermittent aeration or the creation of oxygen-poor zones. In a few German paper mills, measures to reduce nitrogen in the effluents have been applied (see Table 2.34).

2.9.11.3.3 Ozonation and biofiltration

See Section 6.3.9.

2.9.11.3.4 Additional techniques for TSS reduction

Description

Unfavourable settleability of the biomass and/or excessive hydraulic load of the secondary clarifier of a biological treatment plant may lead to increased concentrations of suspended solids in the final effluents. An alternative to enlarging the sedimentation tank is the installation of filtration units downstream of the aerated tanks that can be operated continuously or only in case of malfunctions. In pulp and paper mills, different types of microfilters, cloth filters or sand filters are used. Flocculation/flotation individually or in combination with filtration also prevents increased TSS loads.

Achieved environmental benefits

Reduced emissions of TSS. The filtration units enhance the operational reliability and prevent target values being exceeded due to malfunctions of the plant [92, F.Schmidt et al. 2002].

Environmental performance and operational data

Normally, also without additional measures, effluent concentrations of 20 mg TSS/l are achieved after biological treatment over longer time periods. In less stable processes, a cloth filter used continuously or in bypass mode as a contingency measure (polishing filter used in case of disturbances or failures) can guarantee permanently low TSS levels.

Low TSS emissions reduce releases of organic substances and nutrients to water bodies and are a prerequisite for successful treatment. 1 mg TSS/l retained roughly corresponds to 1 mg COD/l (0.8 – 1.5 mg COD/l) not discharged to the water body.

Table 2.35 shows an example of TSS levels achieved by a pulp and paper mill.

Table 2.35: Example of TSS control measures and achieved emissions of a pulp and paper mill

Paper mill and [source]	Applied techniques for TSS removal	Achieved TSS values (mg/l) daily + yearly averages
50 000 t/yr wood-free coated and uncoated paper	Micro-filtration, biofilter	Daily average: 0.0 – 12 Yearly average: 0.02
Source: Questionnaire 2006 German mills.		

The example mill that operates a biofilter confirms that biofilters virtually remove all suspended solids (yearly average 0.02 mg/l).

Cross-media effects

None reported.

Technical considerations relevant to applicability

None reported.

Economics

No information provided.

Driving force for implementation

Reduction of emissions of TSS.

Example plants

Mills using biofilter: Glatz Neidenfels, Drewsen Lachendorf, Paper mill Königstein, Norske Skog Walsum or RCF DE 5.

2.9.12 Prevention of pollution risks from decommissioning

Description and achieved environmental benefits

Soil and water protection are the major issues once a pulp and paper mill or part of it is closed. The general measures during operation that can avoid pollution risks in the phase of the decommissioning of a plant are given below.

- Minimise the input of substances into the soil by leakage, aerial deposition and the inappropriate storage of raw materials, products or residues during the operational phase of a facility.
- Ensure that underground tanks and piping are either avoided or are well-documented.
- Establish a spill management programme and extend the containment of relevant sources thus preventing the contamination of soil and groundwater.
- Establish instructions for emptying process equipment, vessels and piping.
- Ensure a clean closure when the facility is shut down, e.g. clean up and rehabilitate the site with regard to the future use of the area. Natural soil functions should be safeguarded, if feasible.
- Use a monitoring programme that is especially relative to groundwater in order to detect possible future impacts on site or in the neighbouring areas.
- Draft a decommissioning scheme that includes the transparent organisation of the shutdown works taking into account specific relevant, local conditions. This decommissioning plan may facilitate action and communication as the availability of information will generally decrease since the staff responsible for environmental matters may have left the closed company.

The operators of the pulp or paper mill should guarantee that the necessary activities during the decommissioning of the plant be supported by technically trained staff. A prerequisite for a smooth decommissioning is a good relationship with the competent authority based on regular meetings and open discussions during the period of operation.

Site reports are a measure that, at the earliest opportunity, allow for establishing a baseline from which further site contamination can be assessed. This baseline report can then be compared to later reports when the installation is sold, closed or redeveloped. The baseline report can also be used to prioritise action to be taken at the installation.

Actions to be taken are specific to individual sites and the pulp or paper grade manufactured. For new plants, decommissioning should be considered at the design stage, thereby minimising risks and excessive costs during later decommissioning. The design of planned installations may include:

- ensuring that the provision for the draining and cleaning-out of vessels and pipework prior to dismantling is incorporated in the design;
- designing aerated lagoons and landfills with a view to their eventual clean-up or cessation; risk assessment may be a useful tool to evaluate the specific requirements;
- giving recyclable materials priority.

The initial state of a site should be assessed before building a new plant.

For existing installations, a general site closure or cessation scheme should be developed and maintained. The scheme will also take into account the utilisation purpose of the site in question. The individual plan and goals for the decommissioning are based on a risk analysis. The cessation scheme should be completed before the real shutdown plan, to demonstrate that the installation can be decommissioned avoiding any pollution risk and returning the site of operation to a satisfactory state. According to this programme, the potential environmental problems should be addressed and measures for improvements of its state proposed. The programme should be kept updated when relevant material changes occur.

The programme for cessation of activities may also include the following actions:

- if underground tanks and pipework are installed in installations, they should be equipped with the proper system for cleaning up and emptying them;
- necessary measures to restore aerated lagoons to a satisfactory state;
- foreseeable measures for restoring on-site landfills to a state that enable cessation in accordance with environmental regulations;
- measures ensuring that insulation will be dismantled without dust or hazards arising;
- measures for the removal or the flushing out of pipelines and vessels where appropriate and completely emptying any potentially harmful contents;
- the closure programme should develop a number of plans and methods for analysing the possible concerns, e.g.:
  - specifications for all underground pipes and vessels;
  - the method and resources necessary for restoring aerated lagoons to a satisfactory state on the basis of a risk assessment;
  - methods for redesigning and modifying the waste water treatment plant for a reduced waste water charge;
  - the method of ensuring that any on-site landfills cause no risk after cessation of the activities;
  - methods of dismantling buildings and other structures to prevent dust and for the protection of soil and surface and groundwater at construction and demolition sites;
  - testing of the soil to ascertain the degree of pollution caused by the activities and the need for remediation to return the site to a satisfactory state as defined by the initial site report.

If the soils of a site are ever severely contaminated, measures may include intermediate soil coverage, leachate collection and treatment, removal of contaminated earth and the provision of geological barriers.

Environmental performance and operational data

There is little public documented information on the closure of pulp and paper mills. Some experience has been gathered that can be used as a general checklist of issues that operators and authorities may face in the case of pulp or paper mill closures.

One practical experience is described in an 'Inquiry of measures related to closing down pulp and paper mills' carried out by the Southeast Finland Regional Environment Centre in 2009. The inquiry concerned measures related to the closing-down of seven pulp or paper mills in Finland and it was sent to both environmental authorities and Finnish Forest Industries Federation. In the project, information was received from replies to the inquiry and from the documents related to the decommissioning of the plants. The answers from seven companies, four environment centres, and the Finnish Forest Industries Federation indicated the items listed below.

- There are no exceptional waste water emissions during the shutdown of a waste water treatment plant or afterwards. In the case of external treatment of the paper mill waste water or common treatment with municipal waste water, the cessation of activities may cause problems when the incoming loads change drastically. The waste water treatment plant would then need some modifications.
- The treatment of sludge of mills still operating may raise difficulties if the sludge has previously been burnt in an auxiliary boiler of the closed mill. The accumulated sludge may cause nuisances and the waste management must be organised in a satisfactory way.
- Waste from demolition work may form a significant waste fraction, which can be recycled, taken to a landfill and/or partially sent to the municipal waste treatment facilities. Problems may also emerge if there is no space in the landfill, and the environmental permit does not allow the use of closed landfills.
- After closing a company-owned landfill, a number of measures are necessary such as investigations of the soil, leakage, gas production, restoration measures, treatment of run-

off waters and gases, quality assurance and monitoring. These activities are part of the requirements of the landfill permit. The possible risk of contaminated land can be investigated by taking samplings based on a risk assessment and the historical information of the site and the company. The plan and the environmental permit application concerning the treatment of contaminated lands are made based on the sampling results. The investigation should be included in the shutdown plan, a plan that is normally made after the decision to cease activities. The mills that are still in operation do not possess such plans. In some cases, it has been difficult to find out where the contaminated lands are actually located. With a lack of historical information, there may be uncertainty about the location of the restored and contaminated lands and who is responsible for restoring the area.

- The use and treatment of the remaining raw materials and semi-finished products have been organised according to the plan for the cessation of the activities that has been prepared after the declaration of decommissioning. Usable chemicals, batches of pulp, timber, etc. can be transported to the other mills of the companies. The material unfit for use is treated as waste or hazardous waste.
- Demolition work causes increased transport and noise. The organisation of the workplace for the demolition of the plant requires surveillance and specific agreements. The absence of a valid permit for the disposal of demolition waste can also be a problem. Asbestos waste requires specific measures.
- In one case, significant odour nuisances have been reported caused by an aerated lagoon where waste water was led during shutdown and that was left without maintenance. Now there is aeration in the lagoon to prevent the nuisance. A year after the shutdown, the odour was no longer noticed. Negative impacts can be avoided by restoring these kinds of ponds to a satisfactory state.
- After the cessation of activities, the supervision and monitoring of water bodies should be continued for years to investigate the effect of the reduction of discharged pollutant load to water bodies. Additionally, monitoring the run-off waters from landfills should be continued for many years. In order to accomplish the decommissioning activities, i.e. the measures carried out on-site after the shutdown of the mill (e.g. the dismantling of buildings and restoration of contaminated lands) supervision from the competent authorities is needed. The monitoring frequency must correlate with the risks and emissions, and time intervals for analysis should be established so that the results can be used for the monitoring of change.

All these examples are from mills where the decommissioning process is still on-going and the final decisions by the competent authorities might deviate from the opinions given in the interviews/inquiry. The result of ongoing analyses of soil as well as of former waste water recipients, etc. will influence the perceived need for further treatment.

The main experience gathered during personal interviews conducted with representatives of Swedish mills that have been shut down [202, Svanberg 2010] are highlighted below.

- A prerequisite for a smooth decommissioning is a good relationship with the competent authority based on regular meetings and open discussions during the period of operation.
- The authorities have been informed and involved from the time the decision is made known to the public and the employees.
- Each closing is unique but common for all is that the basic procedure is identical to a normal maintenance shutdown but modified due to the fact that all tanks have to be emptied, i.e. do not need any liquors for start-up.
- With good planning, very few chemicals and intermediates are left and those quantities can be sold/delivered to other mills still in operation.
- It is common that some parts (wood yard, bark boiler) of the mill are taken over by a new operator which makes some kind of documentation of the historical responsibility, e.g. soil for contamination, necessary. Usually this documentation also involves legal assistance.

- If demolition work is going to take place, i.e. no continuation of some sort of activities in existing buildings, it is very important to choose an experienced contractor to minimise risks and to accomplish an open dialogue with the authorities. Many times the contractors take on the responsibility of sorting the demolished material, sending what is possible for recycling, etc.
- Since all sites concerned have been utilised for industrial activities for more than 100 years, the most time-consuming issue has been the possible historical contamination of the soil. Sweden has an ongoing national programme to develop an inventory of all contaminated land areas. All three mills had, already before the closure decision, finalised Stage 1 in this inventory that includes the tracking of historical activities but still no drilling and sampling. After the closing decision, the results from Stage 1 were used as background material to decide, together with the competent authorities, on the location and number of drilling holes. The samples were/will be analysed for different components depending on the historical activity.
- So far no major surprises have emerged and no demands for the treatment of contaminated land have been made. Because the sites have been under different ownership over time, there is often a need for legal investigations regarding responsibility.
- There are different experiences when it comes to demands on the future monitoring of recipients but common for all is that no final decisions have been made.

Cross-media effects
The technique has only positive effects, preventing or reducing the pollution of all media. Possible pollution caused by the contaminated soil or sludge needs to be evaluated, prevented or reduced.

Technical considerations relevant to applicability
For new plants, decommissioning should be considered at the design stage to prevent contamination. For example, the UK Environment Agency requires operators to submit a decommissioning plan to supplement their permits.

For existing installations, the operator should produce a general scheme related to the cessation of activities as part of an environmental improvement programme.

When a decision to close the mill has been taken, a shutdown plan should be agreed upon in cooperation with the competent authorities. The main reason for not issuing a closure plan for an existing mill in advance is that the plan should consider all relevant information (analytical methods, sanitation techniques, etc.) available at the time of the decision and not be based only on older facts.

Economics
The costs of the described measures have not been reported but they can be quite substantial. Cost also depends on the need for the mentioned activities that are assessed by the competent authorities. The costs of the preventive measures described in the text have also not been reported but they can possibly minimise excessive costs during later decommissioning.

Example plants
Several plants in Finland and Sweden. Even if plants have been shut down in Europe earlier, there are few recent examples (with permits according to modern legislation) where all measures have been carried out and a final agreement has been settled with the applicable competent authority. The experiences recounted under 'Environmental performance and operational data' are given for projects that are not yet finalised.

References
[202, Svanberg 2010], [275, Inquiry Ojanen 2009].

2.9.13 Reduction of noise

Description

Effective reduction of noise emissions is either achieved by directly applying measures/techniques at the source of the noise, or by secondary noise protection measures that reduce the propagation of noise, e.g. barriers such as buildings, walls, banks or trees and bushes between the noise activity and the protected area. The most effective combination of measures/techniques has to be identified individually for each plant or production site.

Sources of noise are distributed over the whole production chain from the unloading of raw material (wood/pulp) to the shipping of final products. The most significant sources of permanent noise are:

- equipment for mechanical treatment such as wood drums, refiners, grinders, etc.
- cutting of wood before debarking for the mechanical pulp mill
- transport of media in pipelines and other systems such as conveyors without optimal dimensions
- temporary steam blowing during process disturbances
- hydraulic units
- fans, e.g. for heat recovery of paper machines
- motors, compressors
- compressors of the cooling machines
- trucks for loading and unloading
- all transport in and near the mill site including railways
- cleaning of process equipment such as lime silos with a vacuum tube to a tank truck.

Various measures/techniques for noise abatement can be applied at pulp and paper mills in order to reduce the noise levels for neighbourhood protection, such as:

- appropriate choice of location for noisy operations (for new plants)
- enclosure of noisy units, i.e. as an example but not limited to the machines mentioned above
- vibration insulation of units such as fans
- soundproofing of buildings to shelter any extremely noisy operations such as wood handling, hydraulic units and compressors
- outlet silencers for exhaust stacks, a technique that can also be applied to cooling towers
- using internal and external lining made of resistant material for chutes
- sound insulation of machine buildings
- sound insulation of ducts
- decoupled arrangement of noise sources and potentially resonant components, e.g. of compressors and ducts
- larger wood-handling machines to reduce lifting and transport times; also reduces noise from dropping wood material
- improved maintenance of the equipment to avoid failures, e.g. in blowers and bearings
- improved ways of working, e.g. lower dropping levels of the logs; immediate feedback of the level of noise for the workers.

If the above-mentioned noise protection measures/techniques cannot be applied and if the transfer of noisy units inside a building is not possible, e.g. because of the size of the involved process units, secondary noise protection measures/techniques may be considered appropriate.

Before implementing noise reduction measures, it is beneficial to make an overall assessment of the noise sources at the individual site, the legal requirements, the complaints from people living in the vicinity of the mill, the available measures and their costs.

The most effective noise abatement approach does not necessarily include noise reduction measures/techniques at the loudest unit, because noise levels decrease significantly with distance to the source. Accordingly, a combination of measures/techniques at noise sources close to the affected areas may be more efficient. In some cases, organisational measures/techniques, such as reducing night-time activities, may be sufficient to reduce nuisances for the neighbourhood and to comply with legal requirements.

An overall noise reduction programme for a pulp and paper mill may include the following steps:

- listing all major sound sources and determining their sound pressure levels, made by segments of octave and including analysis of impulses;
- identification of the affected areas, e.g. housing areas;
- computer-based calculation of the noise propagation (modelling of the site and its surroundings); also checking the real noise level in the housing area by direct measurements;
- ranking of the noise sources according to their relevance for individual affected areas (separately for day and night-time);
- evaluation of noise abatement measures/techniques with regard to their relevance for the noise level in affected areas and estimated costs;
- identification of the most cost-effective combination of measures/techniques that ensures compliance with the legal requirements as well as acceptance in the neighbourhood;
- taking account of noise control in the processes of maintenance.

This noise abatement scheme (seven steps) should be used in pulp and paper mills which are located in the vicinity of residential areas.

Achieved environmental benefits
The effect of reduced noise emissions are primarily related to the well-being of the people living in the vicinity.

Environmental performance and operational data
Permits require that noise levels must not exceed certain noise immission levels which are normally set on a case-by-case basis. Separate noise immission levels may be set for residential and business areas in daytime (07:00 – 22:00) and at night-time (22:00 – 07:00). The operator of a plant normally has to give information on noise dissemination and measures taken for noise abatement.

Besides the absolute value at a certain location (in dB(A)), the distance to the closest residential area is to be considered. Since the operation of most mills is continuous all day and night (with some variations as regards activities in the wood room and the transportation of goods) the target noise levels during the night will determine the measures for the whole operation. In case of impulse noise, it is a common practice to add 5 dBA to measurement results when comparing to limit values.

Regarding existing examples for noise reduction, measures applied, achieved improvements and some cost data, the reader is referred to the 'techniques for noise reduction' sections of the process-specific Chapters 3 to 7.

Cross-media effects
No significant issues are reported.

Technical considerations relevant to applicability
Measures/techniques for noise reduction can, in principle, be applied to new as well as existing mills. Existing plants are often upgraded to comply with the national legal requirements and the older designs may create difficulties such as lack of space to place linings, access for maintenance work, etc.

Economics

Additional investments are needed and maintenance costs usually occur due to the addition of noise-protection measures/techniques. This is especially valid for existing installations. The exact cost level depends on the local conditions but for two studied mills in Sweden, a lowering of the allowed value from 50 to 40 dB(A) and 45 to 40 dB(A) respectively made an investment in the magnitude of EUR 10 000 to 500 000 necessary [201, Ingemansson Technology AB 2005]. The higher figure corresponds to a completely new wood room. Specific cost data on noise reduction should be interpreted carefully considering that costs depend on the type of noise sources to be muted, their quantity and how far from the mill those results are to be achieved. The cause for noise annoyances can range from one major noise source up to approximately 100 different output places for noise.

In the latter case, muting the noise level of a multitude of noise sources by 1 dB(A) may cost EUR 1 million (a UPM mill).

At the Stora Enso Heinola mill, an investment of EUR 200 000 reduced the noise level three hundred metres from the mill by 1 dB(A) (55 dB(A) down to 54 dB(A)). Additional noise reduction measures were not required by the competent authorities due to the unreasonably high costs and due to the fact that other noise sources exist near the residential area.

Driving force for implementation

Legal requirements from competent authorities and in some cases national regulations. Some examples of noise target levels are listed in Table 2.36.

Table 2.36: Noise target levels in some European countries

Country	Noise target or limit values
Finland	In current permits there are limit values or guiding values of 55 dB(A) in the daytime (07:00 – 22:00) and 50 dB(A) at night-time (22:00 – 07:00). In recreational areas there may be limit values of 45 dB(A) in the daytime and 40 dB(A) at night-time.
Sweden	All mills have limit values of 45 – 50 dB(A) at night.
Germany	Depends on the classification of the area (type of use). Most mills belong to type C, i.e. mixture of occupational and residential, and consequently have a limit value of <60 dB(A) during daytime and 45 dB(A) taken at night at the closest residential house. New installations must meet <40 dB(A).
Austria	Similar to Germany.
Holland/ Belgium	For existing industry with >500 metres to the closest residential area, the limit is 45 dB(A). If the distance is greater or the mill is located in an 'industrial area' the allowed limit is 55 dB(A). For new installations, the corresponding value is 40 dB(A). The point of measurement is at a height of 3 metres from the ground.
England	When deciding on limit values the noise background level is considered, which means that the spread of applied target values is wide. Some examples are 60 dB(A) at the site fence (where the closest house is on the other side of the road) or 38 – 41 dB(A) (with measuring points at a distance of 800 – 1 600 metres).
Southern Europe	No individual limit values but references to 'General Noise Regulation' that states 55 dB(A) at night at 65 dB(A) during the day for industries in mixed zones, i.e. combinations of offices and housing.

Example plants

Many pulp and paper mills in Europe have implemented a number of the noise reduction measures mentioned in this section.

Reference literature

[201, Ingemansson Technology AB 2005]

2.9.14 Reduction of odour

Description
Pulp and paper production is often associated with bad odour by the public. The odour caused by the emissions of malodorous gases such as mercaptans and other reduced sulphur compounds that are released from kraft pulp mills are a particular nuisance due to their repellent odour and their low odour threshold of human detection. The collection and treatment of these malodorous gases are discussed in Sections 3.3.15 to 3.3.16.3.

Although the majority of the odorous compounds are reduced sulphur compounds (e.g. H_2S), there are also odorous compounds originating from the decay and decomposition of organic and biological matter. Decomposition occurs when the conditions become favourable for decaying and putrefying bacteria.

In the kraft pulping process (see Section 3.2.2.6.4), odour is primarily emitted with the release of total reduced sulphur (TRS) compounds from sources such as recovery boiler, lime kiln and a large number of diffuse sources of malodorous gases (continuously and intermittent). In the sulphite and neutral sulphite pulping process, fewer emissions of odour compounds occur. Odour and nuisance may arise due to the emissions of furfural mercaptans, hydrogen sulphide or sulphur dioxide. They are described in Sections 4.2.2.5 and 4.3.22 in more detail.

The main and the most frequently occurring odour emissions related to pulp and paper operations other than chemical pulping are odours from the sources listed below.

- Wood extractives (terpenes, etc.) emitted from wood handling and mechanical pulping.
- Volatile fatty acids from closed water circuits primarily in paper mills that use paper for recycling as fibrous raw material. The starch in waste paper and board can readily decompose to the odorous compounds.
- Organic decomposing products from various sources in waste water treatment and waste sludge handling.

I. Odours from wood handling and mechanical pulping
In units where logs, wood and wood chips are mechanically processed, volatile extractives are emitted into the air. These VOC are odorous. Odorous volatile wood extractives are emitted in debarking and chipping plants and from chip storages. Mechanical pulping by chip refining and log grinding emits odorous VOC. Methods to control VOC emissions from mechanical pulping, and thus odour emissions as well, include various destruction methods such as thermal oxidation.

However, in Europe there is no known pulp or paper mill controlling their odours related to VOC emissions. Elsewhere, for example in UPM-Kymmene, Blandin Paper Mill and New Page, Duluth Paper Mill, a Regenerative Thermal Oxidiser (RTO) controls VOC from the main grinder stack (PGW mill) and grinder chamber evacuation vent [188, Pöyry 2010].

II. Odours related to high degree of water systems closure
In paper mills with closed water systems, dissolved matter accumulates in the circulating white water systems. The concentration increases as a function of system closure until it reaches a stable plateau. In some recycled fibre mills with a high degree of closure, the organic dissolved matter reaches COD concentrations of 40 000 mg/l. The availability of this biodegradable organic material under warm and anaerobic conditions is favourable for the decomposition (hydrolysis) of organic matter by acidifying bacteria to volatile organic acids. Carbohydrates are converted to volatile fatty acids such as butyric acid, lactic acid, acetic acid and propionic acids, all of which are odorous.

Possible techniques for preventing or reducing odour in paper mills with closed water circuits are given below.

- Proper design of paper mill processes with focus on optimal sizing and choice of equipment to avoid prolonged retention times, dead zones or areas with poor mixing in water circuits and related units in order to avoid uncontrolled deposits in pipes and chests.
- Design requirements and criteria related to closed-mill processes and the associated 'water-sensitive' operation are crucial to reduce odour problems (not only odour, but also corrosion, scaling and deposits, and to improve process runnability and availability in general).
- Optimal management and operation of the white water system including control and monitoring of inputs, flow rates, and white water characteristics. This also includes maintenance and cleaning of equipment and internal selective clarification of process waters in some cases.
- Use of biocides to control bacteria growth. Biocides will inhibit bacteria growth in water systems but will not reduce concentrations of dissolved matter. Application points of biocides are wire pit, broke, long circulation, etc. The use is often intermittent and 'shock dosing' is often favoured over continuous treatment in terms of costs and efficiency.
- Use of oxidising agents to control odour and bacteria growth. Oxidisers such as hydrogen peroxide may be used to manage local odour problems. Some paper mills successfully apply catalytic disinfection in their water systems for the reduction of microbiological growth [187, Bussmann et al. 2008].
- Use of calcium nitrate in white water towers and pulp storage tower, if H_2S is formed.
- Installation of internal treatment processes ('kidneys') to reduce concentrations of organic matter and consequently odour problems in the white water system. Internal processes may involve either membrane separation or biological (anaerobic/aerobic) treatment or a combination of both. Internal biological treatment combined with measures to control calcium precipitation are efficient methods for lowering white water COD. Internal biological treatment is applied in some closed or low-effluent paper mills (RCF DE 6, VPK Oudegem, BE, and Papelera de la Aqueria, ES). It should be considered that total closure of the water loops may have negative effects on paper quality, require additional equipment to operate and some extra chemicals, and may decrease the runnability of the paper machines. In the US there are closed-cycle paper mills with membrane technology in combination with biological treatment (McKinley paper company, New Mexico, USA), see Section 6.3.4.
- Open the closed cycles to bleed out impurities.

Only the last two options quantitatively reduce the dissolved matter and thus also impact positively on wet-end chemistry, chemical consumption and corrosion.

III. Odours related to waste water treatment and sludge handling
In waste water treatment there are several potential areas and reasons for odour generation. In general, conditions where waste water or sludge become anoxic or anaerobic are likely sources of odours.

In waste water treatment, the sources of odours given below have been observed.

- Emission of volatile waste water compounds such as reduced sulphur compounds from sewer systems and pretreatment units. Incoming waste water typically has a high temperature and emissions of odorous gaseous compounds may occur in:
  - mixing waste water streams in the sewer (different pH or different temperatures)
  - open sewers or sewer vents
  - primary clarifiers (open surface and overflow)
  - waste water cooling towers
  - surface aeration in equalisation tanks.

- Emission of odorous compounds formed through anoxic decomposition of organic matter and under reducing conditions in secondary treatment processes and sludge handling including:

  - anoxic degradation of sludge in primary clarifier
  - insufficient airflow or overloading of trickling filters
  - poor aeration and/or mixing in aeration tank
  - extended retention time of sludge in secondary clarifier
  - sludge storage vents
  - sludge dewatering units
  - spill basins
  - emission of odorous compounds from sludge dryers.

Possible methods for managing odours related to waste water treatment and sludge handling are:

- Sewer systems and primary treatment:
  - Ensure proper design of sewer systems (controlled vents, closure); this may be an issue for older mills with complex and sometimes open sewer systems.
  - Use of chemicals to prevent/reduce formation of hydrogen sulphide in sewer systems, or to oxidise it. Hydrogen sulphide may either originate from the process upstream or form under the conditions prevailing in the sewers. This measure is only carried out in a few specific problematic cases. Ferrous salts (like $FeCl_2$), pure oxygen and blends of nitrate have been used successfully in this application and also in sludge storage tanks or primary settling tanks with odour problems.
  - If possible avoid air cooling towers for untreated effluent. However, cooling is often required before biological treatment and in some cases due to recipient limitations. Direct cooling of untreated effluent (after primary clarification) in cooling towers is a relatively frequently applied method both in paper and pulp mills in Europe. The alternative is indirect cooling with heat exchangers where the recovered heat may be reusable in other processes. The main operational issues are related to clogging/scaling, and availability needs to be considered in design. Examples of mills applying heat exchangers for effluent cooling are Norske Skog, Follum mills (NO), Billerud AB, Gruvön mill (SE), Palm Eltmann mill (DE) and Stora Enso Oulu and Veitsiluoto mill (FI).
  - Avoid extensive aeration/maintain sufficient mixing in equalisation basins. Good mixing can be achieved, e.g. with submerged mixers. If mixing performance is not adequate, deposits on the bottom can be observed in some cases. Also, extensive aeration in equalisation tanks is a source of odour since the effluent at this point still contains odorous reduced sulphur compounds.
- Secondary treatment process methods:
  - Ensure proper aeration capacity and mixing properties. Very often in paper mills there are changes over time in the production rate, specific pollution loads and/or flow rates which gradually take the actual operation off its optimal operation window. A regular reassessment of the aeration system with regard to this issue is therefore recommended. Aeration systems with surface aerators are especially prone to inefficient aeration and mixing.
  - Ensure proper operation of secondary clarifier sludge collection and return sludge pumping.
  - Limit retention time of sludge in sludge storages by sending the sludge continuously to the dewatering units. Retention of excess biological sludge in storage tanks or thickeners should be limited to a maximum of 3 – 5 days. In the case of young sludge age in treatment or if other sludges are mixed into it, even shorter retention periods may be required.
  - Avoid storing waste water in the spill basin longer than necessary. Effluent streams directed to the spill basin tend to be exceptional in composition (high COD, extreme pH, etc.). These streams may become odorous relatively quickly while sitting in the basin. Also, additional streams with low pH may generate the emission of hydrogen sulphide from the basin. As a general rule, the spill basin should always be kept empty and available in case of an accidental spill.
- Use of sludge dryers:

- Treatment of thermal sludge dryer vent gases by scrubbing and/or biofiltration (such as compost filters). Vent gases from (biological) sludge dryers have a specific unpleasant odour. Vent gas scrubbing and/or biofiltration are potentially efficient treatment methods. In the pulp and paper industry, there are a few mills with thermal sludge drying after mechanical dewatering. In Norske Skog, Follum mills, NO, the excess biosludge and chemical sludge is dewatered mechanically and then thermally in a dryer. Vent gases are treated in a scrubber and a compost filter. The Botnia/UPM-Kymmene Rauma mills, FI, are other examples.

Achieved environmental benefits

The reduction of odour decreases the potential nuisances in the vicinity of the mills. Individuals react to odours differently. How much an individual feels disturbed by odours can depend on the frequency and duration of the odour and time of exposure, and the character, intensity and location of the odour.

Environmental performance and operational data

Some information can be found under the 'Description' heading of this section.

Because complaints are an important trigger for actions to reduce odour, a system for complaint registration and handling is a useful tool to control the current situation, achieve improvements from applied measures and to document or prove the good performance of the mill.

Cross-media effects

No significant issues are reported.

Technical considerations relevant to applicability

Measures/techniques for odour control can be applied to new and existing mills.

Economics

No information provided.

Driving force for implementation

In most cases, the driving forces for implementation of the measures are complaints about unpleasant smells from communities living near the pulp and paper mills. Occupational health and safety and national legislation may be another reason for reducing odour, e.g. in Germany, the Guideline on Odour in Ambient Air, GOAA (in German: Geruchsimmissionsrichtlinie, [192, GIRL 2008]), stipulates that the assessment of the concentration of unpleasant smells in the environment and the derived requirements for odour-emitting plants be performed in a uniform way (definition of odour measurements, frequency, duration, character and intensity of the odour; maximum tolerated odour nuisances).

H_2S emissions are not only an odour issue, but also a health issue which has to be addressed for workers' protection (see the Council Directive 98/24/EC).

Example plants

Many pulp and paper mills in Europe have implemented a number of the measures to prevent, control and reduce odour problems in the vicinity of the mills. However, odour is still a cause for complaints in the vicinity of some paper mills. For some of the measures, examples mills are referred to under the 'Description' heading above.

Reference literature

[88, CEN 2003], [187, Bussmann et al. 2008], [188, Pöyry 2010], [192, GIRL 2008].

2.10 General trends in the pulp and paper sector

Traditionally, most emerging techniques have been smallish refinements on existing processes (adaptation) or incremental improvements to the way of doing business. At the same time, there are also some wider scale activities and examples investigating new approaches and challenging existing frameworks (e.g. the energy transition programme for the paper production chain, Dutch Paper Association, VNP).

At the confluence of driving forces from multiple directions, many industry sectors, among them pulp and paper, are in a transitional phase. The possible directions are numerous, the outcome uncertain. The term 'knowledge-based bioeconomy' is one of many flourishing in the current atmosphere of change. 'Biorefineries' and 'biofuels' are examples of technical emerging concepts that involve many techniques.

Emerging techniques linked to the larger general trends in the sector can be subsumed to three main categories within which a variety of developments takes place:

(i) The 'bio-boom' that includes techniques dealing with reduced use of fossil fuels/use of more CO_2-neutral fuels or new raw materials, bio-based chemicals, coatings and enzymes. By integrating biorefinery operations within the pulp- and papermaking process, the industry is set to produce a wide variety of materials based on biomass, from chemicals to fuels, in addition to paper products.

(ii) Integrated resource efficiency (energy, water, fibre raw material, coating and fillers).

(iii) More simplified processes with multi-purpose in-line equipment.

Some of these technological trends and some others will be discussed in the process-related 'emerging techniques' sections of Chapters 3 to 7.

3 THE KRAFT (SULPHATE) PULPING PROCESS

The sulphate or kraft process, accounting for approximately 80 % of the world pulp production, is the most commonly applied production method of the chemical pulping processes. The importance of the sulphite process has steadily decreased and today only 10 % of world production is obtained by this method. The term 'sulphate pulping' is derived from the make-up chemical sodium sulphate, which is added in the recovery cycle to compensate for chemical losses. In the chemical pulping process, the fibres are liberated from the wood matrix as the lignin is removed by dissolving it into the cooking chemical solution at a high temperature. Part of the hemicellulose is dissolved as well in the cooking. In the kraft pulp process, the active cooking chemicals (white liquor) are sodium hydroxide (NaOH) and sodium sulphide (Na_2S). As a result of the large amount of sodium hydroxide used, the pH value at the start of cooking is between 13 and 14 (alkaline pulping process). It decreases continuously during the course of cooking because organic acids are formed during the pulping reaction.

Today the kraft process is the principal chemical pulping process worldwide due to the superior pulp strength properties compared with the sulphite process, its applicability to all wood species, as well as to the efficient chemical recovery systems that have been developed and implemented. But the chemistry of the kraft process carries with it an inherent potential problem in the form of malodorous compounds. However, modern mills with an optimised gas collection system can be limit unpleasant odours in the neighbourhood to process disturbances or other than normal operating conditions.

As a result of chemical reactions in the cooking stage, chromophoric groups of the residual lignin are formed thus causing the pulp to become darker in colour than the original wood. Because of the higher pH, the kraft pulping process induces more chromophores than sulphite pulping and unbleached kraft pulp has a considerably lower initial brightness than unbleached sulphite pulp.

3.1 Applied processes and techniques

Figure 3.1 gives an overview of the main processes of a kraft pulp mill.

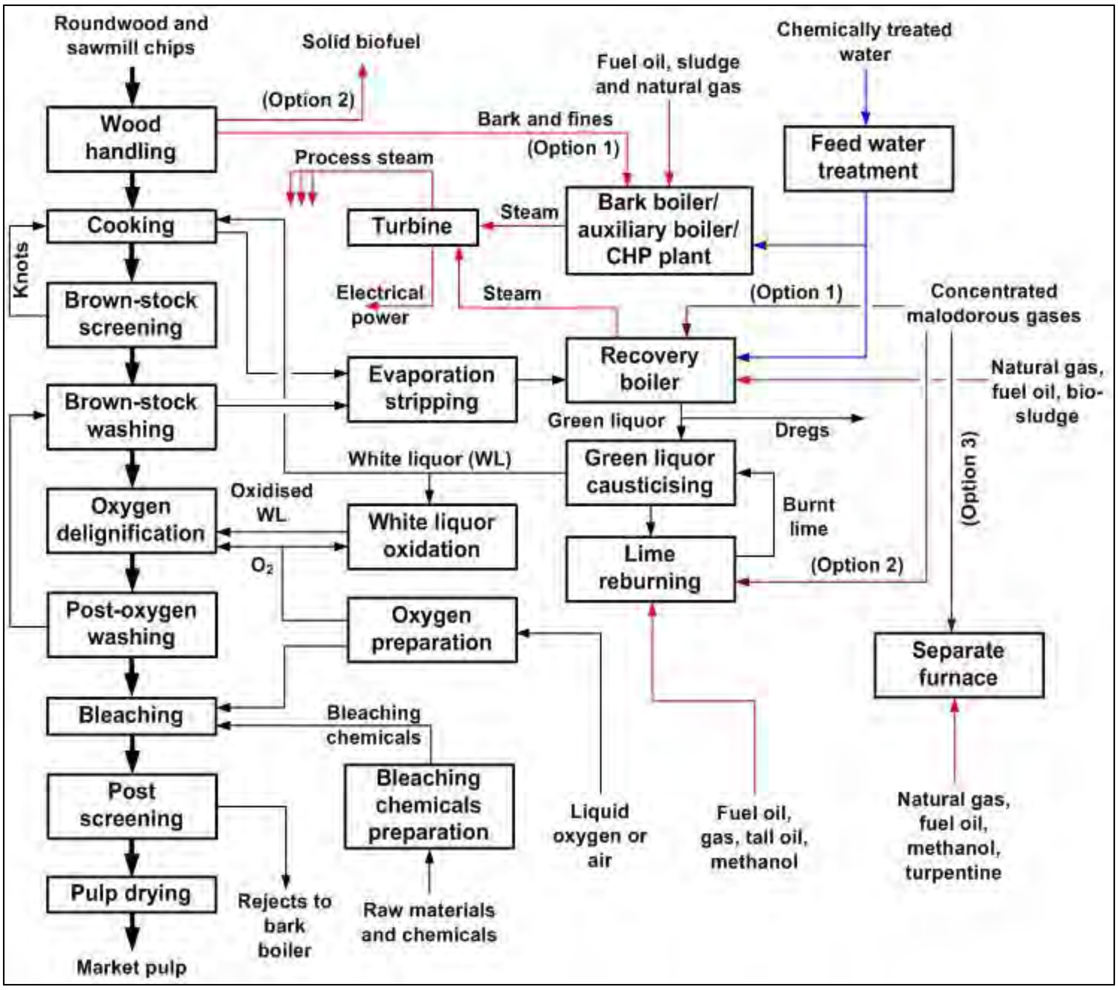


Figure 3.1: Overview of the main processes of a kraft pulp mill

A kraft pulp mill can be divided into four main parts: raw material handling, chemical defibration (delignification) with an almost completely enclosed chemical and energy recovery system, bleaching with an open water system and the process external waste water treatment system. Another more conventional division is the fibre line, recovery system, the lime cycle and the external waste water treatment. Some auxiliary systems like reject handling, the manufacturing of bleaching chemicals and auxiliary power generation are connected to the main departments. A more detailed explanation of the major processes involved in kraft pulping that are simplified in Figure 3.1 is given in Sections 3.1.1 to 3.1.12.

Dissolving kraft pulp is also produced in the EU-27, although only on a small scale (in 2013, one mill in the EU-27 devoted a third of its production capacity to dissolving kraft pulp, with the other two-thirds devoted to kraft pulp). This type of pulp is produced by a prolonged process in the digester and the bleach plant with the purpose being to eliminate all hemicellulose. It results in a 35 % lower wood yield compared with the kraft pulp process, while emission loads are expected to be higher (initial estimations suggest loads could be up to 35% higher).

3.1.1 Reception and storage of wood

Wood may be received as logs directly from the forest or as by-product chips from some other woodworking industry like sawmills and plywood mills. Logs are mainly delivered with the bark on them and have to be debarked before further processing. Chips are normally free of bark and can be used after screening and possibly washing. The wood is transported to the mills by ship, truck or rail but also to a limited extent by floating logs to the mill site. Where the latter is used, there will be some leaching of resin acids and nutrients while the wood is in contact with water. Mechanical pulping techniques may use either logs or chips but chemical pulping techniques will always use chips.

3.1.2 Debarking

The most common method for debarking is drum debarking. Bark is removed as the logs rub against each other when made to tumble by the rotating action of the debarking drum. Loose bark and wood sticks fall from the drum through special chutes. Debarked logs are showered with water before being delivered to the pulp mill. Bark from the debarking unit is typically fed into a bark shredder and, if wet, pressed for burning. Some alternative uses for the bark exist and in some cases it is sold as solid biofuel after drying with secondary heat from the mill.

It is common practice to debark wood from mature eucalyptus trees at the harvesting site. This is justified by economic reasons or when there are no options to obtain energy from biomass.

3.1.3 Wood chipping and screening

For chemical pulping processes, the logs are reduced to chips in a chipper. The objective in chipping is to form uniform-sized chips, which will result in a better pulp product. A uniform chip distribution is necessary for the efficiency of the processes and for the quality of the pulp. The more uniform the chips are after the chipper, the lower the raw material consumption. After the chipper station, the chips are screened in order to remove oversized chips and fines. Fines can also be cooked together with the chips or separately in a sawdust cooker, or they can be burnt or used for other purposes. The screening of chips is not always applied. It depends on the required pulp quality, e.g. screening is not necessary for the manufacturing of unbleached kraft pulp for packaging paper grades. Oversized chips may be sent for reprocessing in a crusher or rechipper. Chips are screened for thickness, as this is a critical parameter both in chemical and mechanical pulping. Often the overall optimum conditions are reached by sacrificing some raw material to secure stable processing conditions, which, in turn, promote better pulp quality and less pollution. The material removed in the screening operation can be sold for other purposes or burnt in a solid fuel boiler with heat recovery together with bark and/or sludge from the waste water treatment plant.

3.1.4 Cooking and delignification

The main chemical components of wood are cellulose, lignin and hemicellulose. Wood also contains small quantities of extractives. In the kraft process the fibres are liberated in the cooking plant by dissolving the lignin and part of the hemicellulose in the cooking chemical solution (white liquor), which contains sodium hydroxide (NaOH) and sodium sulphide (Na_2S) as active chemicals. When the final product is unbleached pulp, the cooking is the only delignification stage.

Chemical pulping aims at removing lignin not only from the fibre walls but also from the middle lamella so that the wood fibres can separate. Ideally, each fibre should receive the same amount of chemical treatment for the same time at the same temperature. This means that chemicals and energy must be transported uniformly throughout each wood chip to the reaction sites. However, cavities inside fresh wood chips are partly filled with liquid and partly with air. The air must be removed from the chips before they can be fully penetrated by cooking liquor. This is usually done by preheating with steam. Chips are heated with steam, which reduces the air content of the chips. Well-steamed chips absorb liquid more easily at an elevated pressure.

Lignin reactions in kraft pulping are carried out in an impregnation phase (initial delignification) and in a cooking phase at elevated temperatures where the bulk of the lignin is removed (bulk delignification). The initial delignification takes place mainly at lower temperatures than during final cooking. Very little lignin is dissolved here (20 – 25 % of the total). Impregnation improves the penetration of the cooking liquor into the chips during the cooking phase.

The cooking process can be performed either in batch digesters or in a continuous digester. When using batch processes, in the cooking stage, the preheated wood chips and the liquors are charged into a batch digester where the cooking is carried out at elevated temperatures and pressure. When the desired residual lignin content (measured as the kappa number) is reached, the contents are discharged to a blow tank and the cooking cycle is repeated.

In the late 1980s modified cooking was introduced into the sector and all new fibre line mill projects applied it. The extended delignification through modified cooking uses the principle of alkali concentration profiling, i.e. the alkali concentration at the beginning of the cooking (in impregnation) is lower and is increased towards the end of the cooking process. This allows cooking to lower the residual lignin content without undue carbohydrate degradation or excessive loss of pulp strength, thus reducing the delignification demand in the bleaching plant and its environmental load. For batch digesters, the extended delignification through modified cooking is termed 'displacement batch processes' and variations include 'rapid displacement heating' (RDH), 'superbatch cooking' (SB) or 'white liquor impregnation' (WLI).

In all these modified batch cooking methods, chips are impregnated in the digester before the bulk delignification process which has an alkali concentration profile. In displacement batch cooking the heat in the spent cooking liquor is recovered by displacing it from the digester with a washing liquid and using it to preheat chips in the next cooking batch (impregnation).

The cooking can also be carried out in a continuous digester (see Figure 3.2) where the wood/chemical charge and retention time, as well as the temperature in the cooking zone, define the resulting lignin content. The chips are preheated by steam before entering the continuous digester in order to remove air which interferes with the impregnation. Before entering the main digester, the chips are impregnated with cooking liquor in an impregnator vessel. After that the temperature is raised to 155 – 175 °C. The cooking time at the maximum temperature is in the range of 1 – 2 hours. For continuous cooking applications, the modified cooking methods include modified continuous cooking (MCC), extended modified continuous cooking (EMCC), isothermal cooking (ITC), and low solids cooking (LSC). All these modified cooking methods, whether operated as continuous flow processes or as displacement batch applications, are variations on the same theme and are based on the principle of alkali concentration profiling.

In conventional cooking, the delignification of softwood (spruce or pine) can be brought down to a kappa number of 28 – 35 whilst maintaining acceptable pulp strength properties. For hardwood (aspen, birch and eucalyptus) the kappa number can be brought down to 14 – 22 [14, CEPI 1997].

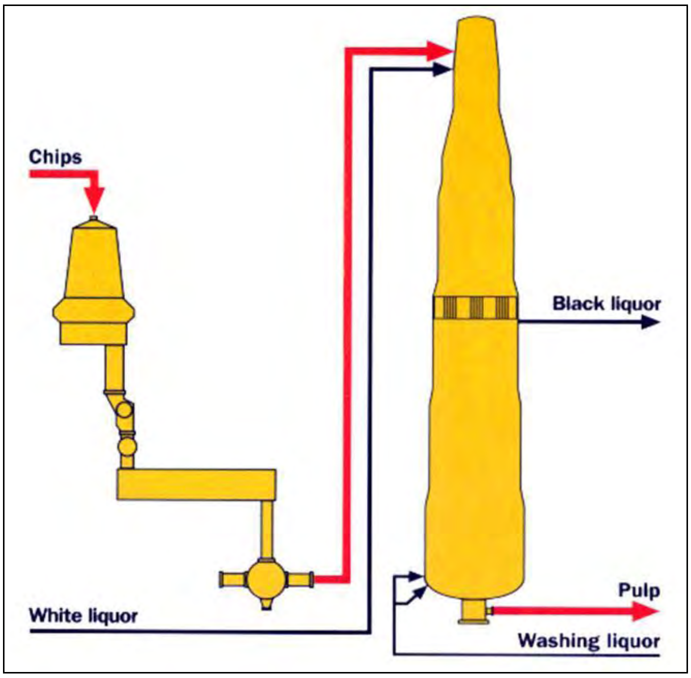


Figure 3.2: **Example of a continuous digester**

The cooking modification methods already mentioned have been developed with the aim of removing more lignin from the wood during cooking without reducing the yield and without extended cellulose degradation, thus reducing the organic load caused by pulp bleaching. The kappa number from the cooking of softwood can be reduced to a level of 15 – 25 through extended delignification [1, Finnish BAT Report 1997], while the yield and strength properties are still maintained. This means that 25 – 50 % less lignin is left in the pulp compared with pulp that has a kappa number of 32. The requirements for any subsequent bleaching chemicals are therefore reduced and the effluent discharges from the bleaching plant are decreased. Comparable kappa reductions can be achieved in the cooking of hardwood (see also Section 3.1.6).

3.1.5 Washing and screening

The pulp coming from the digester contains both fibres and spent cooking liquor (black liquor). About half of the wood is dissolved in the cooking. Consequently the black liquor contains inorganic chemicals and a large amount of organic substances. The black liquor is removed from the pulp in the subsequent washing step and is led to the chemical recovery system, where cooking chemicals and energy are recovered.

The dissolved organic substances together with the spent cooking chemicals are recovered from the cellulose fibres in the brown stock washing stages that are run counter-currently. Modern systems normally recover at least 99 % of the chemicals applied in the digester applying a minimum amount of dilution water while achieving the highest possible degree of pulp purification. Washing the pulp coming from a conventional batch digester plant is normally carried out with drum washers, while a continuous digester plant utilises the wash zone in the bottom of the digester with additional drum washers or diffuser washers. In modern batches as well as continuous cooking fibre lines, washing already starts in the digester by displacing hot black liquor with cold wash liquor. Subsequent washing is carried out in various types of washing equipment, e.g. vacuum drum washers, wash presses, diffusers or wire-type washers.

Efficient washing generates a number of benefits: it reduces the carry-over of black liquor with the pulp into the bleach plant resulting in a decreased consumption of chemicals in bleaching and reduced discharges from the bleaching plant; it results in a decrease in the disturbances to the screening that can be caused by foaming; it reduces the total consumption of cooking chemicals (chemical losses) and the chemical consumption in the oxygen delignification step (see Section 3.1.6). The outcome of the washing is highly dependent on the efficiency of the equipment used, the outlet consistency of the pulp, the temperature and the amount of wash water applied. However, if washing is improved by increasing the amount of wash water, the demand for steam will increase in the subsequent stage to evaporate and concentrate the black liquor.

Wash presses and diffuser washers are especially effective in the removal of dissolved organic substances, and this is one reason why wash presses have become more common, especially as the last washing stage before bleaching. Adding carbon dioxide to the wash water or directly to the pulp may improve the washing effect.

Before further processing, the pulp is screened with pressure screens and sometimes centricleaners (for the production of unbleached pulp). The objective of screening is to separate knots and fibre bundles from the main pulp stream with a series of vibrating pieces of equipment, filtration through pressure screens and centrifugal separation of fibres and other particles with different specific weights. Rejects from screening are either removed from the process, mechanically treated and returned to the screening, or are directly recycled to the digesters.

3.1.6 Oxygen delignification

After cooking, delignification can be continued with oxygen in one or two stages and with or without intermediate washing. Oxygen delignification can be combined with conventional and extended cooking.

Oxygen delignification takes place in alkaline conditions. In order to maintain the sodium balance of the mill, the oxygen stage normally uses the oxidised white liquor, where sodium hydroxide is the main alkaline chemical and sodium sulphide (Na_2S) has been oxidised to thiosulphate ($Na_2S_2O_3$). Due to the relatively low solubility of oxygen to the alkaline liquor, the delignification reactor is pressurised and the temperature is elevated to about 90 – 100 ºC. In oxygen delignification, magnesium salt ($MgSO_4$) is added in order to preserve the strength of the pulp. The oxygen is mainly purchased but some on-site oxygen production plants are also in operation. Because of their better selectivity and the lower investment, the medium consistency systems (MC, 10 – 15 % DS) have dominated mill installations for the past ten years although high consistency installations (HC, 25 – 30 % DS) are in use as well.

Oxygen delignification is usually an intermediate stage in the pulp washing process. The wash water is added in the last washing stage after oxygen delignification and sent counter-current to the pulp flow. Washing after oxygen delignification is usually done with two washing stages. The organic material that is dissolved during oxygen delignification can be recovered and led to the chemical recovery system without major changes in the process. The recovery reduces the amount of organic material that ends up in the waste water and the amount of chemicals needed.

The kappa number after conventional cooking and oxygen delignification is typically 18 – 22 for softwood and 13 – 15 for hardwood without extended delignification [14, CEPI 1997]. kappa numbers for kraft pulp mills that manufacture unbleached sackpaper are between 40 and 55. Depending on the wood species, oxygen delignification with extended cooking can achieve a reduction in the kappa number to around 8 – 12 for softwood and 8 – 10 for hardwood. The overall pulp yield might decrease by 1.5 – 2.5 % and there is still lignin left that has to be removed by other means when high brightness pulp is demanded.

The reduction of the kappa number of unbleached pulp (brown stock), whether it is achieved through extended cooking delignification, oxygen delignification or some other method, will reduce the load of bleaching plant pollutants that enter the biological effluent treatment system.

This is because dissolved substances are returned to the recovery system and then burnt in the recovery boiler.

3.1.7 Bleaching

The purpose of bleaching chemical pulp is to obtain certain pulp quality criteria with respect to brightness, brightness stability, cleanliness and strength. The brightness of unbleached kraft pulp is rather low, below 30 % ISO, whereas fully bleached pulp has a brightness of 88 % ISO or higher. Cooking and oxygen delignification cannot remove all the lignin and, to achieve this brightness, it is necessary to remove or oxidise the remaining lignin and impurities in the pulp. The kappa number after bleaching is reduced to less than 1 unit [14, CEPI 1997].

The introduction of extended cooking (see Section 3.1.4) and oxygen delignification (see Section 3.1.6) has resulted in more efficient recovery of organic substances and has also allowed the use of other chemicals in bleaching and minimisation of the use of chlorine chemicals. As a consequence, the total release of organic and chlorinated organic compounds from the bleaching plant has been reduced significantly compared to the 1980s or 1990s. However, bleach plants discharge their effluents whereas delignification can be carried out within closed water systems.

The acidic effluents from the bleach plant cannot easily be recirculated into the chemical recovery system, mainly because the recirculation of these effluents would increase the build-up of chlorides and other unwanted inorganic and organic non-process elements in the chemical recovery system, which can cause corrosion, scaling and other problems.

The bleaching of kraft pulp is carried out in several stages, usually four to five. Recently three-stage bleaching plants have become more common. The most commonly used chemicals are chlorine dioxide (ClO_2), oxygen (O_2), hydrogen peroxide (H_2O_2), sodium hydroxide (NaOH), and sometimes ozone (O_3). Lately, peracetic acid (CH_3CO_3H) has become commercially available as a bleaching chemical. In Europe, chlorine (Cl_2) and hypochlorite (e.g. NaOCl) have been phased out as primary bleaching chemicals in recent years (e.g. PARCOM Decision on the Phasing-out of the Use of Molecular Chlorine (Cl_2) in the Bleaching of Kraft and Sulphite Pulp). In older chlorine dioxide production processes, small amounts of chlorine are formed as a by-product and a part of this chlorine will be present when chlorine dioxide is used in bleaching. Chlorine dioxide and ozone have to be produced on site (see Section 3.1.12). At some mills, oxygen is also produced on site by separating the oxygen from the air. Peroxide, oxygen and alkali can be delivered to the mills.

Ozone is a very reactive bleaching agent whilst chlorine dioxide, oxygen and hydrogen peroxide are less reactive. Because of the different reaction mechanisms, different types of bleaching chemicals are utilised in a bleaching sequence. Acid and alkaline stages are used to complement each other.

Peroxide bleaching is relatively slow and requires long reaction times and therefore large reactor volumes or increased pulp consistency. Increased pressure makes higher reaction temperatures possible, resulting in a reduced reaction time or an improved bleaching outcome. It is necessary to remove metal ions, to avoid degradation of the hydrogen peroxide, using metal chelating agents (EDTA or DTPA) or acid washing. An advantage with peroxide compared with the other oxygen bleaching chemicals is that peroxide bleaching at optimal conditions brightens the residual lignin.

Enzyme treatment before bleaching has been in use at some plants in North America since 1991. It can be combined with different bleaching sequences to enhance the effectiveness of the chemicals used but typically results in a small loss of yield.

A bleach plant consists of a sequence of separate bleaching stages with different chemicals added. Each bleaching stage consists of:

- devices for mixing the chemicals and the pulp;
- a bleaching reactor (upflow or downflow towers) designed with a suitable residence time for chemical reactions;
- washing equipment for separation of used chemicals, removed lignin and other dissolved material from the pulp (drum washer, wash presses or diffuser washer).

The bleaching stages are designated using symbolic shorthand for the type of bleaching agent applied.

A	Acidic stage for removal of hexenuronic acid (HexA) through mild acid hydrolysis.
Q	Acid stage where the chelating agents EDTA or DTPA are used for the removal of metals.
Z	Ozone stage using gaseous ozone (O_3).
P	Alkaline stage with hydrogen peroxide (H_2O_2) as a solution.
D	Chlorine dioxide stage using a water solution of chlorine dioxide (ClO_2).
E	Extraction stage using sodium hydroxide (NaOH).
E/O	Extraction stage using sodium hydroxide with the subsequent addition of gaseous oxygen as a reinforcing agent.
P/O	Alkaline stage with hydrogen peroxide as a solution with a small oxygen charge.
E/P	Extraction stage using sodium hydroxide with the subsequent addition of hydrogen peroxide solution as a reinforcing agent.

Nowadays, oxygen delignification has become a more and more common delignification stage followed by a bleaching sequence of D-EOP-D or D-EO-D, D-E-D-E-D, D-E-D-D, D-EOP-D-E-D, QP-DQ-PO, D-EOP-D-D or Z-E/O-D-P/O.

The two main types of bleaching methods in use are elemental chlorine free (ECF), i.e. when no molecular or gaseous chlorine is dosed in the bleaching, and totally chlorine free (TCF) bleaching. All ECF mills use chlorine dioxide in the bleaching sequences and in a few cases also ozone, alkali for the extraction of the dissolved lignin, and peroxide and oxygen for the reinforcement of the extraction stages. TCF bleaching uses oxygen, ozone or peracetic acid and peroxide with alkali for lignin extraction. Selectivity is important as far as the total yield and pulp quality are concerned because high selectivity means that the bleaching chemical is primarily reacting with the lignin.

Some mills have responded to the market demands of TCF pulps by modifying the bleaching sequence. Nowadays, TCF bleaching is an established technique. A number of mills are able to produce both ECF or TCF pulps depending on the market situation. New sequences based on combinations of chelation stage (Q), peroxide stage (P) and ozone (Z) have been and are being developed, such as Q-E/P-E-P, Q-Z-P-E-P, OP-ZQ-PO, Q- OP-Q-PO, OOQPoP [CTP, 2010] or Q-OP-(Q+Paa)-PO, Q-OP-Q/Paa-PO [257, Soedra 2009]. At least one mill has given up the production of TCF pulp: the Metsä Botnia Rauma mill changed its bleaching system from TCF to ECF in the summer of 2007 for quality, energy and cost reasons.

A brighter pulp at the same kappa number and viscosity level can be achieved after oxygen delignification if the cooking is ended at higher kappa numbers. When using a peroxide-based TCF sequence, this is a major advantage since the bleachability is shown to be dependent on the brightness rather than the kappa number at the time of entering the bleach plant. From an economic point of view this is preferable since selectivity is better during oxygen delignification than during cooking. For the TCF sequence it is, however, important to keep in mind that the yellowing tendency (heat-induced) of the fully bleached pulp increases with increasing kappa numbers after cooking, probably due to a higher hexenuronic acid (HexA) content in the pulp [257, Soedra 2009].

The discussion about modern ECF versus TCF bleaching

During the 1980s and 1990s, there were intensive discussions and research on the environmental benefit of TCF compared to ECF bleaching. The evaluation of the results of the research and of syntheses of the great amount of laboratory and model ecosystem tests as well as field studies with whole mill effluents from bleached kraft mills can be summarised below.

- The chemical composition of the effluent from kraft mills using modern ECF or TCF bleaching of oxygen-delignified low-kappa pulp has changed significantly in comparison with the situation in the 1970s and 1980s, even if the operational standard of the individual mills is still of major importance for the amount and quality of emissions [129, SEPA report 1997].
- Pulp mills with modern ECF bleaching give very low emissions of chlorinated organic substances and highly chlorinated phenolic compounds generally cannot be detected in the effluent. [ibid.]
- A comparison of toxic responses of bleach plant and whole mill effluents from mills using different schemes for non-chlorine bleaching, i.e. modern ECF versus TCF bleaching, shows that neither technique consistently produces effluents with a lower toxic potency [47, FEI 1996]. No clear difference in the effect pattern and effect intensity between effluents from mills using modern ECF (chlorate reduced) and TCF bleaching has been detected.
- Secondary treatment of effluents usually tends to decrease the toxicity of the effluents and, according to model ecosystem studies, effects on ecosystem levels are mitigated after external treatment. [ibid.]
- The special focus on the question of whether modern ECF or TCF bleaching is better from an environmental perspective seems to be too narrow; the entire mill operation including the waste water treatment system and the avoidance of disturbances and accidental releases are also crucial aspects to consider. For example, the amounts of fatty acids, resin acids and sterols in the effluent from modern kraft mills are affected more by the fibre raw material or by contributions from the unbleached side than by the bleaching process.
- A TCF bleaching sequence is the more advantageous alternative for further water system closure. However, technical difficulties regarding the enrichment of non-process elements in the water circuits and undesired scaling, especially of oxalates, remains an unsolved challenge for further closure of the bleach plant effluents. [233, Hamm et al. 2003].

3.1.8 Bleached stock screening

After bleaching there is generally a final screening of pulp. Secondary screening takes place with the same type of equipment as the screening of unbleached pulp (see Section 3.1.5).

3.1.9 Drying

In an integrated pulp and paper mill, the pulp stock will be transferred forward to papermaking in a wet state (at about a 4 % consistency) and the accompanying water forms part of the overall water balance of the mill. For a non-integrated pulp mill where the pulp is not used for the manufacturing of paper at the same site, the pulp will be first pressed and then dried for transport. The drying machine consists of a wire part similar to but simpler than the wire part of a paper machine for the initial dewatering of the pulp, a press section and a dryer. After the dewatering stage, the pulp is dried with steam in a multistage dryer. After being cut into sheets, bales for shipment are formed.

3.1.10 By-products of kraft pulping

Tall oil soap (TOS) originates from extractives in the pulpwood, primarily resin and fatty acids. In the kraft process the acids are saponified due to the alkaline conditions in the digester and form sodium soaps (crude tall oil soap) which dissolve in the black liquor. In the chemical recovery process the soap separates from the water phase and forms a soap layer on the liquor surface as the black liquor is successively concentrated and the solubility of the soap is decreased. For process reasons most of the soap has to be removed from the black liquor in order to avoid foaming in the evaporators and to maintain stable combustion in the recovery boiler.

Crude tall oil (CTO) is produced by acidulation of tall oil soap in a batch or continuous process. The acid used is normally sulphuric acid or generator waste acid (GWA) from chlorine dioxide generation. Different species of pine have the highest content of resins and give the highest tall oil yield. Spruce and birch give a much lower tall oil yield and also a lower quality. Crude tall oil is a tar-like dark brown liquid with high viscosity and an unpleasant odour of sulphur compounds from the pulping process. A typical yield of crude tall oil from tall oil soap is about 10 - 75 kg per tonne of pulp. Crude tall oil is normally sold to the chemical industry and the pitch fuel, generated while distilling crude tall oil, is used as a biofuel at the mills. Some pulp mills burn crude tall oil directly for bioenergy.

At the Zellstoff Stendal mill in Germany about 13 450 tonnes of tall oil are produced by decantation of tall oil soap from the black liquor before evaporation. The tall oil is partly sold on the market and partly used as fuel in the lime kiln. Dilute non-condensable gases may occur during processing of the tall oil. At the Stendal mill the waste gas is treated in a scrubber and the remaining emissions are treated in the dilute NCG treatment system.

Crude sulphate turpentine (CST) originates from volatile organic compounds in the pulpwood (conifer). In the pulping processes the wood chips are heated and the terpenes are volatilised. Turpentine can be recovered from the terpene-rich vapours. The composition varies depending on the wood species used. α-Pinene is the main component in crude sulphate turpentine. The highest content of terpenes is found in fresh pine wood. In spruce the content is much lower. Crude sulphate turpentine contains significant amounts of malodorous sulphur compounds and has a very unpleasant odour and a dark colour. The yield can vary in the range 0.5 -15 kg per tonne of pulp.

3.1.11 Chemical and energy recovery system

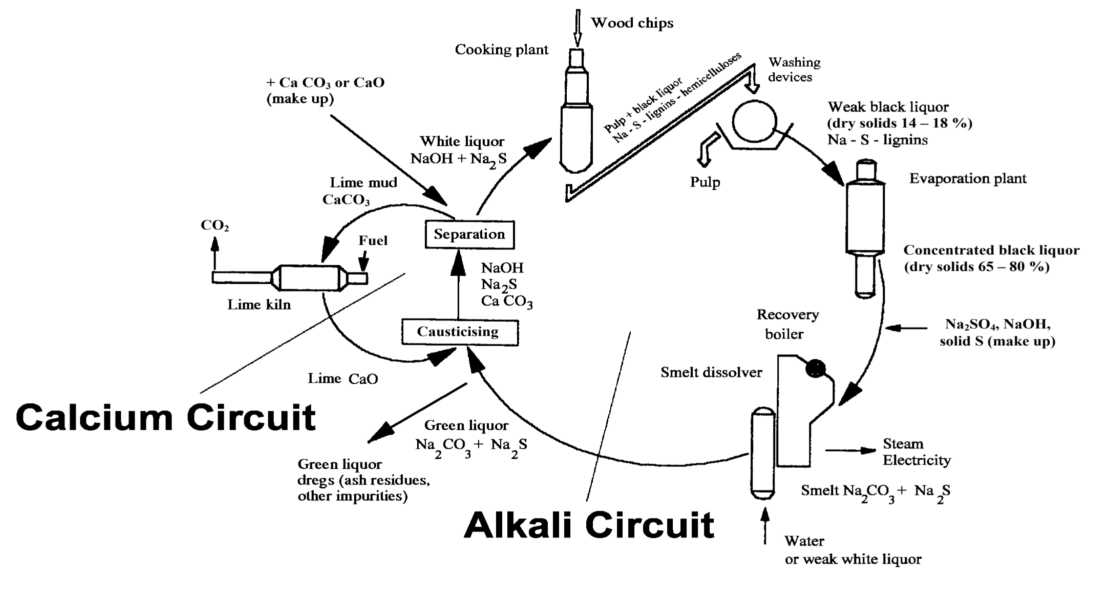
The recovery system in a kraft pulp mill has four functions:

- the recovery of the inorganic pulping chemicals;
- the incineration of the dissolved organic material and the recovery of the energy content as process steam and electrical power;
- the recovery of valuable organic by-products (e.g. tall oil);
- the prevention and control of pollution: a significant reduction of the waste water load discharged to the biological waste water treatment plant and an extensive reduction of emissions to air.

The fuel value of the recoverable black liquor is normally enough to make the kraft pulp mills more than self-sufficient in heat and electrical energy. Organic by-products such as methanol, turpentine or tall oil play a limited economic role in most kraft pulp mills.

The main processes in the chemical recovery system are the evaporation of the black liquor (cooking liquor and counter-current washing liquor), incineration of the evaporated liquors in a recovery boiler and causticising, including lime regeneration.

An overview of the recovery circuits of chemicals is presented in Figure 3.3 illustrating the main process steps and their functions.



Source: [6, BMU Austria 1995]

Figure 3.3: Recovery circuit of chemicals for a kraft mill

Black liquor from pulp washing normally has a dissolved solids content of 14 – 18 % which has to be increased considerably before the liquor can be burnt. The liquor is concentrated in a multi-effect evaporation plant to a dry solids content of 70 – 85 %. At atmospheric pressure the upper limit for the increase of the dry solids is about 72 – 74 %. In recently modernised plants, the liquor is concentrated up to 85 % DS by pressurising the liquor so that higher temperatures can be used, resulting in lower viscosity. The dry solids content of black liquor from eucalyptus pulping does not reach such high levels; the maximum DS content achievable is about 72 – 75 %. In evaporation, some of the combustible material separates as non-condensable gases (NCG) which contain malodorous gas compounds often expressed as total reduced sulphur (TRS). These gases are collected and burnt together with other malodorous gases.

Condensates from the black liquor evaporators and the cooking plant will vary in their degree of contamination according to their origin but will typically contain TRS, methanol and some other volatile organic compounds. They are treated in a stripper column that is normally integrated with the black liquor evaporation using secondary (or primary) steam. Stripping the condensates makes it possible to reuse them in washing unbleached pulp and in the causticising plant.

The concentrated black liquor is burnt in the recovery boiler to recover the sodium and sulphur content in a suitable chemical form to regenerate the pulping chemicals and recover energy from the flue-gases.

An increase in the dry solids content of the black liquor from 65 – 70 % to 80 – 85 % changes the material and energy balances and the burning conditions in the recovery boiler. The flue-gas flow decreases as less water enters the furnace. By increasing the dry solids content, e.g. to over 80 %, an increase in production or extended delignification with more efficient recovery of the black liquor can be possible in a mill where the recovery boiler is the production capacity bottleneck. In general, two operational modes for recovery boilers can be distinguished; one is focused on energy efficiency, the other one on low NO_X emissions.

Operating on black liquor with a very high dry solids content (> 80 %) leads to improved energy efficiencies, allowing for pulp and paper mills to operate self-sufficiently in terms of energy or even to generate excess energy, while at the same time resulting in lower sulphur and carbon monoxide emissions and decreased fouling. Developments in material technology have enabled temperature and pressure increases in recovery boilers, which enable electricity production to be maximised. With a higher combustion temperature, the amount of sodium (Na) vaporised is higher, thus more SO_2 can be bound and Na_2SO_4 can be formed. Therefore energy-efficient boilers are also effective in chemical recovery and have low SO_2 emissions. However, the increased temperature leads to an increase in NO_X emissions.

When low NO_X emissions are a priority, the DS content of black liquor needs to be limited to lower levels, thus reducing the temperature in the recovery boiler. In this case, NO_X emissions are reduced, but also the potential for energy recovery (lower electricity and energy efficiency). Sulphur and CO emissions are higher compared to high dry solids content firing. High CO emissions means a high amount of incombustibles, therefore the VOC and PAH (polyaromatic hydrocarbon) emissions might also be higher.

Developments in recovery boilers over the past 20 years have been towards energy-efficient operation and higher black liquor dry solids (over 80 %).

The smelt from the recovery boiler is dissolved in water or weak white liquor to produce 'green liquor' which consists mainly of sodium sulphide (Na_2S) and sodium carbonate (Na_2CO_3). The green liquor is clarified or filtered (modern technique) and causticised with lime, and sodium carbonate (Na_2CO_3) is converted into sodium hydroxide (NaOH) to produce 'white liquor' for pulping. Ash residues and other impurities are removed from the process as green liquor dregs. The calcium carbonate lime mud from causticising is separated from the white liquor, washed and calcined in a lime reburning kiln (somewhat resembling a standard rotary lime kiln) to regenerate the lime. This calcination is a high-temperature, endothermic reaction requiring external fuel.

The handling of black liquor with a high sulphur content may release sulphur-containing gases into the air as sulphur dioxide after incineration and as malodorous gases containing reduced sulphur compounds such as hydrogen sulphide (H_2S), methyl mercaptan (CH_3SH), dimethylsulphide (CH_3SCH_3) and dimethyldisulphide (CH_3SSCH_3). When using the appropriate techniques (see Sections 3.3.16.1 to 3.3.16.3) these emissions can for the most part be prevented.

Strong malodorous gases are collected and generally burnt in the recovery boiler, a dedicated burner or in the lime kiln. The burning of odorous gases in the recovery boiler is widely used in European pulp mills and is considered the preferred option at the time of writing (2013). For its application, all safety measures can be applied with special care for burner design and air distribution to avoid explosive conditions. Dedicated burners are also frequently used to burn the strong gases. Flue-gases from dedicated burners are in most cases treated through scrubbers (e.g. with oxidised white liquor) for heat recovery and for the removal of sulphur dioxide. The scrubber water is led back to the chemical recovery system. The gases from the separate incinerator can be utilised to produce sodium bisulphate ($NaHSO_4$), which can be internally used in bleaching for rendering the chlorine dioxide residuals harmless thus replacing external sulphur dioxide (SO_2) in the washing of bleach plant vent gases. Burning of the malodorous gases in the lime kiln is less favoured because it might upset the operation of the lime kiln. The burning of the strong gases in the lime kiln can also form so much SO_2 that SO_2 emissions increase.

Many kraft pulp mills also collect weak malodorous gases but to a varying extent. Weak gases are emitted from chip presteaming, screening, pulp washing, the smelt dissolving, the recausticising plant tank ventilations, etc. A few mills collect and treat the weak malodorous gases almost completely.

3.1.12 Preparation of bleaching chemicals on site

The most commonly used chemicals for bleaching of chemical pulps are chlorine dioxide, oxygen, ozone and peroxide. Chlorine dioxide and ozone are produced on site. Oxygen is also produced on site, in some cases being separated from the air. Peroxide, alkali and oxygen can be delivered to the mills.

3.1.12.1 Chlorine dioxide

Chlorine dioxide is thermodynamically unstable and is usually manufactured at the place of use, except in very small quantities. The gas however is stable and safe to handle at temperatures of up to 80 °C as long as the partial pressure of chlorine dioxide is kept at a low pressure (below 12 kPa). If stable conditions are not met (e.g. too high a gas concentration) the gas can more or less spontaneously decompose according to the reaction $2\ ClO_2 \rightarrow 2\ Cl_2 + O_2$. Typically, unintentional releases are very small and, as the gas is diluted, the likelihood of explosion is almost zero.

To prevent decomposition, chlorine dioxide is stored as a water solution with a maximum concentration of about 1 % ClO_2 (approximately 10 g ClO_2 per litre of solution). In water solution the stability is good and the solution can be kept for several months when stored in cold and dark conditions.

The ClO_2 preparation process is designed to comply with all safety requirements and to avoid unintentional releases of chlorine gas and is described below.

- ClO_2 is dissolved in water to avoid decomposition as the above-mentioned reaction is a gas reaction.
- The concentration in the water solution is maintained low so as not to create an equilibrium gas concentration above the liquid that is high enough to cause explosion-like decomposition.
- All systems are rated to withstand the forces of decomposition and are equipped at critical points with pressure-relief valves.
- The ClO_2 generation plant is operated by specially trained staff who apply the adopted safety standards.

In pulp mills, chlorine dioxide is produced from chlorate (ClO_3^-) supplied as the sodium salt. For the reduction of chlorate, a number of reducing agents are commercially applied (see equation below): methanol (extra safety measures required), hydrogen peroxide, sulphur dioxide (extra safety measure also required) and chloride ions. Sulphuric acid is used as the acid. There are several techniques available to carry out the following reaction in a cost efficient manner:

chlorate + reducing agent + acid → chlorine dioxide + by-products.

Efficient ClO_2 generation methods maximise the chemical yield of chlorine dioxide from chlorate, minimise the by-product formation and ensure the stable and easy operation of the process.

This is normally achieved by operating under a stoichiometric excess of acid and reducing agents (see Table 3.1).

By operating under boiling vacuum conditions, the acid consumption can be decreased as the only emissions or waste from the reactor are the ClO_2 gas which is absorbed into water in the absorption tower, and the solid by-product (sodium salt) that is formed when the solubility limit is exceeded and which is separated on a filter (salt cake).

If operated under atmospheric conditions, the by-product salts are mixed with the excess acid and become 'spent acid'.

The partial pressure of chlorine dioxide is kept below the stability limit by either a low total pressure (vacuum processes) or by dilution with air (atmospheric processes). Table 3.1 shows the most important techniques for the on-site generation of chlorine dioxide at the time of writing (2013).

Table 3.1: Important large-scale techniques for manufacturing chlorine dioxide

Reducing agent	By-products in the ClO_2 product	By-products	Process technologies		Potential specific environmental concern
			Vacuum	Atmospheric	
Methanol	Formic acid	Sodium Sulphate (1)	SVP-LITE, SVP-SCW, R8, R10	(Solvay)	NA
Hydrogen peroxide	(Oxygen)	Sodium Sulphate (1)	SVP-HP, SVP-Pure, R11	HP-A	NA
Sulphur dioxide	NA	Sodium Sulphate (1)	NA	Mathieson	Handling of SO_2
Chloride ions	Elemental chlorine	(Sodium Sulphate (1)) Sodium chloride	(SVP-Classic), (R3), R6, (R7), SVP-Total HCl, Lurgi, Chemetics	(Day-Kesting), (R2), (R3)	The ClO_2 water becomes saturated with Cl_2

NB: Processes mentioned within brackets are no longer relevant for new plants; some units are still in operation.
NA = not available
(1) The generated salt can be used as a make-up chemical in the recovery boiler or for pH adjustments.
(2) Chlorine dioxide is not traded as such. Important trade does however exist for various large-scale processes.

- SVP-SCW, SVP-LITE, HP-A, SVP-HP, SVP-PURE, SVP-Classic and SVP Total HCl are trademarks of Akzo Nobel.
- ERCO R3, R3H, R5, R6, R7, R8, R10, R11, R12 and R13 are trademarks of ERCO Worldwide.
- Some other common names are Mathieson and Solvay processes.

Source: [213, Pelin 2009]

The formation of by-products is critical for both process economics and for the quality of the generated ClO_2. Table 3.2 shows the consumption of raw materials and the formation of by-products for some commercially important chlorine dioxide generators (in t/t ClO_2). It also shows that the main techniques which produce minimal by-product chlorine are the Mathieson process, the higher R–Series ClO_2 processes (e.g. R8, R10, R11) or the HP-A or SVP processes.

Table 3.2: Consumption of raw materials and by-product formation for some commercially important chlorine dioxide generators

Technique	Mathieson (1)	HP-A	SVP-LITE, R8	SVP-SCW, R10	SVP-HP, R11 (2)	Integrated SVP Total HCl or R6
Raw materials (t/t ClO_2)						
Sodium chlorate	1.8	1.65	1.65	1.64	1.65	NA
Sulphuric acid	1.40	2.10	1	0.8	0.78–1.03 (2)	NA
Sulphur dioxide	0.8	NA	NA	NA	NA	NA
Methanol	NA	NA	0.17	0.17	NA	NA
Hydrogen peroxide	NA	0.29	NA	NA	0.29–0.32	NA
Elemental chlorine	NA	NA	NA	NA	NA	0.73
Steam	NA	NA	4.2	5.5	5.5	8
Electrical power (kWh)	80	80	130	160	130	8 900
By-products (t/t ClO_2)						
Chlorine in ClO_2 (aq)	0	0	0	0	0	0.24
$Na_3H(SO_4)_2$	NA	NA	1.35	NA	1.35 (2)	NA
Na_2SO_4	1.20	1.10	NA	1.1	1.1 (2)	NA
H_2SO_4	1.5	1.30	NA	NA	NA	NA
O_2	NA	0.26	NA	NA	0.26	NA

NB: NA = not available
(1) Operated without the addition of salt.
(2) The amount of acid consumed in the vacuum hydrogen peroxide-based processes depends on the operating conditions. These conditions also determine if $Na_3H(SO_4)_2$ or Na_2SO_4 are formed.
Source: [213, Pelin 2009]

For most pulp mills the by-product sodium sulphate is a usable salt. It can be added to the concentrated black liquor before entering the recovery boiler and can be recovered as a cooking chemical. The sulphate from the Mathieson and HP-A processes also contains considerable amounts of sulphuric acid (H_2SO_4). It can be used for pH adjustment or in the soap acidification in the tall oil process. If the by-product salt is sodium chloride, it can be used for chlorate production. Ideally, any sodium and sulphur by-product from the generation of chlorine dioxide could be taken into the pulp mill as make-up chemicals and there would be very little or no effluent. However, if sodium or sulphur is produced in excess of the mill make-up requirements, they have to be removed from the process.

The only processes that can provide chlorine dioxide without formation of elemental chlorine are the methanol-based vacuum processes (SVP-LITE, SVP-SCW, R8, R10), the hydrogen peroxide-based processes (vacuum: SVP-HP, R11, atmospheric HP-A) and the atmospheric sulphur dioxide-based Mathieson process.

A potential problem when ClO_2 is used is the formation of chlorate. About 10 % of ClO_2 as active chlorine is converted into chlorate. This means that about 4 – 6 kg of chlorate is formed per tonne of pulp in ECF bleaching at kappa 18. Chlorate is toxic to bacteria and plankton at levels of about 3 – 4 mg/l. In addition, it inhibits the growth of brown algae, e.g. bladderwrack, at concentrations from about 20 micrograms/litre. The reason is that when N is the limiting factor for growth, algae take up chlorate, which is a known herbicide, instead of NO_3^-. However, chlorate is a manageable issue for mills with properly designed and operated effluent treatment plants. For example, the modern Fray Bentos mill (UPM) in Uruguay reduces the chlorate from the discharged effluent to > 99 % in the final effluent when compared to the incoming effluent from the bleach plant. Measurements from Swedish mills (*Source*: Swedish statistical data 2008) give chlorate emissions between 0.05 and 1.5 kg chlorate per tonne of ECF kraft pulp, with 0.22 kg chlorate/t ECF kraft pulp being the average.

In bleached kraft pulp mills using chlorine dioxide as a bleaching chemical, chlorine compounds from the bleach plant and the ClO_2 production are released to the atmosphere. In both the vacuum and the atmospheric processes the chlorine dioxide water is produced in the absorption tower. From there, the chlorine dioxide water is pumped to the storage tanks of the bleach plant. The tail gas is further scrubbed to avoid Cl_2 emissions. However, low concentrations of Cl_2 are measured after the scrubber and for example in ventilations from the bleach plant (see also Section 3.2.2.2).

3.1.12.2 Ozone

Ozone is produced from dry air or oxygen by the application of high voltages (10 – 20 kV) across two electrodes separated by the reactant gas. Ozone is not very stable and the yield of ozone is fairly low with a high level of unreacted oxygen expected in the product gas. Ozone is a very hazardous chemical and has strict limits for its release to atmosphere in terms of occupational health and safety. Most mills produce ozone on site, but in some cases it is supplied by outsourced equipment.

The first fibre lines producing ozone-bleached pulp are mainly from the emergence of totally chlorine free (TCF) bleaching during the 1990s. Today, 28 pulp mills, distributed in various parts of the world, producing hardwood and softwood bleached pulps, are using ozone in their bleaching process with good results with regards to product quality, and environmental and process performance. In recent years, significant progress has been made in the use of ozone, favouring on-site chemical production including complete reuse of by-products, and reducing operating costs. Concerning optimisation of on-site chemical production, the overall concept is based today on 100 % oxygen recycling since each oxygen molecule is used twice: first to produce ozone and then for other applications such oxygen delignification, white liquor oxidation and effluent treatment.

In some cases, ozone is used to reduce the chemical cost and to improve the environmental impact. It is generally applied just after oxygen delignification to finalise lignin removal before the final bleaching phases. Keeping the bleaching chemical cost low, extended ozone delignification offers the possibility to reduce the effluent to be treated since the filtrate from the ozone (Z) stage and further alkaline stages can be circulated back to the recovery boiler. Finally, whether it concerns greenfield mills, capacity expansion projects or retrofit options, ozone is frequently investigated at the initial phase of the project, giving the mill the opportunity to adopt an efficient bleaching process like those, as latest references, in operation in Portugal (Celtejo), Australia or India.

For chemical pulp bleaching, the ozone charge is generally in the range of 4 – 8 kg per tonne of pulp. Depending on the mill expectations and equipment supplier, the ozone stage can be supplied at high (HC) or medium (MC) pulp consistency. The advantages of the implementation of this technology are:

- Minimise water usage as much as possible with closure of water loops, reducing environmental impact (low or no AOX, limited COD and colour emissions) using ECF-light or TCF bleaching.
- Favour on-site chemical production including partial or complete reuse of by-products (avoid transportation, delivery and storage of dangerous chemical precursors).

- Guarantee a pulp quality at least equivalent to common standards (ECF), and providing opportunities to develop new pulp and paper grades (food contact applications as an example).

The low kappa number obtained after the Z stage together with the recycling of the Z filtrate makes it possible to minimise the bleach plant impact. For ECF, an adequate balance between ozone, chlorine dioxide and peroxide charges was found to optimise variable costs. The potential for savings is even boosted by the recycling of the off-gases.

A complete, newly designed oxygen recycling system was installed at Celtejo, Portugal. Due to this new design, the off-gas from the Z stage contains more than 85 % oxygen. The gas is recycled through a two-stage liquid ring compressor system. Several control and bypass systems guarantee the independent optimisation of each stage. Liquid oxygen is used as a back-up. The recycled oxygen is supplied to two independent operating consumers: to the Total Oxidised White Liquor (TOWL) process and to the oxygen delignification stage. The 'unconsumed' part is handled in a catalytic ozone destruction system which is considered a back-up safety system.

3.1.12.3 Other bleaching chemicals

Other bleaching chemicals are mainly brought in ready for use, e.g. hydrogen peroxide as a solution; dithionite as a solid; solutions that contain enzymes (in some mills); etc. Oxygen is mainly purchased but there are a few mills in Europe which generate oxygen on site (separation of O_2 from air). In a few pulp mills, in TCF bleaching sequences, peracetic acid is used as a bleaching chemical. Peracetic acid can also be used for ECF bleaching. For the production of peracetic acid, about 3 kWh electricity/kg of product is required.

3.2 Current consumption and emission levels

3.2.1 Overview of input/output for the production of kraft pulp

An overview of the raw material and energy input as well as the output of products, by-products and the major releases (emissions, waste, etc.) of the production of kraft pulp is presented in Figure 3.4.

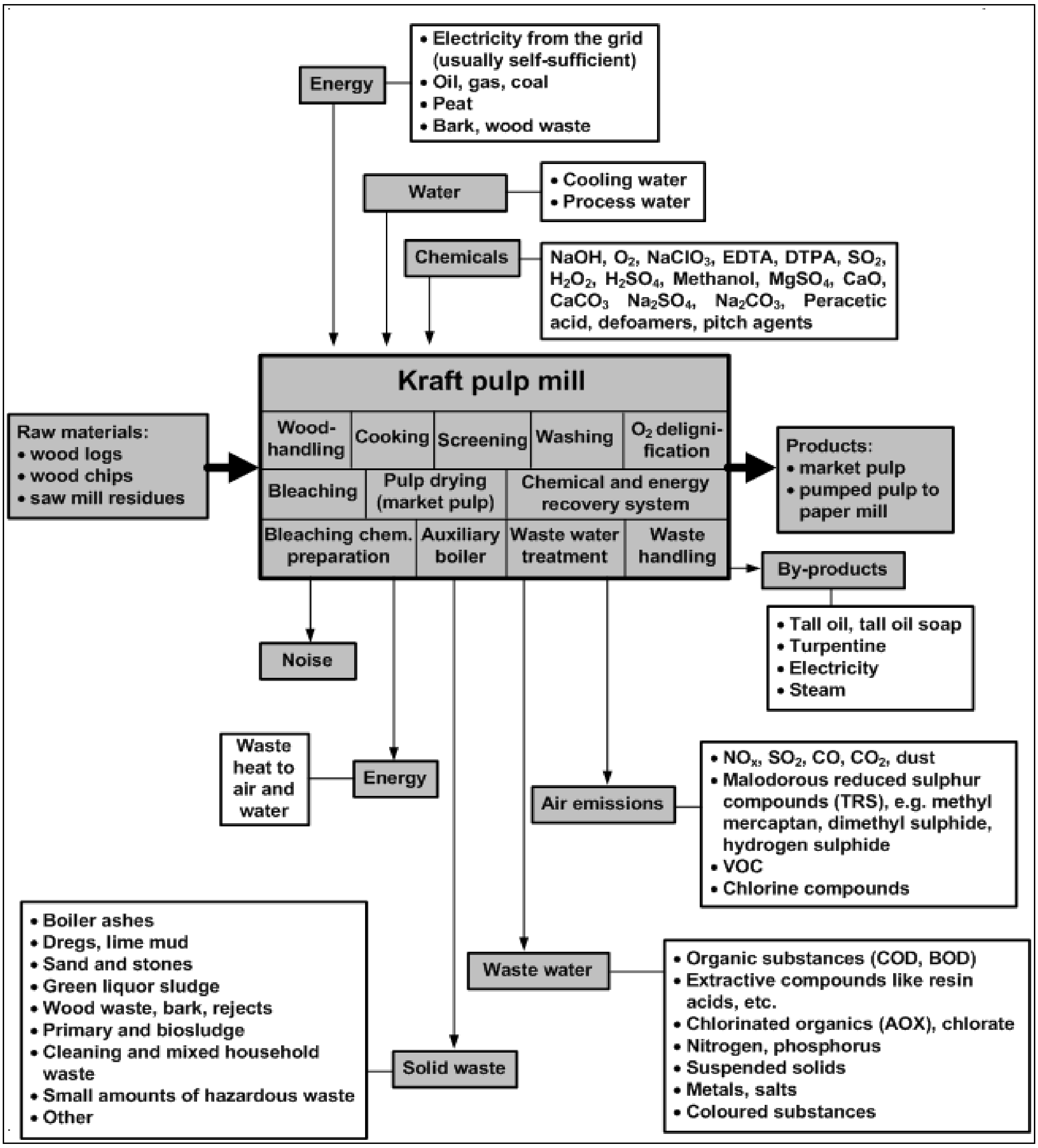


Figure 3.4: Mass stream overview of input and output of a kraft pulp mill

The use of some chemicals depends on the type of delignification and bleaching. Whether they are released to the environment depends on the process design and operation (recovery system, recirculation flows, etc.) and the waste water treatment plant.

The subsequent sections present specific consumption data, as well as specific emissions data, for individual operational units associated with kraft pulp manufacturing.

3.2.2 Consumption and emission levels arising from process units

In kraft pulping, the waste water effluents and the emissions to air including malodorous gases are the points of interest but in recent years integrated concepts for utilisation and disposal of solid waste have become an environmental issue of concern. These waste management concepts include the comprehensive and best possible material or thermal utilisation of all waste materials particularly the residues with a high content of organic matter. The aim is to reduce the amount of waste that has to be disposed of in landfills.

The most relevant consumption of raw materials and emissions to water, air and soil (waste) as well as energy aspects are discussed below covering the following aspects:

- wood consumption;
- water consumption and waste water emissions from different process units:
    - wood handling
    - condensates from evaporators
    - spillages
    - washing losses
    - bleaching
    - discharges of nutrients
    - discharges of metals;
- emissions to the atmosphere such as:
    - from the recovery boiler
    - from the lime kiln
    - from auxiliary boilers
    - malodorous gases
    - chlorine compounds from bleaching and bleaching chemical preparation;
- solid waste generation;
- consumption of chemicals;
- use of energy;
- noise.

Where data are available, emissions to water, air or soil (waste) are given before and after external treatment.

3.2.2.1 Wood consumption

All wood species can be used as raw material in the kraft pulp process. Logging and sawmill residues can also be pulped with the kraft pulp process. The use of wood and the yield for the production of bleached pulp is dependent on the selectivity in delignification and bleaching. The wood required for manufacturing 1 tonne of chemical pulp is normally between 3 m^3 and 6 m^3. The amount of bark is generally between 12 – 15 % by weight. The yield and amount of bark generated depend on the wood types used (see also Section 3.3.1).

3.2.2.2 Consumption of chemicals

The consumption of chemicals varies from mill to mill and is to a certain extent regarded as confidential. However, the typical consumption of the main chemicals is reported in Table 3.3.

Table 3.3: **Consumption of main chemicals for bleached and unbleached kraft pulp production**

Substance	Consumption for unbleached kraft pulp (kg/ADt)	Consumption for bleached kraft pulp (kg/ADt)
NaOH	10 – 20	25 – 50
O_2	NA	5 – 25
$NaClO_3$	NA	15 – 50
EDTA	NA	0 – 4
SO_2	NA	2 – 10
H_2O_2	NA	2 – 30
O_3	NA	0 – 5
$MgSO_4$	NA	0 – 3
CaO	5 – 10	5 – 10

NB: All chemical consumption values are expressed as 100 % effective chemicals and not as commercial solutions containing various amounts of water.
NA = not available
Source: [14, CEPI 1997].

The main purposes of the chemicals mentioned are indicated below.

- Magnesium sulphate is added at the rate of 0 – 2 kg $MgSO_4$/ADt for hardwood or 2 – 3 kg $MgSO_4$/ADt for softwood in order to preserve the strength of the pulp in oxygen delignification.
- The consumption of oxygen for delignification is 12 – 15 kg/ADt for hardwood pulp and 20 - 25 kg/ADt for softwood pulp.
- The alkali consumption is 12 – 15 kg NaOH/ADt for hardwood and 20 – 25 kg NaOH/ADt for softwood [1, Finnish BAT Report 1997].
- Chelating agents like EDTA and DTPA are used to remove the metals in hydrogen peroxide bleaching sequences in order to prevent the decomposition of the hydrogen peroxide. Emissions of chelating agents might affect the distribution of the metals in the receiving water body and in the organisms living there. Moreover, the use of chelating agents causes emission of nitrogen, the amount of which depends on the amount of agent used.

Under stable running conditions, it is a fundamental physical rule that any substance entering a mill also exits the mill. In kraft pulp mills using NaOH and Na_2S as the main cooking chemicals the input and output of sodium and sulphur have to be controlled and balanced. The requirement for reduced emissions of sulphur dioxide from mills implies that preferably less sulphur should enter the mill or that sulphur has to be discharged as a less harmful substance (for example as sulphate). The main sources of sulphur are listed in Table 3.4.

Table 3.4: **Typical sulphur inputs to a bleached kraft pulp mill**

Source	Amount of sulphur [kg S/ADt]
Wood, water, chemicals	0.3 – 0.5
Fuel oil to lime kiln and recovery boiler	1.0 – 2.0
Tall oil production	2.0 – 3.0 (1)
Chlorine dioxide generation	0 – 15 (2)
Magnesium sulphate for oxygen stage	0 – 0.8
Total	3.5 – 25.5

(1) Often spent acid from chlorine dioxide production can be used.
(2) Depending on the type of process and valid for a mill using up to 40 kg/ADt of chlorine dioxide expressed as active chlorine.
Source: [127, SEPA report 1992]

The sulphur emissions to air from process point and non-point sources of kraft mills can be approximated as 0.2 – 0.4 kg S/ADt. Losses of sulphur in water effluents can be estimated to correspond to 2 kg S/ADt [127, SEPA report 1992]. Thus, the total losses of sulphur from a pulp mill would be around 2.3 kg S/ADt. A comparison with the intake of sulphur when operating with a high proportion of chlorine dioxide in bleaching shows that a high amount of sulphur may have to be discharged or disposed of as neutral salts (e.g. Na_2SO_4). However, this will simultaneously cause sodium losses that need to be compensated for by more expensive sulphur-free sodium make-up chemicals. To determine the correct chemical consumption levels, the chemical balances have to be worked out on a case-by-case basis for each mill and each process.

3.2.2.3 Energy consumption

Most of the heat energy is consumed for heating different fluids and for evaporating water. Heat energy is also used to accelerate or control chemical reactions. Electrical energy is mostly consumed for the transportation of materials (pumping) and for the operation of the paper machine (only in integrated pulp mills).

The manufacturing of bleached kraft pulp consumes about 10 – 14 GJ/ADt of heat energy (excluding steam for the production of electrical power). The consumption of electrical energy is 600 – 800 kWh/ADt, including the drying of pulp. The energy consumption for pulp drying is about 25 % of the heat energy and 15 – 20 % of the electrical energy. Over 50 % of the electrical energy consumption is used for pumping.

The trend today is to decrease power consumption and increase power production, and now the pulp and paper industry power plants tend to be equipped with a small condensing tail to their back-pressure turbine. Modern pulp mills in particular are more than self-sufficient and surplus power has become a sales commodity with a good profit margin due to increased power prices.

Table 3.5 shows the heat and power balance for a typical modern kraft pulp mill and an integrated pulp and paper mill.

Table 3.5: Heat and power balance for typical modern market pulp mill and an integrated pulp and paper mill

Mill type	Units	Non-integrated bark-fired pulp mill	Fully integrated bark-fired pulp and paper mill
Heat generation			
Black liquor	GJ/t pulp	18.0	18.0
Bark and wood waste	GJ/t pulp	4.2	4.2
Heat consumption			
Pulp mill process	GJ/t pulp	11.0	8.5
Paper mill process	GJ/t paper	-	6.0
Back-pressure power	GJ/t pulp	3.0	4.0
Condensing power	GJ/t pulp	8.2	3.5
Power generation			
Back-pressure power	kWh/t pulp	820	1 150
Condensing power	kWh/t pulp	800	340
Total	kWh/t pulp	1 620	1 490
Power consumption			
Pulp mill process	kWh/t pulp	700	550
Paper process	kWh/t paper	-	650
Power to grid	kWh/t pulp	920	290
Source: J.Suutela, Pöyry Finland Oy			

Table 3.5 shows how a market kraft pulp mill and an integrated pulp and paper mill can generate large amounts of electrical energy for other consumers outside the pulp and paper industry sector. This is the case when a mill needs energy as heat rather than electricity.

Chemical pulp mills are on the one hand energy-intensive installations that consume high amounts of energy but which at the same time produce steam and electrical power on site by use of regenerative fuels (see Table 3.5). Modern non-integrated kraft pulp mills are energy self-sufficient mainly because of efficient energy recovery by burning 50 % of the incoming wood in the recovery boiler (strong black liquor) and the use of bark as fuel. Furthermore, secondary energy from different process steps can be recovered as warm and hot water (40 – 80 °C). Fossil fuels are mainly used as support fuel, in the lime kiln and in the odorous gas treatment. Some mills reduce the need for fossil fuels for the lime kiln by using biomass-based fuels such as powdered bark, gas from bark gasifiers, methanol or tall oil for lime reburning.

The conventional power plant configuration in a non-integrated kraft pulp mill is a recovery boiler and a bark boiler feeding a back-pressure turbine with intermediate steam tapping and, possibly, condensing. The recovery boiler acts as a power station where the strong black liquor is burnt and the heat generated is utilised for the generation of high-pressure, superheated steam. Part of the energy content in the high-pressure steam is utilised for generating power in a back-pressure turbine. Medium-pressure steam extracted from the turbine and low-pressure exit steam are utilised for covering the heat energy demand in the kraft pulp process.

Malodorous gases are collected and burnt. Burning diluted NCG generates no/little net energy and they are mainly burnt for environmental protection reasons and to avoid unpleasant odours in the neighbourhood and for workers. Concentrated NCG (CNCG) have a heat content of 50 – 200 MJ/ADt and can replace up to 15 – 20 % of the fuel oil used in the lime reburning kiln.

In an integrated pulp and paper mill, the excess heat produced by the pulp mill is often not sufficient to cover the energy consumption of the paper production. The additional demand for heat has to be produced in wood/bark boilers and auxiliary boilers. Fossil fuel is used as support fuel in bark and sludge boilers and as the main fuel in auxiliary boilers as well.

Peaks in energy consumption are often satisfied by using smaller boilers fed with fossil fuel. Combined heat and power (CHP) plants based on a gas turbine in combination with a steam boiler and steam turbine are very efficient and many installations have been built in Europe.

Some additional figures on the energy consumption of the individual process stages of pulp mills are given below.

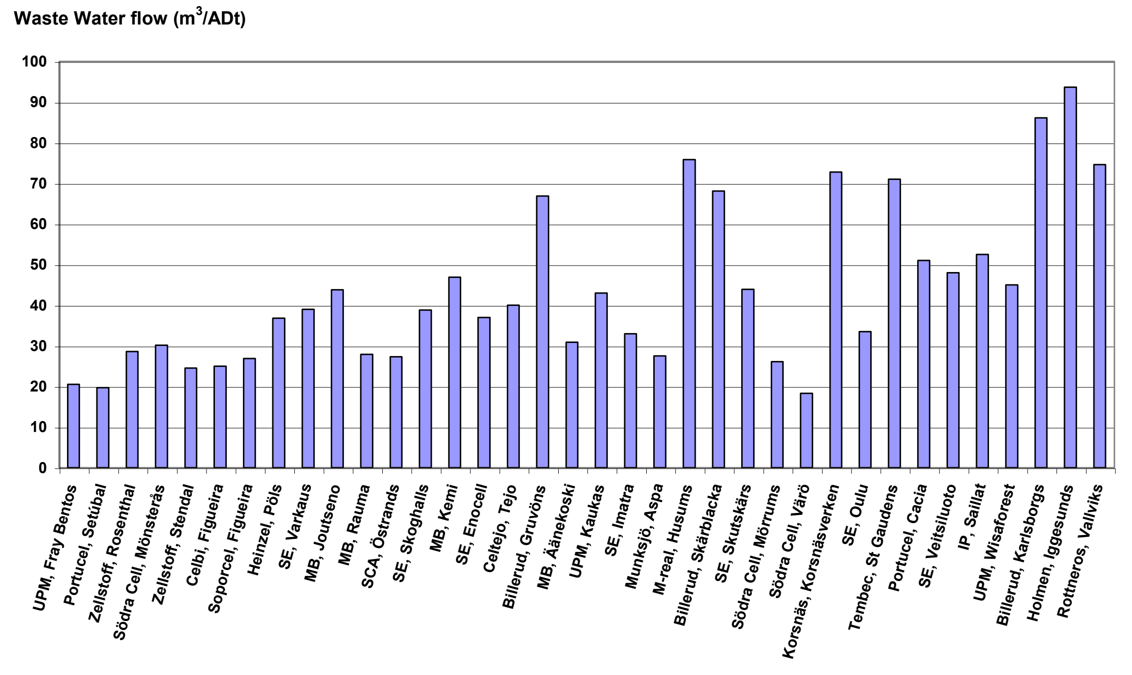
- De-icing will consume about 30 MJ of heat as hot water or steam per m^3 of wood processed.
- The total energy consumption in debarking is 7 – 10 kWh/m^3 of wood [1, Finnish BAT Report 1997].
- The energy consumption of a bark press is about 5 kWh/ADt of bark with an initial dryness of about 35 % and the increase in heat generation is about 2 GJ/ADt or 45 % if the dryness increases from about 35 % to 45 %.
- The energy for pulp drying (only market pulp) can be of the order of 3 GJ/ADt of pulp or some 25 % of the total heat requirement for a kraft pulp mill and 15 – 20 % of the electrical energy.
- The average electrical energy consumption in the manufacture of bleaching chemicals is presented in Table 3.6.

Table 3.6: Average electrical energy consumption in the manufacture of bleaching chemicals

Chemical and (bleaching stage code)		Electrical energy consumption [kWh/kg chemical]
Chlorine dioxide	(D)	10
Oxygen	(O)	0.4
Ozone	(Z)	10
Peroxide	(P)	3.5
Alkali	(E)	1.6
Source: [1, Finnish BAT Report 1997]		

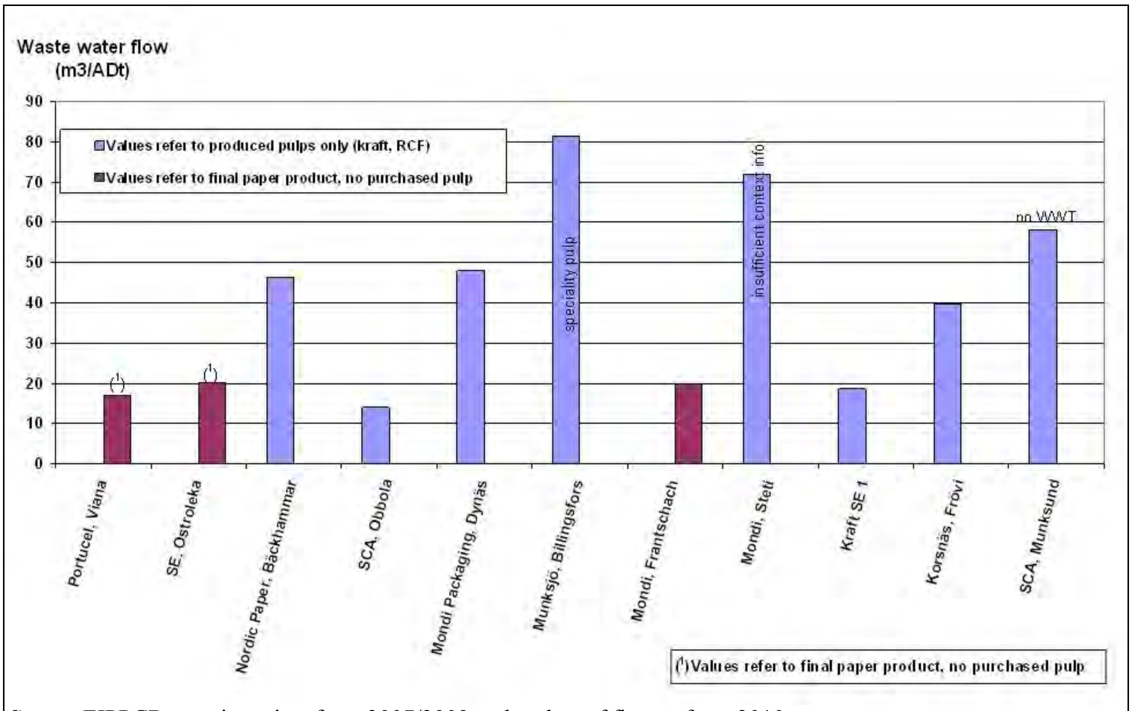
3.2.2.4 Water consumption and waste water flow

The waste water flow of bleached kraft pulp mills vary between 20 and 90 m^3/ADt as shown in Figure 3.5 and for unbleached kraft pulp mills between 14 and 80 m^3/ADt as shown in Figure 3.6.



Source: EIPPCB questionnaires from 2007/2009 and update of figures from 2010

Figure 3.5: Specific waste water flow of bleached kraft pulp mills



Source: EIPPCB questionnaires from 2007/2009 and update of figures from 2010

Figure 3.6: Specific waste water flow of unbleached kraft pulp mills

Water consumption can be reduced in a pulp and paper mill by increasing internal water recirculation. In a kraft pulp mill, it can be achieved for example by changing wet debarking to dry debarking, by changing over to more efficient washing equipment, by recycling alkaline bleach filtrate or filtrates from ozone bleaching, by using the condensates from evaporation and by closing the screen room with respect to water.

There is a difference in water management between integrated and non-integrated pulp mills. In an integrated mill, the pumpable pulp comes from the pulp process to the papermaking process. The pulp consistency depends on the dewatering device between the pulp and paper mill. Waste water from pulping and from papermaking is often treated in one single treatment plant. However, separate treatment plants are also used at integrated mills. In non-integrated pulp mills, the market pulp is dewatered and dried.

The volume of water used is closely linked to the waste water load discharged from the mill. The pollution depends mainly on the design and operation of the processes that cause most of the discharges and on the degree of closure of the mill. The main sources of waste water and the corresponding load of pollutants are discussed below.

3.2.2.5 Emissions to water

As shown in Figure 3.7, emissions to water from a kraft pulp mill originate from different process stages. They also include accidental spills.

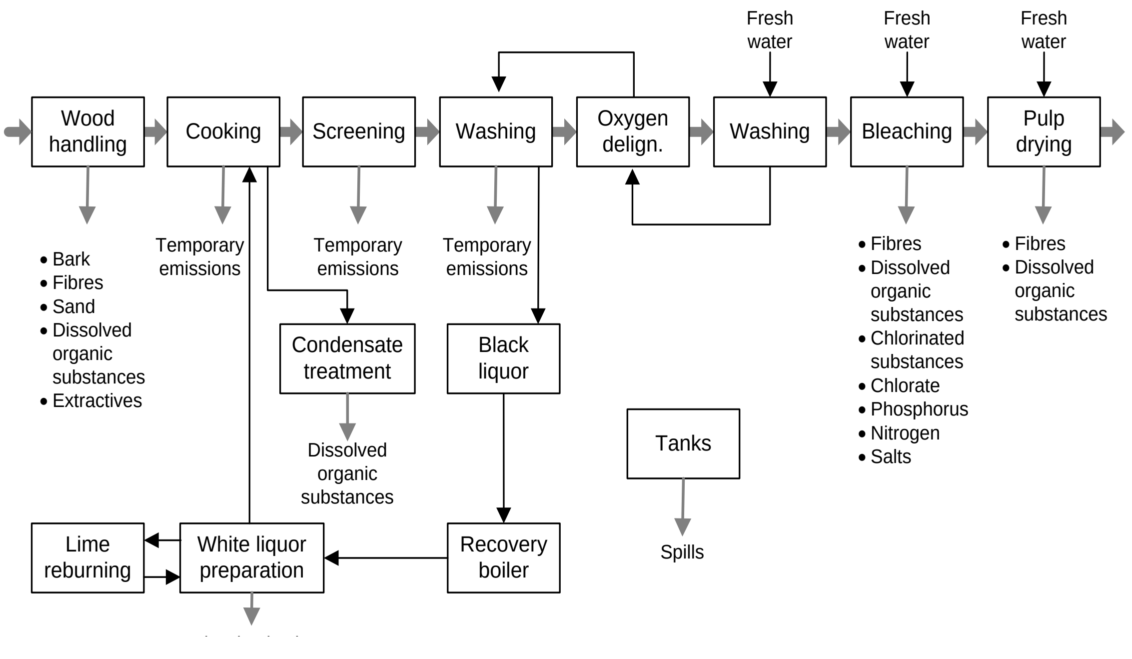


Figure 3.7: **Emissions to water from a kraft pulp mill**

Emissions to water are dominated by oxygen-consuming organic substances, which are measured as COD and BOD and/or TOC. Effluent from the bleach plant, where bleaching chemicals containing chlorine are used, contains organically bound chlorine compounds, measured as AOX, and chlorate. Some compounds discharged from mills show toxic effects on aquatic organisms when untreated. Emissions of coloured substances may affect the living species in the recipient negatively, since the water transparency is decreased. Emissions of nutrients (nitrogen and phosphorus) have a negative impact due to eutrophication. In lower concentrations, individual metals extracted from the wood can be detected in the effluents.

3.2.2.5.1 Waste water from different process steps

Waste water from wood handling

The major source of pollution in wood handling is the debarking plant. Storm water run-off from the wood yard might also be polluted. The debarking plant uses water and creates an effluent containing nutrients, fibres and oxygen-consuming organic compounds like resin acids, fatty acids, etc. that are toxic to aquatic life before treatment. Biological treatment has proven to be very efficient in eliminating toxicity. In a change from wet to dry debarking, water consumption and discharges are reduced significantly (see Table 3.7). In wet debarking 0.6 – 2 m^3 of water is used per solid m^3 of wood. Dry debarking still uses 0.1 – 0.5 m^3 water per m^3 of wood to wash the logs and some organics are dissolved but to a lesser extent compared to wet debarking. Spans in pollution load in debarking effluents are given in Table 3.7 below.

Table 3.7: **Pollution load of debarking effluent before biological treatment**

Debarking technique	Effluent volume m^3/m^3 wood	kg BOD_5/m^3 wood	kg COD/m^3 wood	g $Tot\text{-}P/m^3$ wood
Wet debarking and press	0.6 – 2	0.9 – 2.6	4 – 6	5 – 7
Dry debarking and press	0.1 – 0.5	0.1 – 0.4	0.2 – 2	2 – 4

NB: BOD_7 has been converted into BOD_5 by use of the formula $BOD_7 / 1.16 = BOD_5$ proposed within the same report.
Source: [1, Finnish BAT Report 1997]

Bark is normally 35 – 45 % solid content (dryness) on the tree. After normal wet or dry debarking, the bark is about 30 – 35 % dryness. The dryness of the removed bark is only marginally influenced by the debarking technique. This is because dry debarking means that water is recycled not that water is not used. The dryness of the bark can be increased to 40 – 45 % in a bark press but then there is an additional press effluent to consider. Bark press effluent is toxic and high in COD (20 – 60 kg COD/m^3). It could be dealt with by feeding it to the digester with the chips for subsequent evaporation and burning of the concentrate in the recovery boiler. Pressing of the bark improves the heat generation. A few mills run a bark and sludge dryer that further improves the heating value.

During the winter in northern countries, frozen logs must be thawed before debarking. In wet debarking, this can be done in the debarking drum with hot water or steam. Dry debarking plants use special de-icing conveyors before the debarking drum. At any given installation the water consumption and discharges from dry debarking will increase and will then be in the middle to upper range given in the above table.

Condensates from cooking and evaporation
Condensates originate from the process vapours from digesters and the evaporation plant. About 8 – 10 m^3/ADt of total condensates are formed with an organic load of about 20 – 30 kg COD/ADt or 7 – 10 kg BOD$_5$/ADt. The COD is mainly methanol (5 – 10 kg/ADt) with some ethanol and a number of organic sulphuric compounds (1 – 2 kg TRS/ADt), 1 – 2 kg turpentine and inorganic nitrous compounds. Furthermore, foul condensate contains ketones, terpenes, phenolics, resin and fatty acids and various dissolved gases. A large proportion of nitrogen discharged from a kraft pulp mill is contained in the condensates.

About 1 m^3 of condensate per tonne of pulp has a COD concentration of 10 – 20 kg COD/m^3. The level is higher in condensates from hardwood pulp than from softwood. These strong condensates are normally treated in a stripper where the removal efficiency for most compounds is over 90 % depending on the pH. Stripping systems usually remove malodorous gases (TRS) and COD-contributing substances at the same time. Stripped condensates after treatment can be 1 – 1.5 kg COD/m^3 of condensate. Normally about 0.2 tonnes of steam/tonne of condensate is fed to the stripper column. Energy-saving techniques enable the steam consumption to be lowered from 0.2 t steam/t of condensate down to 0.02 – 0.04 t steam/t of condensate. The stripped gases are either incinerated in a dedicated burner with subsequent SO$_2$ scrubbing or burnt in the lime kiln.

About 7 – 9 m^3 of weaker condensates are formed with an organic load that ranges from 0.5 to 2 kg COD/m^3 containing a total of about 8 – 12 kg of COD/ADt of pulp. These condensates are free of metals and therefore particularly useful for washing in the bleach plant when aiming at closing up this part of the process. They can also be reused as scrubbing liquor for lime kilns or as white liquor make-up water. This means that some condensates will be used in closed parts of the process and not discharged to waste water. Other condensates will be used in open parts, e.g. in the bleach plant, and end up in the effluent together with those condensates which are not reused but discharged directly. Measured as COD, the total discharge of condensates to effluent is normally about 4 – 8 kg COD/ADt and is mostly readily biodegradable.

Alternatively, moderately contaminated condensates can be stripped in a system linked to the evaporation plant thereby affecting treatment without any substantial additional use of energy. In this way, the total COD load before any reuse is reduced to about 5 kg COD/ADt, a reduction of about 50 % compared to only treating the most contaminated condensates.

Spills from different process stages
Spillage of fibres and black liquor occurs in the digestion plant, screening plant, and during washing. There are also spillages from the evaporation plant and from tanks. The spillage of white liquor, weak liquor, lime, etc. occurs during causticising. Most spills can be collected and recycled if adequate buffer volumes are used and appropriate procedures are employed. Leakage from mechanical components such as pumps can be limited, e.g. by choosing the right seals.

The conductivity or the fibre content of individual outflows of waste water are normally checked in order to decide which spilled liquids are recycled to the process and which are directed to waste. Improved collection of spillages can be achieved if clean water, such as cooling and sealing water, is piped off separately. The remaining spillage water can then be more easily recycled into the appropriate part of the process.

Measured as COD, discharge of organic matters in spills is normally between 2 and 10 kg COD/ADt. The lower figure is achieved using sufficiently large buffer volumes and proper supervision procedures. It should in principle be possible to reduce discharges of spills to zero if clean cooling and sealing waters are piped off separately, sufficient buffer volumes are in place and good housekeeping is practised. Improved collection of spillages not only reduces discharges to water but also allows the reuse of valuable resources like chemicals and fibres.

Black liquor residues (washing losses) from the handling of unbleached pulp
Pulp washing efficiency in chemical pulping relates initially to recovering as much as possible of the cooking chemicals and dissolved organic substances. Press washing at the final stage can reduce the amount of water from 6 – 10 m^3/ADt to 2 – 3 m^3/ADt, thereby increasing the amount of chemicals and contaminants burnt in the recovery boiler. The reduction of contaminants in the pulp is however less than the reduction of flow indicates. Washing is not 100 % efficient so a certain amount of chemicals and pollutants are transported with the pulp to the bleaching stage where they consume bleaching chemicals and enter the effluent.

Standardised methods exist for measuring this carry-over, which is often denoted by the term 'washing loss' and was originally measured as kg sodium sulphate per tonne of pulp. In 2013, the washing loss is normally measured as COD. Washing losses are currently typically 5 – 10 kg COD/ADt for softwood and 7 – 12 kg of COD/ADt for hardwood.

Discharges from the bleach plant
The bleach plant is the most important point of discharge of pollutants to water in a pulp mill. If the bleach plant can be entirely or partly closed, this would result in substantial further reductions in discharges to water of organic substances, nutrients and metals. Typical figures for waste water quantities from a bleach plant are around 25 m^3/ADt. Many mills have tried to increase the degree of closure of the bleach plant by reducing the water volume. Partial closure of the bleach plant is currently achieved at both ECF and TCF plants. Compared to open bleach plants, the reduction in COD load has been 25 – 50 % and the reduction in flow has been even greater, down to approximately 12 m^3/ADt compared to the more normal 25 m^3/ADt.

The emissions from the bleach plant depend on a number of factors: the degree of delignification achieved before the pulp enters the bleach plant, the washing loss, the bleaching sequences chosen and bleaching chemicals used, the type of wood, the final brightness of the bleached pulp to be attained and the degree of closure of the bleach plant.

In Table 3.8 examples showing the interrelation between wood type, techniques and degree of delignification before the bleach plant, and COD generated during bleaching are compiled. The kappa numbers are based on values currently attained on a commercial scale using various delignification techniques. The calculation for the discharge of residual lignin in kg COD/ADt assumes a discharge of approximately 2 kg COD per kappa unit and a pulp to be bleached to full brightness. However, where the kappa number is less than 10, the discharge of COD is closer to 1.5 kg per kappa unit.

Table 3.8: **Examples of the interrelation between wood type, techniques and degree of delignification before the bleach plant and COD generated during bleaching**

Cooking method	**O_2 delignification/ ozone bleaching**	**Hardwood pulp**		**Softwood pulp**	
		Kappa number into bleach plant	**COD [kg/ADt]**	**Kappa number into bleach plant**	**COD [kg/ADt]**
Conventional cooking	–	18	38	30	63
Conventional cooking	O_2 delignification	13	27	15	32
Modified cooking	–	16	34	20	42
Modified cooking	O_2 delignification	10	15	12	25
Further modified cooking	–	13	26	15	30
Further modified cooking	O_2 delignification	10	15	10	15
Source: [109, PARCOM 1994]					

For delignification stages, where it is possible to recirculate the filtrate for brown stock washing (O_2, O_3 delignification, acidic stages), the kappa number to be considered is the kappa number achieved after this stage using the same COD/kappa number relationship mentioned before.

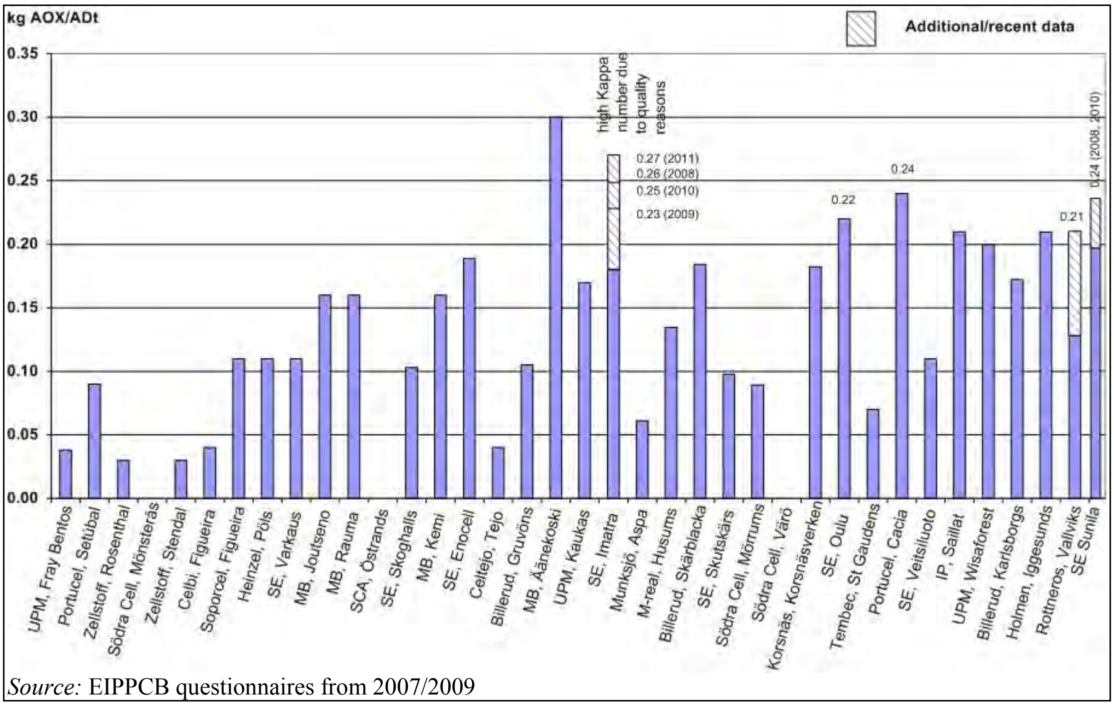
If only partial recirculation of delignification stage or middle bleaching stage filtrate is performed, the COD contribution must be assessed on a case-by-case basis because it is highly dependent on the effectively recirculated flows and the specific COD charge of the stage considered.

3.2.2.5.2 Main parameters and emission levels

Adsorbable organically bound halogens (AOX)

In Europe, mills stopped the use of molecular chlorine for the bleaching of pulp and, to date (2013), most pulp is bleached with chlorine dioxide bleaching sequences. Following market demands, some mills have completely eliminated the use of bleaching chemicals that contain chlorinated compounds by combining oxygen delignification with an ozone stage and/or a peroxide stage (TCF pulp). Peracetic acid (Paa) can also be used in TCF bleaching (see Section 3.3.7).

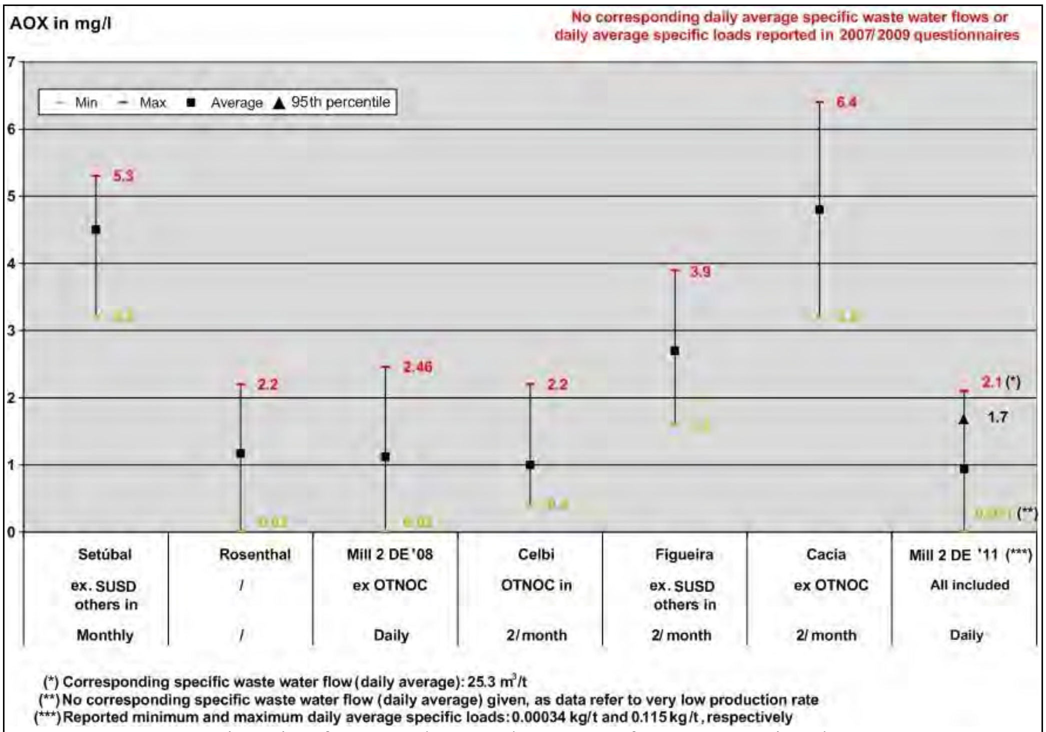
The discharge of adsorbable organically bound halogens, measured as AOX, depends on the kappa number achieved before the pulp enters the bleach plant, the chlorine dioxide charge applied in bleaching, the bleaching sequences including washing and water recirculation, and the effluent treatment. Pulps that enter the bleach plant with low kappa numbers require less bleaching chemicals, i.e. in ECF bleaching a lower ClO_2 charge resulting in lower AOX emissions. Figure 3.8 shows the yearly average specific AOX emissions of bleached kraft pulp mills at the point of discharge, i.e. after waste water treatment. Values vary between undetectable and 0.3 kg AOX/ADt of bleached pulp.



Source: EIPPCB questionnaires from 2007/2009

Figure 3.8: Specific AOX emissions from bleached kraft pulp mills

The short-term values reported for AOX emissions, both for bleached and unbleached kraft pulp, are shown in Figure 3.9.



Source: EIPPCB questionnaires from 2007/2009 and comments from Germany in July 2012

Figure 3.9: Short-term averages of AOX emissions from bleached kraft pulp mills

Chelating agents (EDTA/DTPA)

Modern bleaching sequences often include peroxide bleaching stages that require a removal of the metals (such as manganese, iron, copper ions) from the pulp due to their decomposing effect on peroxide. The removal of metals is usually carried out by a chelating treatment or an acid wash of the pulps. Chelating agents such as EDTA or DTPA are poorly biodegradable under normal conditions. Some mills have noticed that chelating agents are partly eliminated in their biological treatment plants. There is also a possibility to dose some of the chelating agent in the closed part of the mill and thus lower the emissions from the bleach plant. Few measurements were available. The concentration of EDTA in the waste water effluent from one modern mill manufacturing ECF before biological waste water treatment was reported as 50 mg /l as an average of 12 measurements (24-hour composite sample) during the year (variations between 34 mg/l and 63 mg/l).

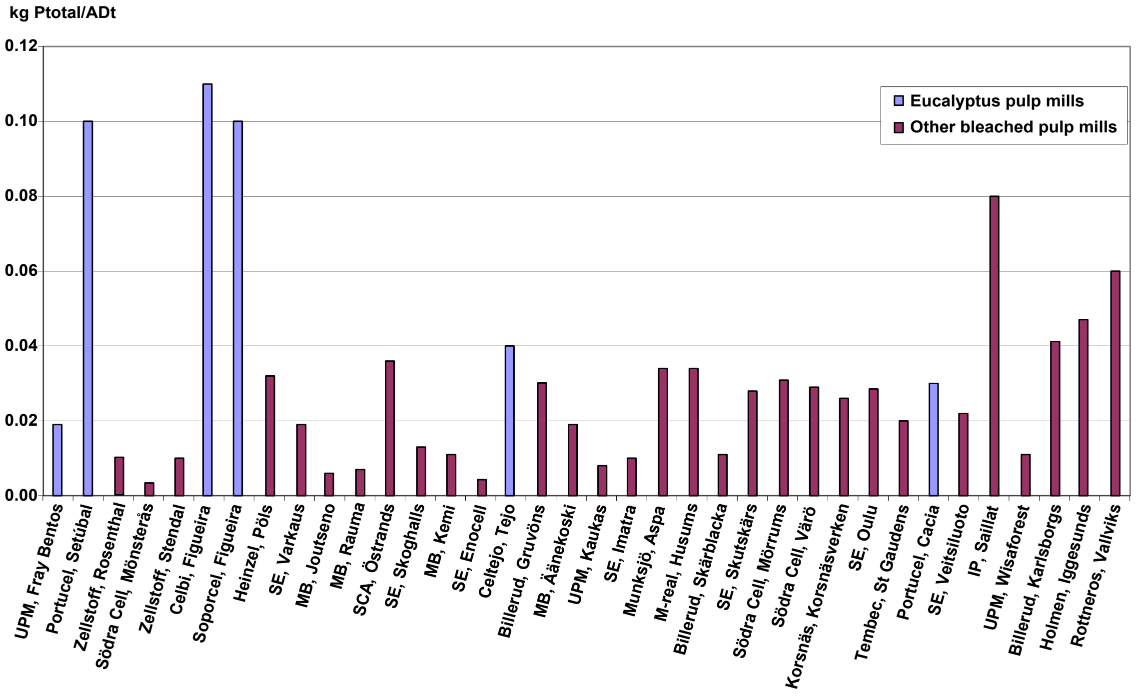
Organic substances (COD or TOC)

The specific emissions of organic substances from modern softwood and from hardwood are similar; only eucalyptus pulp mills may achieve slightly lower emissions. The main processes and events that contribute to the organic discharge from the mills are wood handling, condensates, spillages, washing losses and the bleach plant, which is the main contributor. The lowest total discharges of bleached kraft pulp mills before biological treatment are approximately 25 – 30 kg COD/ADt for softwood and 17 – 20 kg COD/ADt for bleached kraft eucalyptus. Specific COD emissions achieved after biological treatment are given in Section 3.2.2.5.3.

Discharges of nutrients (nitrogen and phosphorus)

Nutrients originate mainly from the wood although biological effluent treatment may require the addition of nutrients if deficient. Studies at kraft pulp mills have shown that nitrogen discharges principally derive from the unbleached part of the process, whereas phosphorus discharges come from the bleach plant.

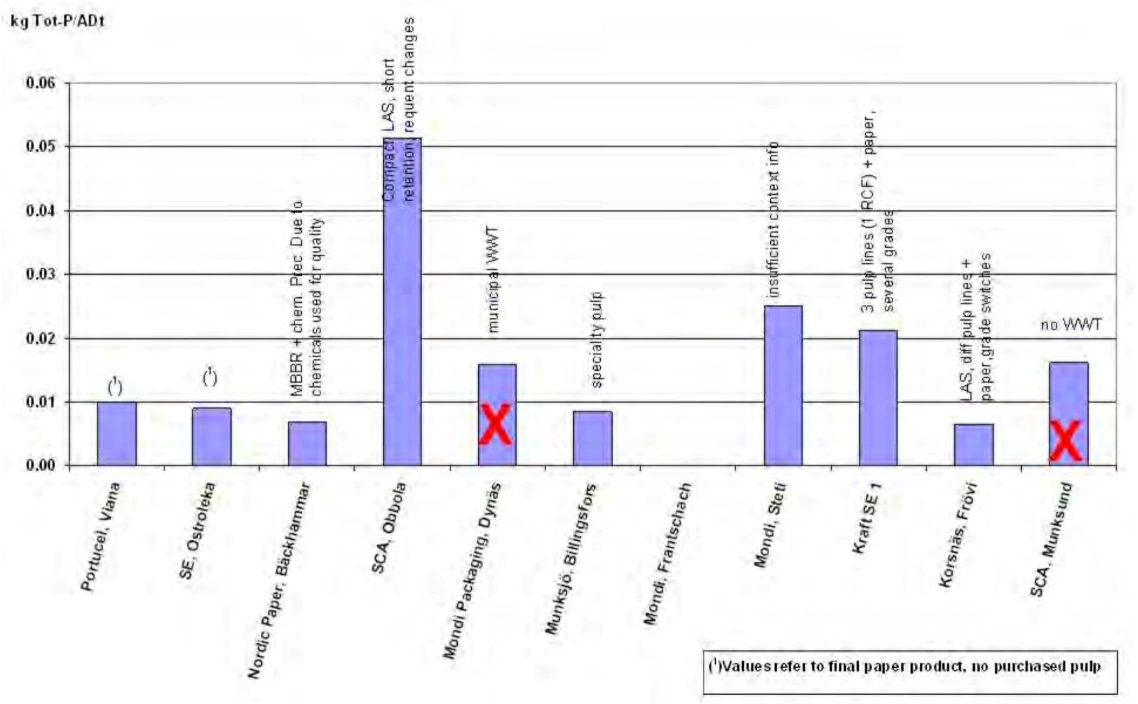
The prospects for reducing nutrient discharges from the process are mainly dependent on the possibilities of further processing the condensate and further delignifying the pulp in the closed part of the process. Figure 3.10 shows the yearly average specific emissions of total phosphorus (tot-P) for bleached kraft pulp mills after biological waste water treatment. Emissions vary between 0.003 and 0.08 kg tot-P/ADt, with the majority of mills achieving values below or well below 0.04 kg tot-P/ADt, and a few eucalyptus pulp mills discharging phosphorus emissions of up to 0.12 kg tot-P/ADt. Wood from Iberian eucalyptus stands contains higher levels of phosphorus compared to other forest species used for pulp production in Europe and elsewhere. Even though no phosphorus is added as a nutrient in a biological treatment plant, the level in discharged effluents is much higher compared to other production sites using non-eucalypt forest species. This is the case assuming that no flocculants are added for phosphorus removal. For eucalyptus pulp mills using wood from regions with higher levels of phosphorus, the average level discharged with the effluent is up to 0.12 kg tot-P/ADt.



Source: EIPPCB questionnaires from 2007/2009

Figure 3.10: Specific emissions of total phosphorus from bleached kraft pulp mills

Specific yearly average emissions of total phosphorus (tot-P) for unbleached kraft pulp mills after biological waste water treatment are shown in Figure 3.11.

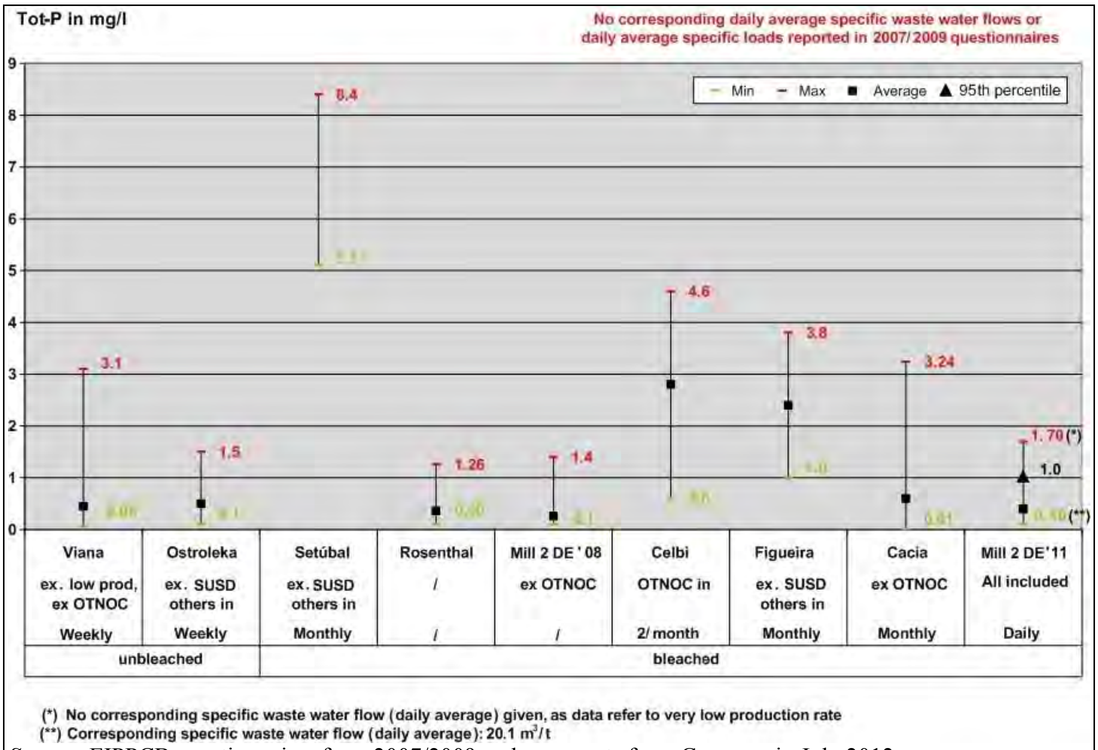


Source: EIPPCB questionnaires from 2007/2009

Figure 3.11: Specific emissions of total phosphorus from unbleached kraft pulp mills

Phosphorus emissions from unbleached pulp production are generally lower than from bleached pulp mills and vary between close to zero and 0.025 kg tot-P/ADt, with one exception discharging phosphorus emissions of 0.05 kg tot-P/ADt.

The short-term values reported for tot-P emissions, both for bleached and unbleached kraft pulp, are shown in Figure 3.12.

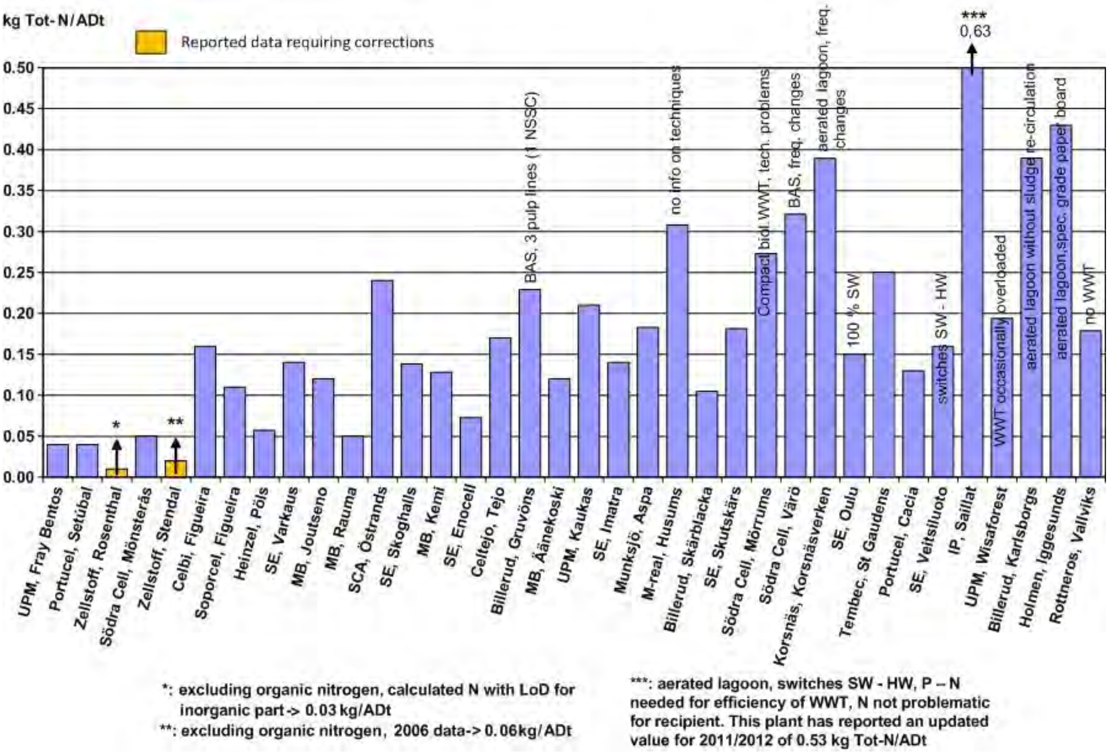


(*) No corresponding specific waste water flow (daily average) given, as data refer to very low production rate
(**) Corresponding specific waste water flow (daily average): 20.1 m^3/t

Source: EIPPCB questionnaires from 2007/2009 and comments from Germany in July 2012

Figure 3.12: Short-term averages of tot-P emissions from bleached and unbleached kraft pulp mills

Specific yearly average emissions of total nitrogen (TN_b) for bleached and unbleached kraft pulp mills after biological waste water treatment are shown Figure 3.13 and Figure 3.14.

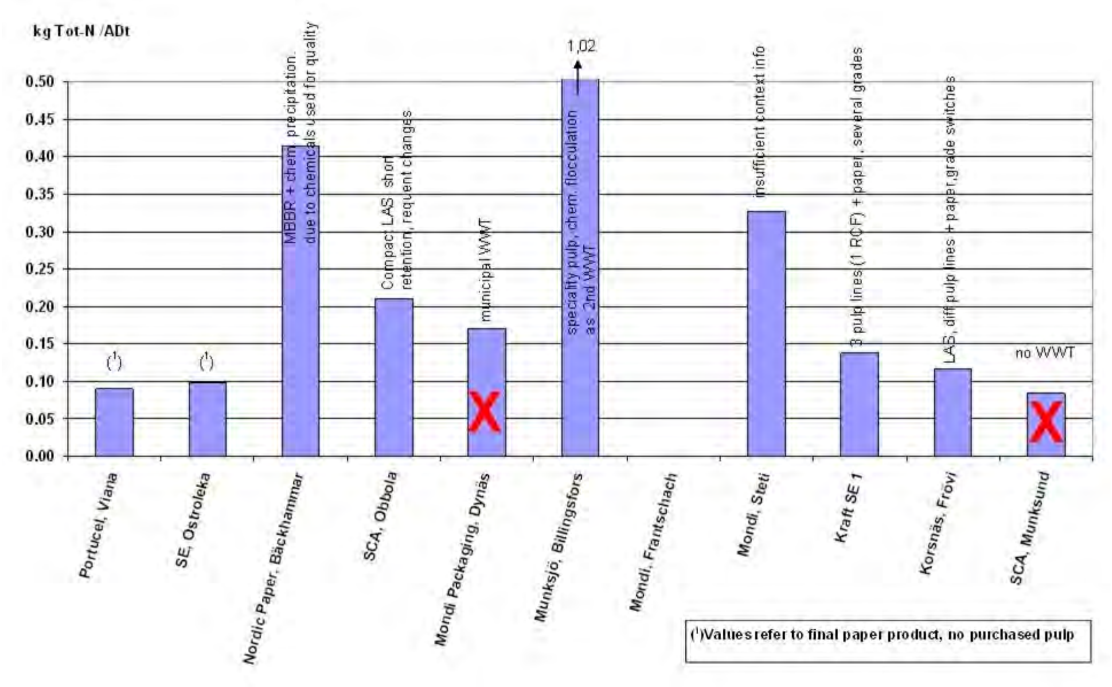


*: excluding organic nitrogen, calculated N with LoD for inorganic part-> 0.03 kg/ADt
**: excluding organic nitrogen, 2006 data-> 0.06kg/ADt

***: aerated lagoon, switches SW - HW, P – N needed for efficiency of WWT, N not problematic for recipient. This plant has reported an updated value for 2011/2012 of 0.53 kg Tot-N/ADt

Source: EIPPCB questionnaires from 2007/2009

Figure 3.13: Specific emissions of total nitrogen from bleached kraft pulp mills



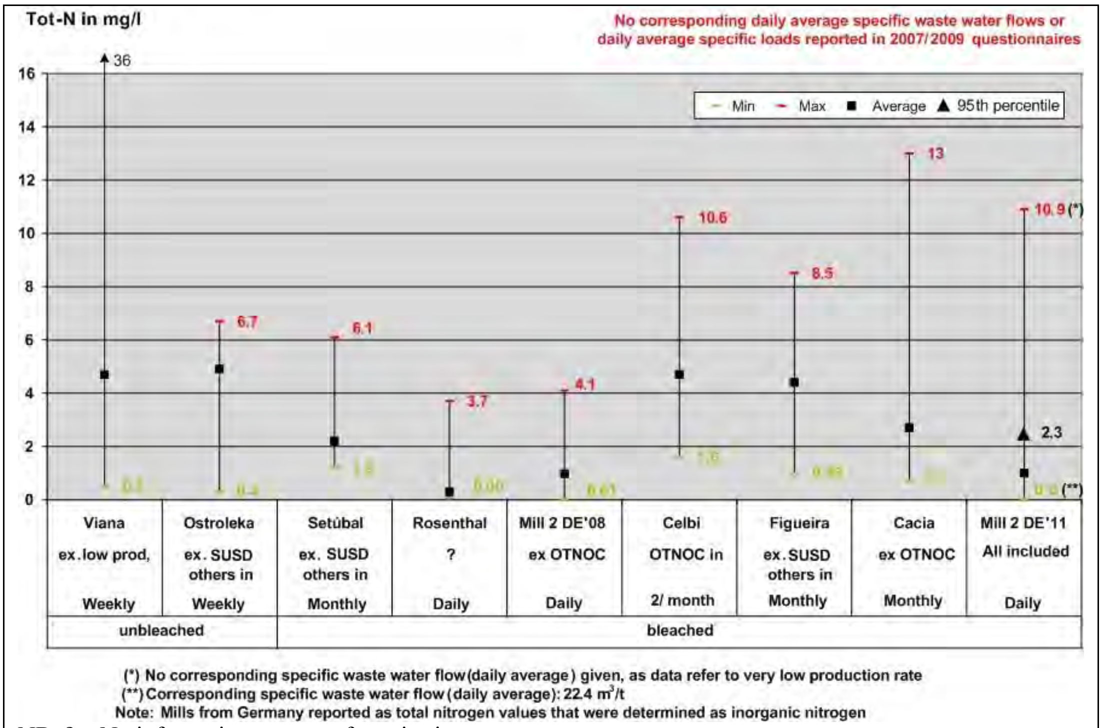
(¹)Values refer to final paper product, no purchased pulp

Source: EIPPCB questionnaires from 2007/2009

Figure 3.14: Specific emissions of total nitrogen from unbleached kraft pulp mills

As illustrated, specific nitrogen discharges vary between 0.01 kg N/ADt and 0.4 kg N/ADt with one emission value reaching 0.63 kg N/ADt. Unbleached and bleached pulp mills have similar specific nitrogen emissions (with the exception of one mill that reaches specific total nitrogen emissions of 1 kg N/ADt). Analysis of emissions data for nutrients and organic substances have confirmed that the reduction of COD and nutrients can be achieved simultaneously.

The short-term values reported for tot-N emissions, both for bleached and unbleached kraft pulp, are shown in Figure 3.15.



(*) No corresponding specific waste water flow (daily average) given, as data refer to very low production rate

(**) Corresponding specific waste water flow (daily average): 22.4 m^3/t

Note: Mills from Germany reported as total nitrogen values that were determined as inorganic nitrogen

NB: ? = No information on type of monitoring

Source: EIPPCB questionnaires from 2007/2009 and comments from Germany in July 2012

Figure 3.15: Short-term averages of tot-N emissions from bleached and unbleached kraft pulp mills

Discharges of metals

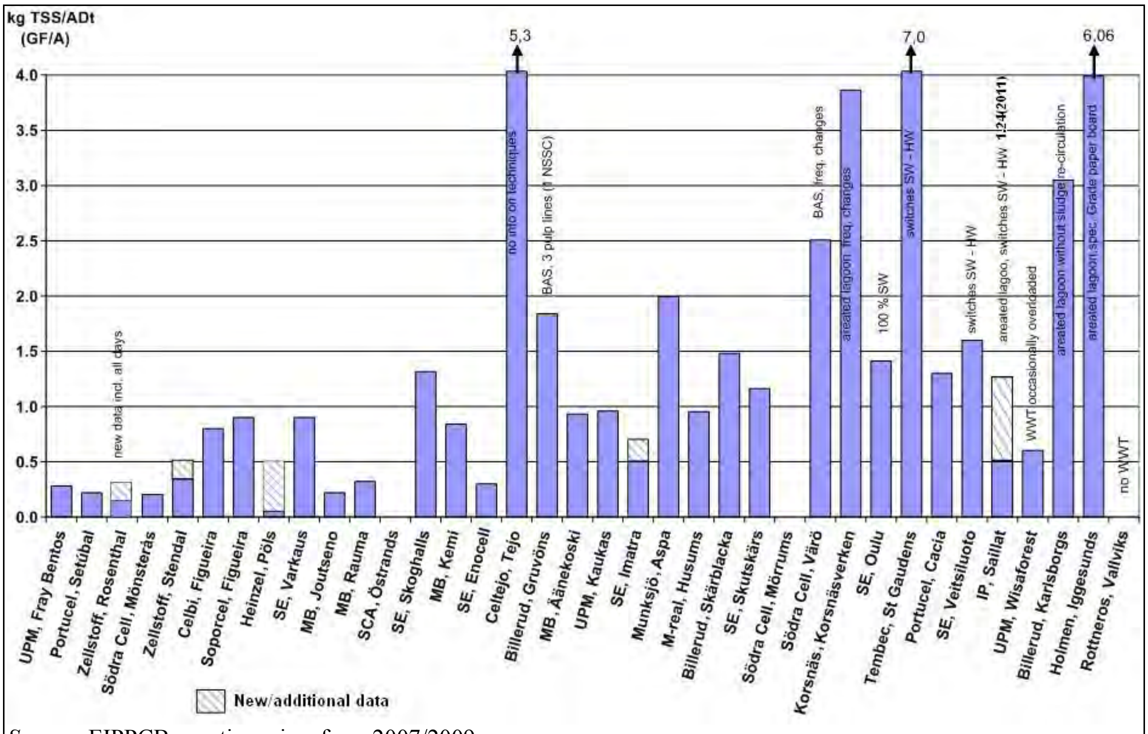
The wood used contains metals which are discharged with the waste water. Table 3.9 shows typical discharges of metals from kraft pulp mills. As is the case for phosphorus, a reduction in discharges of metals is probably possible by increasing the degree of process closure. Options for external treatment to reduce metals emissions are very limited.

Table 3.9: Typical discharges of metals from kraft pulp mills in g/ADt

Process	Cd	Pb	Cu	Cr	Ni	Zn
Unbleached pulp	0.03	0.3	0.5	0.2	0.4	5
Bleached pulp	0.1	0.4	1	0.7	0.9	15
Source: [109, PARCOM 1994]						

Suspended solids

Specific yearly average emissions of suspended solids after biological treatment and removal of biomass by means of sedimentation and comparable techniques are shown in Figure 3.16 for bleached kraft pulp mills. The suspended solids have in most cases been analysed by the use of a glass fibre filter, type A.

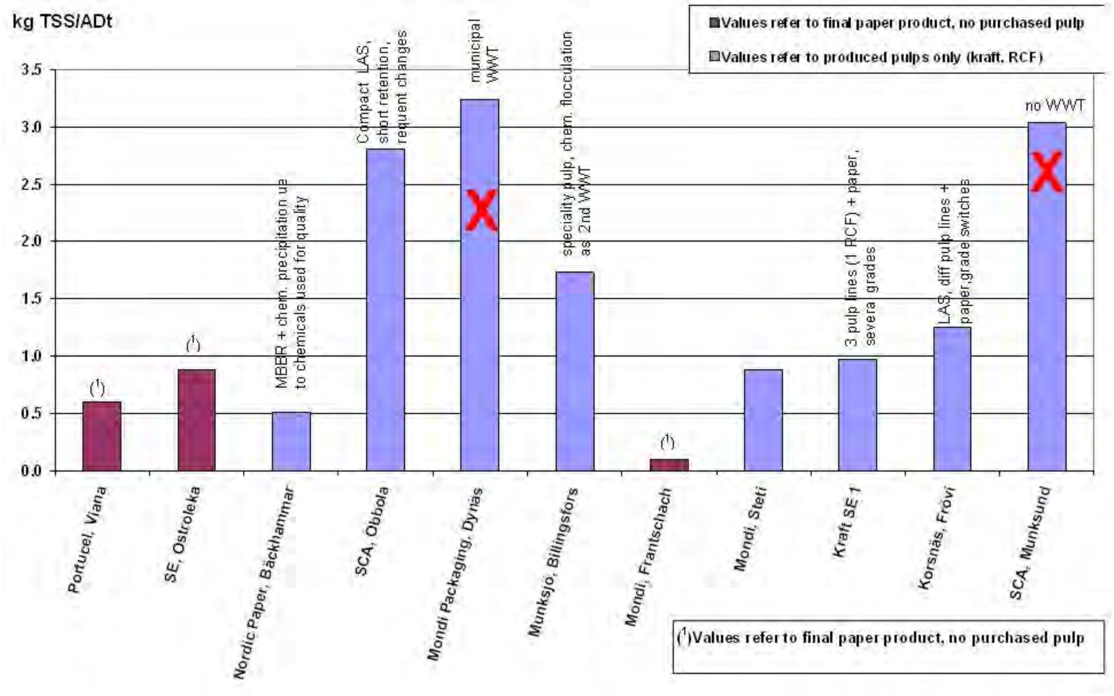


Source: EIPPCB questionnaires from 2007/2009

Figure 3.16: Specific emissions of total suspended solids from bleached kraft pulp mills after biological treatment and biomass removal

The figure shows that specific emissions of TSS vary between 0.02 kg TSS/ADt and 2.0 kg TSS/ADt, most mills achieving specific TSS emissions of below 1 kg TSS/ADt, and with 6 mills discharging considerably higher TSS loads, up to 7 kg/ADt in one case. The higher values are obviously associated with overloaded sedimentation tanks or disturbances of the active biomass.

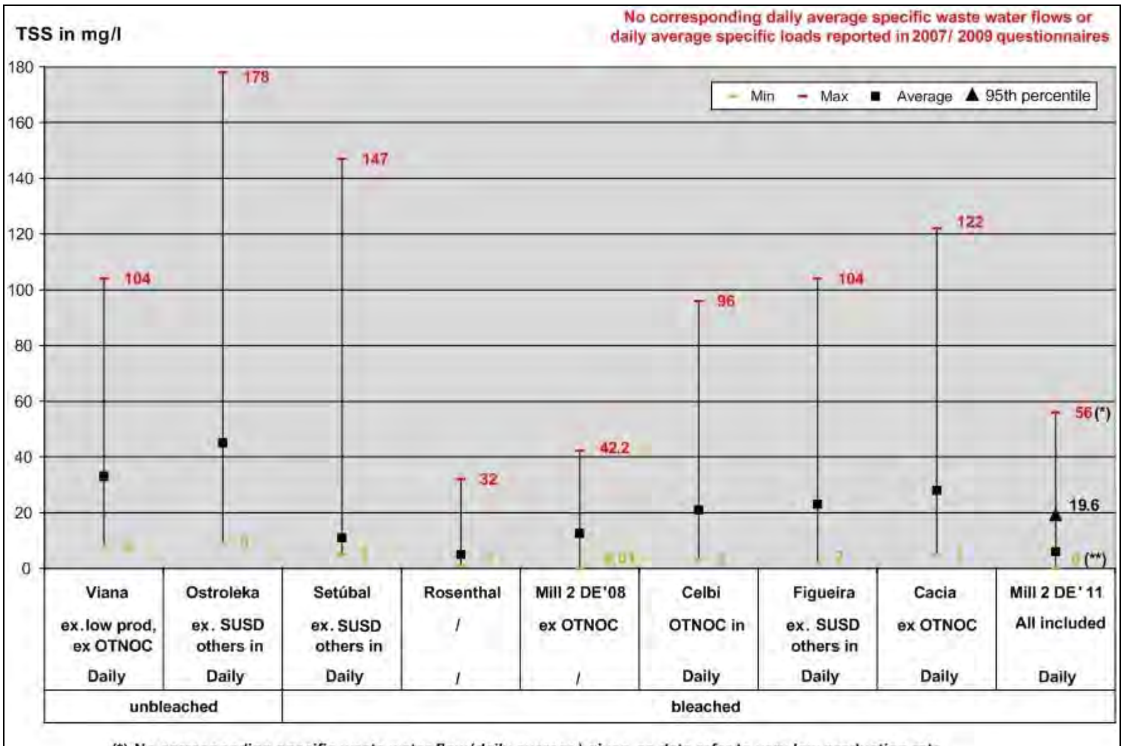
Specific yearly average TSS emissions from unbleached kraft pulp mills are given in Figure 3.17 and show a similar picture: most mills achieve specific TSS emissions below 1.0 kg TSS/ADt with some mills discharging higher TSS emissions of up to 3.25 kg TSS/ADt.



Source: EIPPCB questionnaires from 2007/2009

Figure 3.17: **Specific emissions of total suspended solids from unbleached kraft pulp mills after biological treatment and biomass removal**

The short-term values reported for TSS emissions, both for bleached and unbleached kraft pulp, are shown in Figure 3.18.



(*) No corresponding specific waste water flow (daily average) given, as data refer to very low production rate
(**) Corresponding specific waste water flow (daily average): 21.1 m^3/t

Source: EIPPCB questionnaires from 2007/2009 and comments from Germany in July 2012

Figure 3.18: **Short-term averages of TSS emissions from bleached and unbleached kraft pulp mills**

3.2.2.5.3 Total waste water discharge after biological treatment

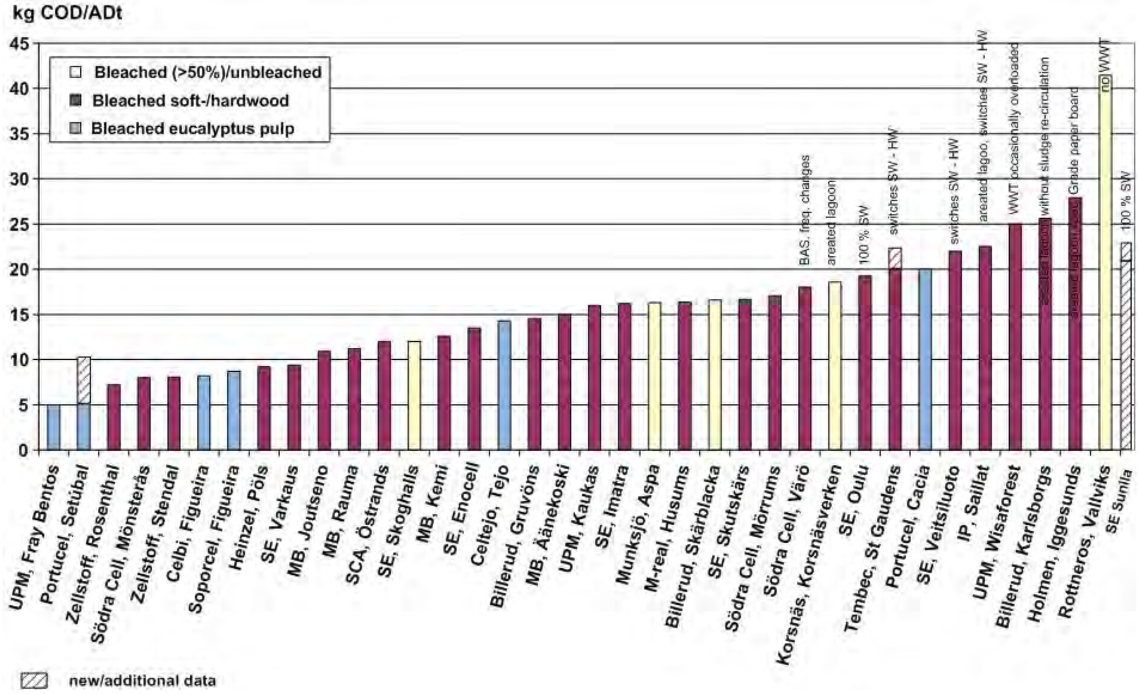
The typical on-site waste water treatment consists of the removal of coarse solids by mechanical screens and sedimentable solids with primary clarifiers. The primary clarifier supernatant is sent to the equalisation basins in order to equalise incoming loads and flows. Biological treatment is carried out in aerated basins, mostly activated sludge tanks with long retention times. Alternatives to the activated sludge process are more and more common, e.g. moving bed biological reactors (MBBR) using carrier materials for the biomass. They achieve equivalent or better reduction rates than the activated sludge process. Aerated lagoons are also used in a few cases. Table 3.10 shows the variations in the total treatment effects of sedimentation and biological treatment of kraft pulp mill effluents as percentage reductions. The more recent plants have reduction figures in the upper part of the ranges given.

Table 3.10: Percentage reduction at waste water treatment plants at chemical pulp mills

Type of biological treatment	BOD_5 (%)	COD (%)	AOX (%)	P (%)	N (%)
Aerated lagoon	40 – 85	30 – 60	20 – 45	0 – 15	0
Activated sludge	85 – 98	50 – 70	40 – 65	40 – 85	20 – 50

Source: [109, PARCOM 1994], [1, Finnish BAT Report 1997].

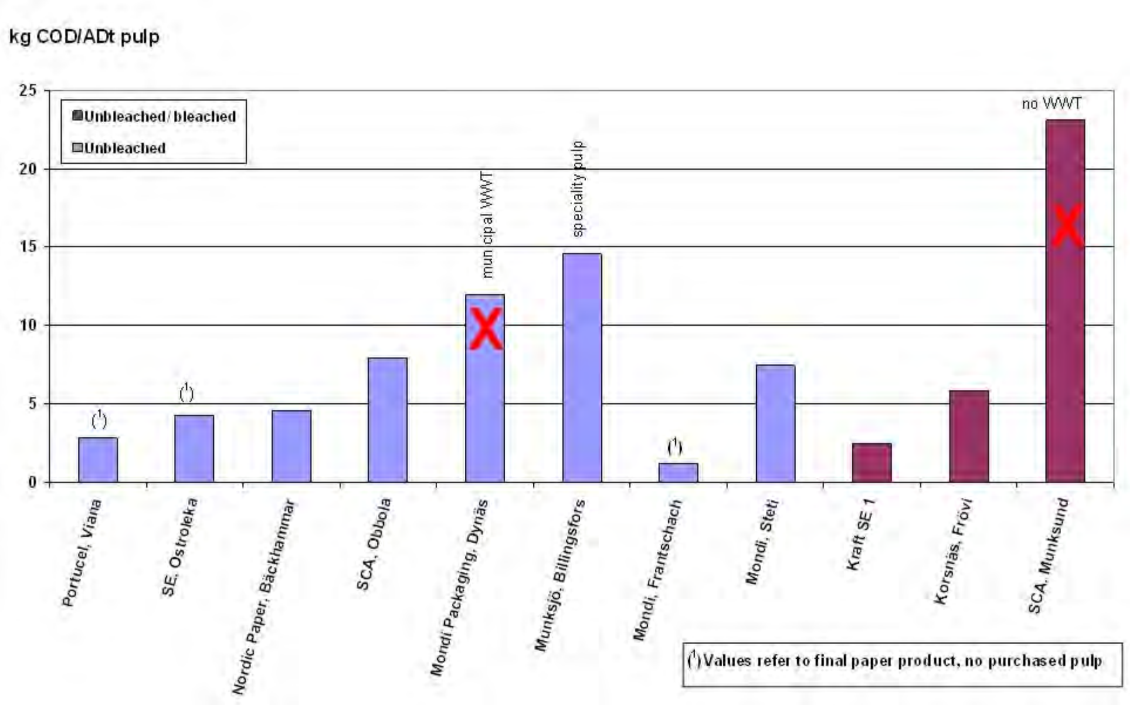
Specific yearly average COD emissions from bleached kraft pulp mills are given in Figure 3.19. The figure distinguishes between eucalyptus pulp mills, mills that manufacture mainly bleached kraft pulp (> 50 %) and all other bleached kraft pulp mills. The reported data show that specific COD emissions from eucalyptus pulp vary between 5 and 20 kg COD/ADt, emissions from other softwood or hardwood bleached kraft pulp manufacturing vary between 7.5 to just below 28 kg COD/ADt.



Source: EIPPCB questionnaires from 2007/2009

Figure 3.19: Specific COD emissions from bleached kraft pulp mills after biological treatment

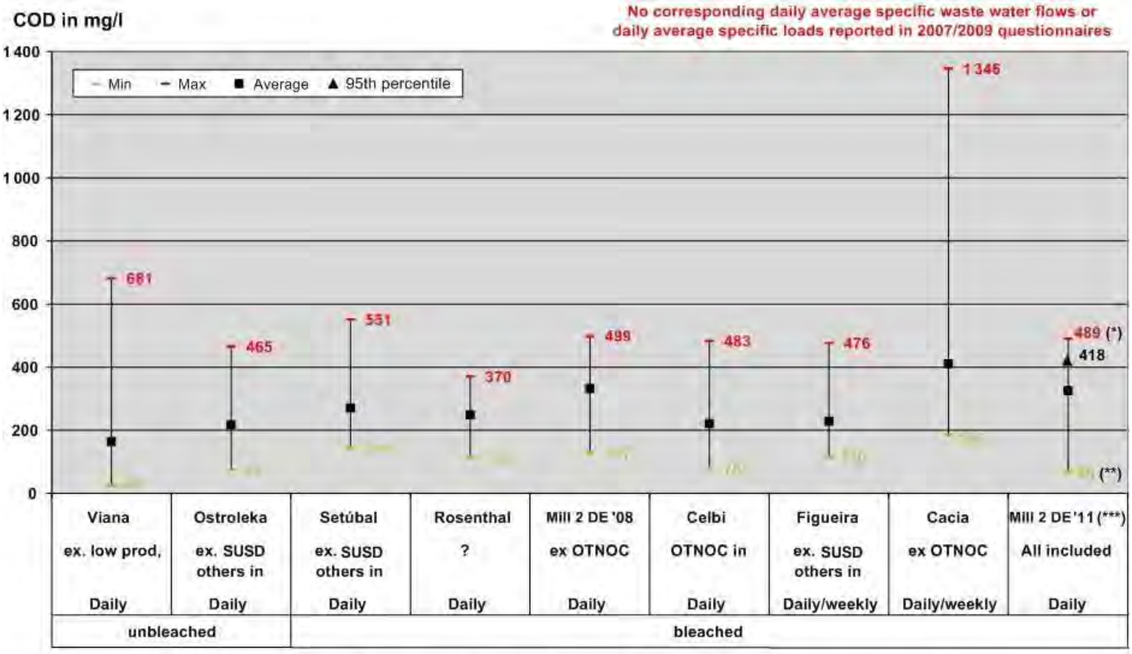
Specific yearly average COD emissions from unbleached kraft pulp mills after biological treatment are given in Figure 3.20. Emissions vary between 1.2 kg COD/ADt and 23 kg COD/ADt.



(¹) Values refer to final paper product, no purchased pulp

Figure 3.20: Specific COD emissions from unbleached kraft pulp mills after biological treatment

As shown in Figure 3.21, a few short-term values were also reported for COD emissions, both for bleached and unbleached kraft pulp.



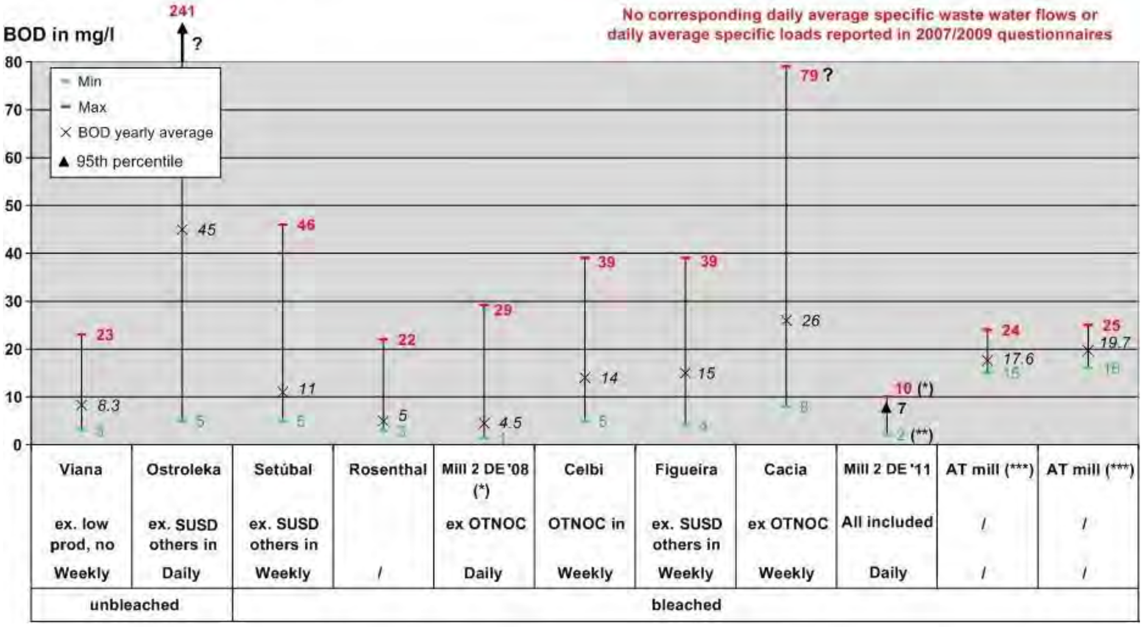
(*) Corresponding specific waste water flow (daily average): 19.9 and 23.8 m^3/t
(**) No corresponding specific waste water flow (daily average) given, as data refer to very low production rate
(***) Reported minimum and maximum daily average specific loads: 3.44 kg/t and 24.84 kg/t, respectively

NB: ? = No information on type of monitoring

Source: EIPPCB questionnaires from 2007/2009 and comments from Germany in July 2012

Figure 3.21: Short-term COD emissions from bleached and unbleached kraft pulp mills

Regarding BOD emissions, the short-term values reported (*Source*: EIPPCB questionnaires from 2007/2009) can be seen in Figure 3.22.



(*) No corresponding specific waste water flow (daily average) given, as data refer to very low production rate

(**) Corresponding specific waste water flow (daily average): 23.5 m^3/t

(***) Data provided during final meeting , values for January and February 2009 (average is monthly average)

Source: EIPPCB questionnaires from 2007/2009 and comments from Germany in July 2012

Figure 3.22: Short-term BOD emissions from bleached and unbleached kraft pulp mills

Specific yearly average emissions to water after biological treatment based on the provided data from kraft pulp mills within the EU are given in Table 3.11.

Table 3.11: Reported annual average discharges from kraft pulp mills within the EU

Process	Flow (m^3/ADt)	COD (kg/ADt)	AOX (kg/ADt)	TSS (kg/ADt)	Tot-N (kg/ADt)	Tot-P (g/ADt)
Unbleached	14 – 82	1.2 – 23	NA	0.1 – 3.25	0 – 1.02	3 – 50
Bleached	18.5 – 94	5 – 42	0 – 0.3	0.015 – 7	0.01 – 0.63	3 – 110

NB: NA = not applicable.
Source: EIPPCB questionnaires from 2007/2009.

3.2.2.6 Emissions to air

An overview of the emissions to air from a kraft pulp mill is shown in Figure 3.23.

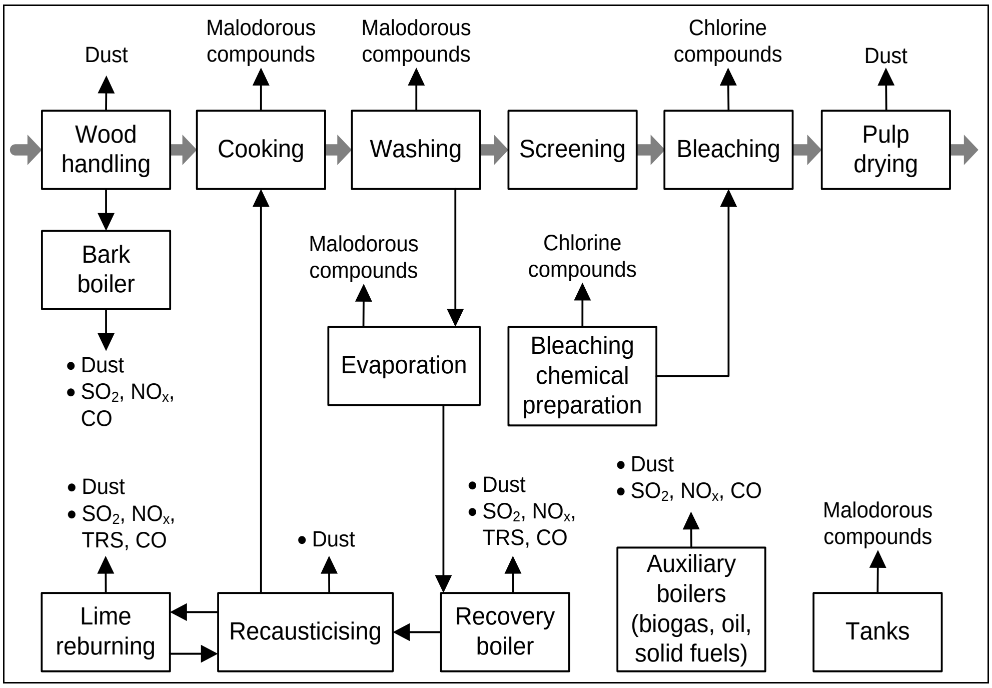


Figure 3.23: Emissions to air from kraft pulp mills

Emissions to air from a kraft pulp mill originate from chip storage, the cooking digester, pulp washing, the bleaching plant, bleaching chemical preparation, recovery of chemicals, evaporation, the bark boiler or other auxiliary boilers, the recovery boiler, white liquor preparation, the lime kiln, tanks and pulp drying (only for market pulp). They consist mainly of compounds containing sulphur, e.g. sulphur dioxide and malodorous reduced sulphur compounds like methyl mercaptan, dimethyl sulphide and hydrogen sulphide. The latter compounds are commonly referred to as total reduced sulphur (TRS). From the furnaces, nitrogen oxides, dust and CO are also emitted. From bleach plants and from bleaching chemical preparation, chlorine compounds may leak to the atmosphere. Volatile organic compounds (VOC), mainly terpenes, are emitted to the atmosphere from wood chips stored in heaps outside the process (outdoors). The VOC emissions from chip piles vary, among other things, in terms of the time chips are stored, the temperature and the wood species. The major sources of air emissions are discussed in more detail below.

3.2.2.6.1 Emissions to air from the black liquor recovery boiler

The black liquor recovery boiler is a major source of atmospheric emissions in a kraft pulp mill. Emissions include nitrogen oxides, dust (primarily sodium sulphate and sodium carbonate), carbon monoxide, sulphur dioxide and minor concentrations of malodorous compounds (hydrogen sulphide).

The recovery boiler is fed with the concentrated black liquor, a by-product from the kraft pulping process that contains valuable cooking chemicals (Na and S). Table 3.12 shows the elemental analysis of the black liquors of two example plants [212, T.Tamminen, et al. 2002].

Table 3.12: **Elemental analysis of two softwood black liquors from Finnish kraft pulp mills**

Parameter	**Boiler A**	**Boiler B**
Dry solids **%**	71.0	79.0
Elemental analysis of the dry solids		
C **%**	31.8	31.0
H **%**	3.3	3.1
N **%**	0.067	0.056
Na **%**	20.8	20.6
K **%**	2.4	2.8
S **%**	6.1	6.3
Cl **%**	0.4	0.2
HHV calorimetric MJ/kg	12.65	12.67

The main purpose of the black liquor recovery boiler is to recover valuable pulping chemicals and to produce energy from the organic residues in the black liquor. The used cooking chemicals are recovered in the form of the inorganic melt. At present (2013), in many kraft pulp mills the inorganic chemicals' contribution to black liquor dry material amounts to 45 – 50 %. Approximately one third of the dry material of the black liquor consists of dissolved organic substances. After evaporation, the black liquor (strong liquor) has a dry solids content of about 70 – 85 % (70 – 75 % for eucalyptus pulp). The aim of evaporation is to achieve a high dry solids (DS) content in the concentrated black liquor fed to the recovery boiler in order to generate more steam.

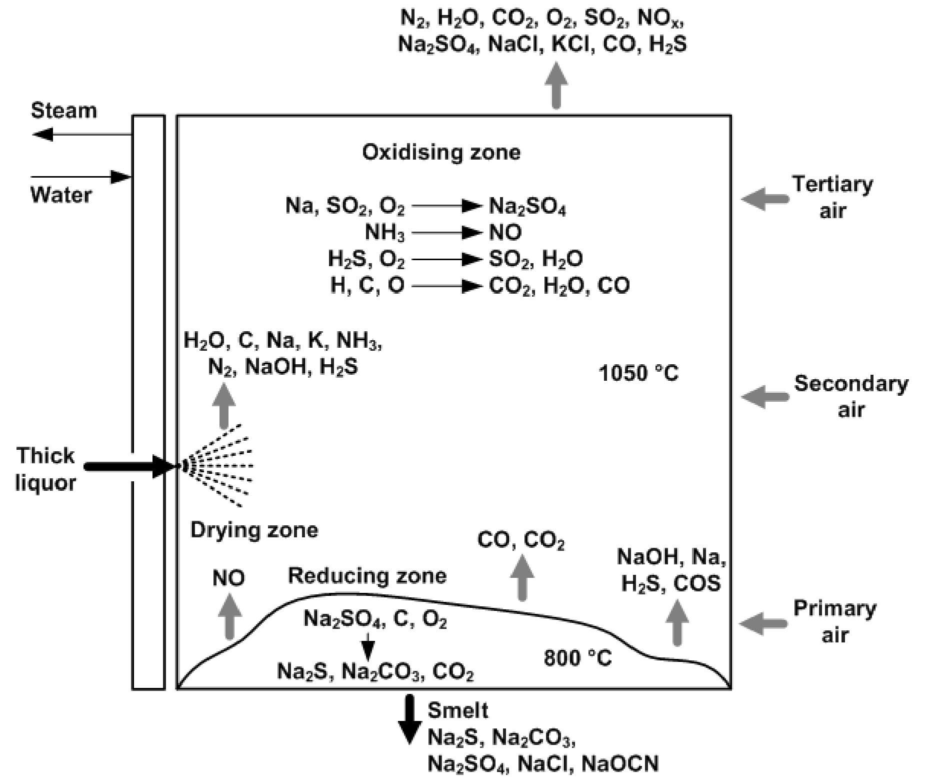
Typical emissions to air from recovery boilers are given in Table 3.13. Depending on the excess of oxygen/air and the dissolved DS/ADt, the gas flow is normally about 6 000 – 9 000 Nm^3/ADt (dry gas) while process steam production is between about 13 GJ/ADt and 18 GJ/ADt.

Table 3.13: **Yearly average specific emission range from black liquor recovery boilers and ranges of emission concentration values**

Sulphur dioxide (as S)		
Varying DS content of black liquor, with or without scrubber	1 – 100 <0.002 – 0.65	mg/Nm^3 kg/ADt
Hydrogen sulphide or total reduced sulphur (TRS as S)		
Annual average (TRS as S)	0 – 50	mg/Nm^3
Annual average (TRS as S)	0.0007 – 0.4	kg/ADt
Temporarily	Higher	
Nitrogen oxides (as NO_2)		
Only primary measures	120 – 250 0.73 – 2.0	mg/Nm^3 kg/ADt
Particulates		
After electrostatic precipitator	5 – 190 0.02 – 1.6	mg/Nm^3 kg/ADt
Source: Questionnaire launched by EIPPCB in February 2011 [33, COM 2011]; for concentration levels: standardised reference O_2 content 6%.		

The main principles and operating variables that influence the emissions from the black liquor recovery boiler are discussed below to explain the complexity of pollution prevention at this plant.

Figure 3.24 below shows some of the principal inorganic reactions in a recovery boiler and also where in the furnace the reactions take place. In recovery boilers there is an oxidising zone in the upper part and a reducing zone in the lower part. The strong liquor is introduced through one or several nozzles into the reducing zone. Combustion air is mostly supplied at three different levels as primary, secondary and tertiary air (from the bottom up). In modern boilers there are more than three levels (quaternary air). The typical temperature is also indicated.



Source: [127, SEPA report 1992, changed by EIPPCB]

Figure 3.24: Principal chemical reactions in a recovery boiler

Most of the dust (90 – 95 %) in the flue-gases is formed from the black liquor droplets of the liquor sprays and only 5 % is released from the surface of the char bed [212, T.Tamminen, et al. 2002]. A smelt consisting mainly of sodium sulphide (Na_2S) and sodium carbonate (Na_2CO_3) is formed at the bottom of the furnace. When the sulphur is reduced to sulphide in the smelt, some hydrogen sulphide is also formed. Small amounts of hydrogen sulphide may leave with the flue-gases if the air supply is not sufficient or if the mixing of air into the furnace is incomplete. Temporary high emissions of hydrogen sulphide from the smelt may occur as a consequence of disturbances caused by deposits of dry substances on the furnace walls falling into the smelt. In the oxidising part of the furnace, the sulphur is oxidised to sulphur dioxide and sodium in the gas phase reacts with the sulphur dioxide to form sodium sulphate. A higher dry solids content leads to a high temperature in the furnace and thus a lower emission of hydrogen sulphide and a higher emission of sodium. The higher sodium emission means that more sulphur is bound as sodium sulphate and thus the emission of sulphur dioxide is decreased.

SO_2 emissions

SO_2 emissions are formed mainly through the oxidation of H_2S and carbonyl sulphide (COS) in the lower furnace. The source of gaseous sulphur compounds is the fuel, i.e. black liquor (see Table 3.12) and sulphur in additional fired streams such as NCG and oil. In general, the emission of sulphur from the recovery boiler is influenced by the temperature in the different zones which is influenced by the dry solids content (heating value) of the strong black liquor, the sulphur to sodium ratio (S/Na_2) in the liquor (sulphidity), the supply (amount of air excess and primary air temperature) and distribution of combustion air, the distribution of the black liquor across the boiler area and the load on the furnace.

In order to decrease the SO_2 emissions from the recovery boiler, some installations are equipped with a flue-gas scrubber operating at pH 6 – 7. The pH is controlled by adding sodium hydroxide (NaOH), weak liquor or oxidised white liquor to the washing liquor of the scrubber. A higher pH would remove hydrogen sulphide but carbon dioxide would be absorbed which would quickly neutralise the alkali. Surplus liquor from a scrubber is recycled to the process, normally to the white liquor preparation.

TRS emissions

The emission of total reduced sulphur (TRS) from the recovery boiler is influenced by the dry solids content, the load on the furnace and the associated temperature in the furnace and the air distribution which affects the sulphur chemistry.

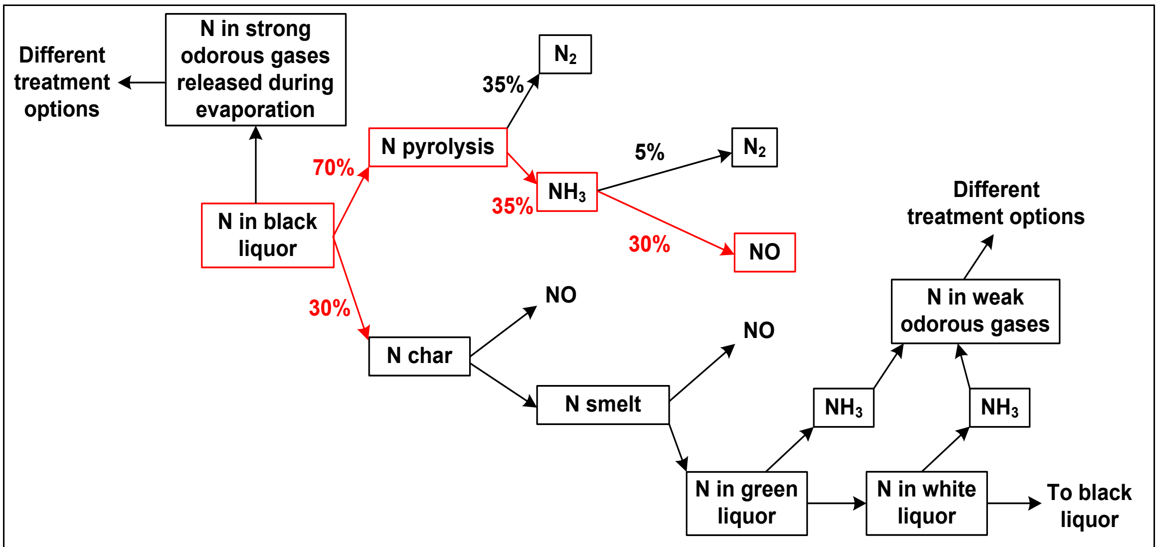
TRS emissions from recovery boilers are very low or even zero (for boilers with very high dry solids content) when the boiler is running in a steady state. However, normally there are a number of peaks during the year.

NO_X formation and NO_X emissions

Nitrogen oxides (NO_X) emissions from the pulp mill are mainly nitric oxide (NO). In the air, NO reacts to nitrogen dioxide (NO_2). NO_X emissions from the recovery boiler correspond to 65 – 85 % of the total emissions from a kraft pulp mill. In general, between mills there is a relatively large variation in reported NO_X emissions (Δ ~ 1.0 $kgNO_2/ADt$), see also Figure 3.60 and Figure 3.61.

The principal cause for NO_X emissions is the black liquor nitrogen and the combustion conditions which can explain the variation of emissions observed. Wood contains 0.05 – 0.15 wt-% of nitrogen [226, Vakkilainen et al. 2005]. Some of the main forms of nitrogen in black liquor are pyrole, pyridine and amino acid. Different wood species have nitrogen in different forms. During kraft cooking most of the nitrogen ends up in black liquor. It seems that the dissolution of nitrogen-containing compounds occurs easily during the first stages of cooking. Very little nitrogen exits with the pulp. Ammonia and other volatile condensates in black liquor are largely vaporised during evaporation and end up in methanol and in the non-condensable gases (NCG).

Figure 3.25 shows the nitrogen reaction paths from black liquor when it enters the recovery boiler. As shown, about two thirds of nitrogen in black liquor is released to air and forms either intermediate ammonia or N_2. The rest remains in the char and exits the recovery furnace with the smelt, probably as sodium cyanate (NaOCN).



NB: N releases in % are indicative as there is some uncertainty about mass flows

Source: [226, Vakkilainen et al. 2005] figure amended by the EIPPCB

Figure 3.25: Simplified nitrogen reaction paths from black liquor

Amended Conversion fractions have been measured in laboratory conditions. The fraction of N that was converted into NO varied between 15 % and 30 % for black liquor (which is less than the proportions shown in Figure 3.25, an example illustrating the upper end of the range, where around 30 % of the nitrogen in the black liquor is oxidised into NO_X) from various wood species, types of cooking and dry solids concentrations. Between 50 % and 70 % was transformed into N_2, around 20 % ended up in the smelt. So, most of the NO is formed during pyrolysis of the liquor droplets that are sprayed with various black liquor guns into the furnace (in-flight release).

The char-NO formation is less significant and this portion of nitrogen usually ends up with the smelt (smelt N). The cyanate nitrogen in the smelt passes into the green liquor through the dissolving tank along with the other salts of the smelt. In the green liquor, alkaline hydrolysis gradually transforms cyanate nitrogen into ammonia [225, Hupa 2005]. The ammonia formed in the green liquor and also in the white liquor partially evaporates into dilute malodorous gases. Another part of the ammonia is recycled as part of the white liquor back to the cooking liquor from which it is finally quantitatively separated in the evaporation plant. From there it passes into concentrated malodorous gases and into the methanol.

The total emissions of nitrogen compounds from a pulp mill are thus dependent on the control of NO_X emissions from the recovery boiler, and also on how the ammonia flows generated in the chemical recovery cycle through the smelt are treated (collection and further treatment of the strong and weak malodorous gases, and of methanol).

Nitrogen is mainly introduced into the mill with wood chips. Other nitrogen sources are defoamers, anti-scaling agents, chelating agents, etc. As the nitrogen content of the black liquor significantly influences the NO_2 formation, suppliers give their guarantees for the performance of the recovery boiler depending on the N content of the black liquor. The following existing example shows this effect. A bleached softwood market kraft pulp mill in Sweden started up its new recovery boiler with a vertical air system in 2006. The supplier gave the following NO_X guarantee values that refer to 3 % O_2 content depending on the N content in the black liquor:

- at 0.07 % nitrogen in the black liquor: 50 ppm or 105 mg NO_2/Nm^3
- at 0.11 % nitrogen in the black liquor: 85 ppm or 178 mg NO_2/Nm^3.

To comprehensively assess the total emission of NO_X from a mill, the N content of the various fuels (black liquor, strong and/or weak malodorous gases, methanol, turpentine, soap) should be taken into account as part of the nitrogen from the black liquor is transferred during processing to these streams which then, in some cases, may be recirculated to the recovery boiler, or be burnt in the lime kiln or a separate furnace for the burning of the strong gases.

However, it should be borne in mind that the differences between the nitrogen contents of the wood raw materials alone contribute around 90 % of the total nitrogen input to the combustion processes of the kraft pulp mill and the impact of the differences between mills with regard to the internal circulations of malodorous gases (or methanol) only represents around 10 % of the total nitrogen compounds carried into the major process units (recovery boiler, lime kiln, TRS burner). It has been reported that an increase in NO from the recovery boiler can essentially be avoided if the malodorous gases are injected in the correct way and in the right location in the furnace of the boiler [225, Hupa 2005].

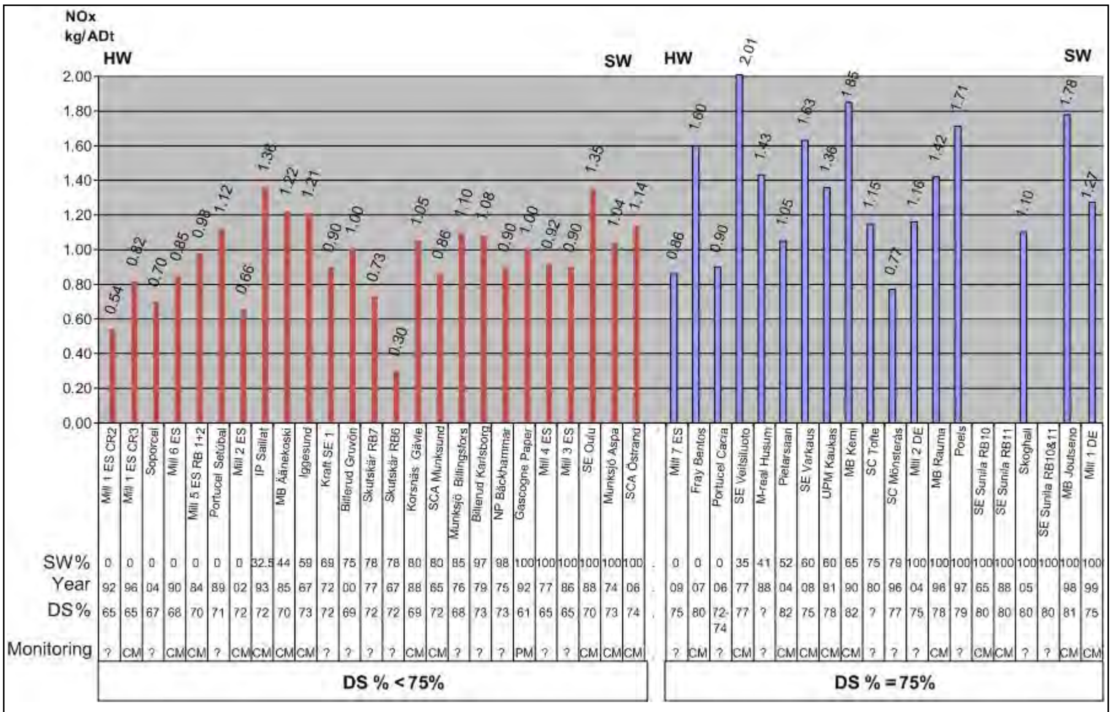
How much N-containing organic material is burnt in the recovery boiler per tonne of pulp is also relevant. Unbleached pulp and wood species that can be cooked and bleached with a slightly higher yield (e.g. eucalyptus pulp) produce less organic materials to be burnt in the recovery boiler and can therefore achieve lower specific NO_X values. These aspects should be considered when comparing specific NO_X emission values between mills.

Mill tests showed [207, T.Tamminen, et al. 2002] a linear dependency between the formation of NO_X emissions and the nitrogen input in black liquor solids (BLS). So, the load of the boiler also has an effect on the NO_X emissions. The conversion of the black liquor nitrogen to NO_X in the flue-gases was 25 – 30 % of the total nitrogen in BLS. This result is consistent with other findings that the total formation of NO corresponds to about one-third of the black liquor nitrogen (as a rule of thumb).

Thermal NO_X is a minor part of the NO_X emissions generated in the recovery boiler, as the temperatures in the recovery furnace are too low for significant thermal NO_X production. The NO_X formation per MJ input of black liquor is also generally low due to the relatively low oxygen concentration needed for an efficient recovery of chemicals.

Reduced NO_X can normally be achieved by modifications to the air feed system and optimising combustion conditions (air distribution, excess O_2, additional air registers, see Section 3.3.18).

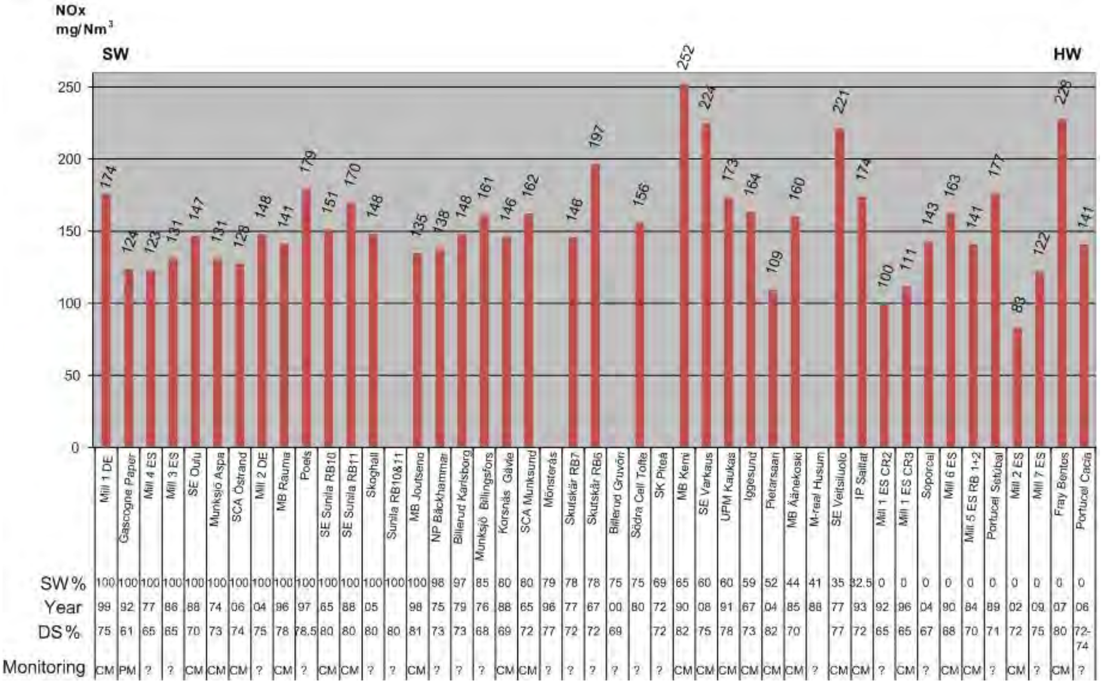
Yearly average emissions (loads and concentrations) can be seen in Figure 3.26 and Figure 3.27.



	NOx kg/ADt	SW%	Year	DS%	Monitoring
Mill 1 ES CR2	0.54	0	92	65	?
Mill 1 ES CR3	0.82	0	96	65	CM
Soporcel	0.70	0	04	67	?
Mill 6 ES	0.85	0	90	68	CM
Mill 5 ES RB 1+2	0.98	0	84	70	CM
Portucel Setúbal	1.12	0	89	71	?
Mill 2 ES	0.66	0	02	72	CM
IP Saillat	1.36	32.5	93	72	CM
MB Äänekoski	1.22	44	85	70	CM
Iggesund	1.21	59	67	73	CM
Kraft SE 1	0.90	69	72	72	?
Billerud Gruvön	1.00	75	00	69	?
Skutskär RB7	0.73	78	77	72	?
Skutskär RB6	0.30	78	67	72	?
Korsnäs Gävle	1.05	80	88	69	CM
SCA Munksund	0.86	80	65	72	CM
Munksjö Billingsfors	1.10	85	76	68	?
Billerud Karlsborg	1.08	97	79	73	?
NP Bäckhammar	0.90	98	75	73	?
Gascogne Paper	1.00	100	92	61	PM
Mill 4 ES	0.92	100	77	65	?
Mill 3 ES	0.90	100	86	65	?
SE Oulu	1.35	100	88	70	CM
Munksjö Aspa	1.04	100	74	73	CM
SCA Östrand	1.14	100	06	74	CM
Mill 7 ES	0.86	0	09	75	?
Fray Bentos	1.60	0	07	80	CM
Portucel Cacia	0.90	0	06	72-74	?
SE Veitsiluoto	2.01	35	77	77	CM
M-real Husum	1.43	41	88	?	?
Pietarsaari	1.05	52	04	82	CM
SE Varkaus	1.63	60	08	75	CM
UPM Kaukas	1.36	60	91	78	CM
MB Kemi	1.85	65	90	82	CM
SC Tofte	1.15	75	80	?	?
SC Mönsterås	0.77	79	96	77	?
Mill 2 DE	1.16	100	04	75	?
MB Rauma	1.42	100	96	78	CM
Poels	1.71	100	97	79	?
SE Sunila RB10		100	65	80	CM
SE Sunila RB11		100	88	80	CM
Skoghall	1.10	100	05	80	?
SE Sunila RB10&11		100		80	?
MB Joutseno	1.78	100	98	81	CM
Mill 1 DE	1.27	100	99	75	CM

NB: CM = Continuous monitoring; PM = Periodic monitoring; ? = No information on type of monitoring

Figure 3.26: NO_X loads from recovery boilers in kraft pulp mills



NB: CM = Continuous monitoring; PM = Periodic monitoring; ? = No information on type of monitoring

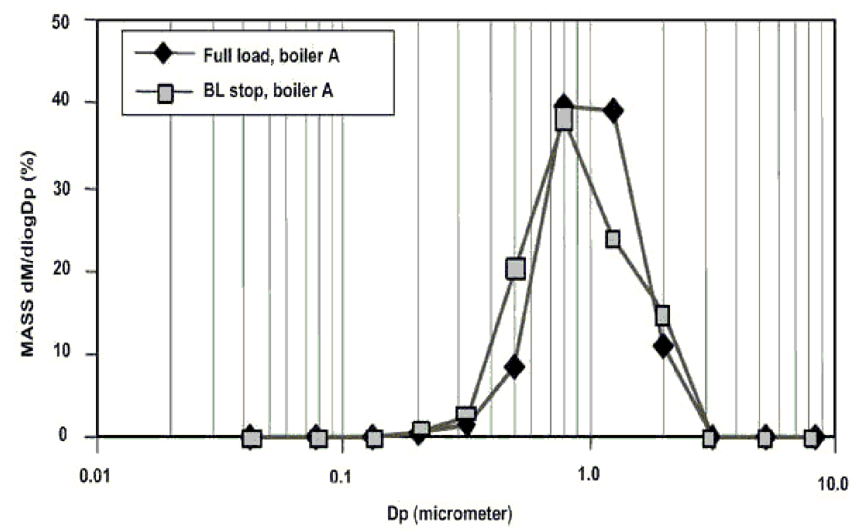
Figure 3.27: NO$_X$ concentrations from recovery boilers in kraft pulp mills

Dust emissions

The dust is mainly formed during the in-flight burning of black liquor droplets that are sprayed into the furnace. Only a small part of the fume (about 5 – 10 %) is volatilised from the surface of the char bed. The more liquor droplets are introduced into the furnace, the more dust is formed. In full load, the amount of fume in the flue-gases may achieve 6 – 8 wt-% of the black liquor dry solids load (i.e. 60 – 80 g dust/kg BLS). The dust before the flue-gas enters the electrostatic precipitators is mainly submicron fume [212, T.Tamminen, et al. 2002].

The results of the analysis of the dust composition generated during the firing of the two softwood black liquors described in Table 3.12 showed that about 6 – 9 % of the input sodium (Na) and 11 – 15 % of input potassium (K) was released in the fume. The dust is mainly comprised of sodium sulphate (Na_2SO_4). The concentration of carbonates in the dust is usually insignificant or under 10 wt-%. There are also low concentrations of potassium and chlorides that may form potassium chloride (KCl).

Figure 3.28 below shows that most of the dust upstream from the ESPs is fine dust, i.e. <2.5 µm. 'Dp' is the particle diameter of micrometre-sized particles. The graph also shows that the particle size does not change when the boiler load is reduced. This is indicated by the line named 'BL stop, Boiler A' which shows the particle size distribution during the total interruption of the black liquor flow in boiler A. The line named 'full load' shows the particle size distribution in full load.



Source: [210, T.Tamminen, et al. 2002]

Figure 3.28: **Example of the particle size distribution of dust from recovery boilers measured upstream of the electrostatic precipitators**

[85, P.Mikkanen 2000] found that 66 % of the measured concentration of particles at the recovery boiler exit (before the ESP) were smaller than 3 µm and 34 % were larger than 3 µm. [84, T.Lind et al. 2006] measured two boilers where 0 – 32 % of dust at the ESP outlet was bigger than 4 µm.

All recovery boilers are equipped with an electrostatic precipitator in order to remove the large amount of dust (mainly Na_2SO_4) from the flue-gas. The dust is fed back into the furnace by mixing it into the black liquor. Additionally, recovery boilers are often equipped with a scrubber in order to recover either sulphur or heat or both. Yearly average dust emissions from recovery boilers vary from 5 mg dust/Nm^3 to 190 mg dust/Nm^3 (at 6 % O_2). The particulate emission can be reduced by installing electrostatic precipitators that are dimensioned to achieve low dust levels, by proper process control and maintenance of the ESPs or by additional use of scrubbers.

CO emissions

The emissions of carbon monoxide (CO) are normally caused by the organic constituents input via the black liquor. During combustion, these are converted into CO_2 and to a minor extent into CO. The CO emissions may result from poor combustion and improper burning conditions. The exhaust gas concentrations of CO and organically bound carbon are a yardstick for the burnout rate of the fuels. In recovery boilers, the CO concentrations vary between 10 mg CO/Nm^3 and 100 mg CO/Nm^3 as a yearly average value with a few mills with higher values. Many mills operate the recovery boiler with between 3 % and 6 % oxygen content.

The higher CO values are observed when oxygen for combustion is kept low (e.g. 1.5 % O_2) in order to reduce the NO_X emissions further. Low oxygen normally coincides with a slight decrease in the NO_X emissions and an increase in the CO emissions. However, high CO levels are a safety issue and high CO may also lead to furnace wall corrosion. A precise process control is needed to achieve the process optimum which is a balance of emissions of CO and NO_X.

Other parameters

In addition to the main emissions, other parameters could be of interest. However, measurement has shown that emissions of metals to air are very low. HCl and HF are also very low or even non-existent. The only problematic level might be TOC (total organic carbon). Recovery boiler flue-gases often include vents, which contain organics [226, Vakkilainen et al. 2005]. Emissions of TOC are in the range of ~ 20 mg/Nm^3.

3.2.2.6.2 Emissions to air from the lime kiln

In the lime reburning process the calcium carbonate formed during the recausticising process (see Figure 3.3) is thermally converted back to calcium oxide according the reaction equation $CaCO_3 \rightarrow CaO + CO_2$. The reaction takes place in a rotary kiln where wet lime mud is dried, heated up to the reaction temperature, calcinated and cooled again. The calcination reaction starts at 800 °C and to complete the reaction temperatures up to 1 000 – 1 100 °C are required in the hot end of the kiln. The cooling is done by air in heat exchangers. The gas flow in a lime kiln is about 1 000 Nm^3/t (dry gas) of pulp and the energy used is about 1.5 – 1.8 GJ/t of pulp, if the purchased burnt lime is included in this figure.

The major air emissions from the lime kiln are sulphur dioxide, nitrogen oxides, reduced sulphur compounds (TRS), carbon monoxide (CO) and particulate matter. Emission of volatile organic compounds (VOC) is also relevant in some locations. For specific emissions and concentrations (at 6 % O_2) for sulphur dioxide, total reduced sulphur, nitrogen oxides (as NO_2) and dust the reader is referred to Figure 3.72 and Figure 3.73 (for SO_2 and TRS), Figure 3.76 and Figure 3.77 (for NO_X as NO_2), Figure 3.80 and Figure 3.81 (for dust).

SO_2 emissions
SO_2 is formed during combustion of the fuel in the kiln when the fuel contains sulphur compounds. The role of sulphur entering the lime kiln with the lime mud is in this respect marginal.

SO_2 emissions are significantly higher when non-condensable gases and/or methanol are incinerated in the kiln without a scrubber.

To minimise the emission of SO_2, either fuels with a low-sulphur content can be used or, if malodorous non-condensable gases (NCG) are burnt in the lime kiln, sulphur compounds can be scrubbed out of the waste gas of the lime kiln. Typical total S emissions from lime kilns are from ten up to several hundred mg/Nm^3 if NCG are burnt, and 10 – 30 mg/Nm^3 if they are not.

An alkali scrubber in one or two washing stages can remove SO_2 from lime kiln flue-gas. The incoming level of SO_2 determines the number of spraying nozzles in the scrubber and the alkali charge.

Total reduced sulphur emissions (TRS)
Flue-gases from the lime kiln may contain minor amounts of hydrogen sulphide due to incomplete washing of lime mud. Some mills also burn collected odorous gases in lime kilns. When the burner is properly designed and the combustion correctly controlled, this does not increase TRS emissions from the kiln. The TRS emissions from a lime kiln consist mainly of hydrogen sulphide. Measured H_2S concentrations are normally between close to zero and 40 mg/Nm^3.

TRS emissions may originate from two sources: If the fuel contains sulphur and insufficient air is present for complete combustion, carbon monoxide and hydrogen sulphide may be formed and exit in the flue-gas. The main origin of H_2S is the remaining sodium sulphide (Na_2S) in the lime mud fed into the kiln. If Na_2S enters the cold drying and heating section of the lime kiln in the presence of CO_2 and water, H_2S is formed according to the following reaction equation:

- $Na_2S + CO_2 + H_2O \rightarrow H_2S + Na_2CO_3$.

H_2S formation in the lime kiln can be controlled by the oxygen level and the amount of sodium sulphide in the mud burnt in the kiln. The presence of sufficient excess air can be ensured by a residual oxygen control system. The sodium sulphide content can be controlled by properly operated lime mud washing and filtering so that sodium sulphide (Na_2S) is prevented from entering the lime kiln.

With a proper capacity lime mud filter, a small amount of air is sucked through the lime mud cake and the residual Na_2S left on the surface of the lime mud particles is then oxidised to sodium thiosulphate which does not cause any H_2S formation in the kiln. If H_2S problems arise, the reason is in many cases poor lime mud quality in terms of its dry solids content (normally over 80 %) and purity (low free alkali concentration is required). Technical options are an improvement of green liquor clarification and the lime mud washing or replacing a part of the lime with make-up lime.

Dust emissions

Particulate matter is made up of lime dust and sodium condensed out of the vapour phase. The emissions can be controlled internally by design and proper running of the kiln and externally by adding an electrostatic precipitator and/or a scrubber. An electrostatic precipitator reduces the concentration of particulates down to about <20 – 50 mg/Nm^3 but some mills also have higher emissions. The actual particulate emission depends on the design, operation and maintenance of the ESP. Dry dust from the ESP returns to the kiln on closed conveyors.

Electrostatic precipitators are efficient in removing dust particles. The advantage that electrostatic precipitators have over wet scrubbers is that they remove dust in the dry state without requiring pumps, valves, and associated equipment. The disadvantage is that the ESP does not reduce emissions of total reduced sulphur (TRS) or SO_2. Wet scrubbers are used for dust separation and gas absorption. A venturi-type scrubber using an alkaline solution is the most common.

NO_X emissions

NO_X emissions are mainly correlated to the burner design, the nitrogen content of the fuel and the combustion temperature. The use of concentrated non-condensable gases, methanol and turpentine increases the NO_X emissions from the lime kiln, while the use of tall oil as fuel lowers NO_X emissions.

NO_X emissions are 150 – 500 mg/Nm^3 depending on the fuel used and the emission control measures applied. They remain at the same level with oil and gas with the correct flame shaping. When burning NCG, NO_X emissions are somewhat higher.

Nitrogen oxide emissions can be controlled by adjustments of the lime kiln temperature distribution (adjustment of primary air distribution, split burning air into primary, secondary and tertiary air) without any special external gas cleaning devices. The kiln temperature profile influences NO_X formation. Flame shaping and adjustment (long versus short flame) also affect the combustion temperature and NO_X formation.

For higher NO_X levels from the lime kiln, the use of selective non-catalytic reduction (SNCR) might be considered. However, there is still no SNCR application for reburning lime kilns.

3.2.2.6.3 Emissions to air from steam boilers or CHP plants

Bark or multi-fuel boilers

Bark is used in steam boilers in pulp mills to a large extent. In addition to bark, biomass from external sources (bought biomass) and other fuels may be burnt in bark or multi-fuel boilers. For data on air emissions from these boilers, the reader is referred to Section 2.6.2.

Energy-efficient non-integrated bleached kraft pulp mills are net exporters of both biofuel and electricity. They do not need bark for steam production and can sell it.

Other steam boilers

In integrated pulp and paper mills the excess heat produced by the pulp mill is often not sufficient to cover the entire energy demand of the pulp and paper production process. The additional heat required is produced in steam boilers. The emissions from these boilers depend on the fuel, the fuel mixture, their impurity content and the emission control techniques applied. Most of the boilers for solid fuels are fluidised bed boilers, especially when difficult mixed fuels with varying properties are incinerated (see Section 2.6.1.2.3). Current emissions data for different types of auxiliary boilers are given in Section 2.6.2.

3.2.2.6.4 Malodorous gases

The problem of kraft mill odour originating from the sulphide in the white liquor, an aqueous solution of sodium hydroxide (NaOH) and sodium sulphide (Na_2S), during pulping has long been an environmental and public relations issue for the pulp and paper industry. It is caused predominantly by malodorous reduced sulphur compounds produced in the kraft pulping process, or total reduced sulphur (TRS), namely, methyl mercaptan (MM), dimethyl sulphide (DMS), dimethyl disulphide (DMDS), and hydrogen sulphide (H_2S). MM, DMS and DMDS are the main volatile organic sulphur compounds and are formed in the pulping process, while hydrogen sulphide is formed in the downstream processes where the pH of the mill streams are reduced to below 10. Although a significant reduction of TRS emissions has been achieved in the pulp and paper industry from approximately the year 2000 to 2010 with advanced collection and odour abatement techniques, subjective odour nuisance at very low concentrations still causes odour problems in communities surrounding a kraft mill. Furthermore, because of the enhanced sensitivity of the human nose to sulphur compounds due to the variability of odour emissions from day to day, kraft mill TRS emissions will always be a sensitive subject in dealing with the public and surrounding communities.

The malodorous gas streams are generally divided into strong (concentrated) and weak (diluted) gases. The latter normally refers to a sulphur concentration of <0.5 g/Nm^3, while the more concentrated or strong gases are normally above 5 g/Nm^3.

Two general approaches are implemented in kraft mills to abate odour: thermal oxidation and absorption using scrubbing technologies. Thermal oxidation of TRS is achieved by two steps: collecting non-condensable gases (NCG) in various emission vents and eliminating odorous compounds in the NCG through combustion to convert them into non-odorous compounds. Absorption is mainly implemented to destroy H_2S and MM in diluted NCG by scrubbing using a spray tower or packed column.

Concentrated gases are collected and burnt either in the lime kiln, the recovery boiler or in a dedicated burner. If a dedicated burner is used, a scrubber is normally added to control the emission of the SO_2 formed.

The heat energy can be used but NO_X formation is high. NO_X emissions can be reduced by about 70 % by optimising combustion conditions.

The advantage of burning the malodorous gases in the lime kiln is that no extra furnace is needed. In addition, the sulphur in the gas can be partially absorbed which reduces the emission of sulphur dioxide. However, the S content of malodorous gases normally exceeds the absorption capacity in the lime kiln and leads to an increase of SO_2 emissions.

On average, 15 % of the fuel used in a lime kiln can be replaced by malodorous gas. However, the variation of the amount of energy of the gas may make it difficult to produce lime of a good and uniform quality. Separating off methanol from the gases minimises the problem of varying gas quality. The separated methanol can then be fed in the liquid phase to the lime kiln or to a burner dedicated to malodorous gases.

Diluted gases at some mills are collected and burnt in the recovery boiler, in the lime kiln, or are scrubbed. Scrubbing is mainly effective on H_2S. Burning the weak gases in the recovery boiler may influence the operation of the boiler and require modification of the boiler. At some mills, both weak and strong malodorous gases are burnt in the recovery boiler.

In cooking and evaporation, some of the malodorous compounds are transferred to the condensates. In addition to reduced sulphur compounds, the condensates contain methanol and some other oxygen-consuming compounds (BOD load). The foul condensates are collected and treated separately as described above (see Section 3.2.2.4).

Odour- and sulphur-containing gases are briefly summarised below.

Concentrated malodorous gases (CNCG)

Malodorous gases - often referred to as non-condensable gases (NCG) - contain gases released during the manufacturing of kraft pulp and volatile compounds entering with the wood. The gases released during cooking, black liquor handling and causticising, i.e. hydrogen sulphide, methyl mercaptan, dimethyl sulphide and dimethyl disulphide, are strongly odorous compounds, which give malodorous gases their characteristic aroma. The volatile compounds entering with the wood raw material, i.e. turpentine and methanol, are not odorous in a pure state, but in pulp mills they contain impurities in the form of odorous components.

Concentrated non-condensable gases originate mainly from the cooking plant, evaporation plant or from the stripping of foul condensates. The total amount of sulphur in concentrated non-condensable gases in a modern chemical pulp mill is in the range of 2 – 5 kg S/ADt and is normally higher at hardwood pulping than at softwood due to the different lignin structure. For process reasons, the amount of concentrated non-condensable gases may vary widely. Typical amounts of CNCG collected from different sources in a chemical pulp mill are shown in Table 3.14.

Table 3.14: Amounts of concentrated non-condensable gases collected from different sources

Source	kg S/ADt	Nm^3/ADt
Batch cook blowing	0.4 – 0.8	5 – 15
Batch cook gassing	0.1 – 0.2	1.0 – 3.0
Continuous cooking	0.1 – 0.4	1.0 – 4.5
Stripper	0.5 – 1.0	15 – 25
Evaporation plant	0.4 – 0.8	1 – 10
Methanol processing	0.5 – 2.0	1.0 – 2.0
Black liquor heat treatment	2 – 3	1.5 – 3.0
Super concentrator	2 – 5	1.5 – 6.0
Total	2 – 5	3 – 40

Source: Sanna Hämäläinen, Botnia (Rauma), 2009.

Dilute non-condensable gases (DNCG)

These gases are the major contributors to the diffuse emissions from kraft pulp mills. Although dilute malodorous gases are less concentrated, the releases are relevant and may account for a significant share of the total emission from the pulping process. Dilute non-condensable gases are collected from tanks and equipment in the fibre line (chip presteaming, screening, pulp washing, ventilation of various tanks that contain black liquor), the evaporation plant, tall oil cooking plant and causticising plant (e.g. smelt dissolver). Non-condensable gases from pressurised liquor tanks should be handled as concentrated non-condensable gases. Dilute non-condensable gases contain the same components as concentrated non-condensable gases but have so much leakage air that their concentrations are considerably lower.

Table 3.15 shows the amounts of dilute non-condensable gases collected from different sources of a kraft pulp mill at 40 °C.

Table 3.15: Amounts of dilute non-condensable gases collected from different sources at 40 °C

Source of the kraft pulp mill	kg S/ADt	Nm^3/ADt
Vent gases from continuous cooking	0.1 – 0.5	100 – 400
Vent gases from superbatch cooking (evacuation air, vents from non-pressurised tanks)	0.1 – 0.5	150 – 300
Pulp washing plant vent gases	0.05 – 0.1	100 – 200
Tall oil cooking plant vent gases	0.05 – 0.2	2 – 3
Tank vent gases, evaporation plant (atmospheric pressure tanks)	0.1 – 0.4	20 – 30
Causticising plant lime kiln area	0.01 – 0.1	5 – 10
Total	0.1 – 0.5	300 – 400
Source: Sanna Hämäläinen, Botnia (Rauma), 2009		

Streams not included in non-condensable gases

There are numerous streams from pulp mills that contain water vapour and air. Examples of streams that are not considered collectible because of their negligible sulphur content are the following:

- ventilation air from buildings
- moist water vapour from pulp or paper machines
- moist air from cooling towers
- water vapour from the surface of effluent treatment ponds
- ventilation from drains
- vapour from vacuum pumps.

3.2.2.6.5 VOC emissions

Emissions of volatile organic compounds (VOC) from the process are reported to be about 0.4 kg/t for softwood kraft and less than 0.1 kg/t for hardwood kraft. There are also some emissions of VOC from the chip heaps. As an example, VOC emissions from the chips are about 0.2 – 0.3 kg/m^3 of wood at kraft pulping.

3.2.2.6.6 Chlorine compounds from bleaching and bleaching chemical preparation

In bleached kraft pulp mills using chlorine dioxide as the bleaching chemical, chlorine compounds from the bleach plant and the ClO_2 production are released to the atmosphere. In Table 3.16 some examples of chlorine emissions to air from some Swedish pulp and paper mills are presented.

Table 3.16: Examples of permitted and measured values of chlorine emissions to air from the bleach plant and ClO_2 production of some Swedish pulp mills

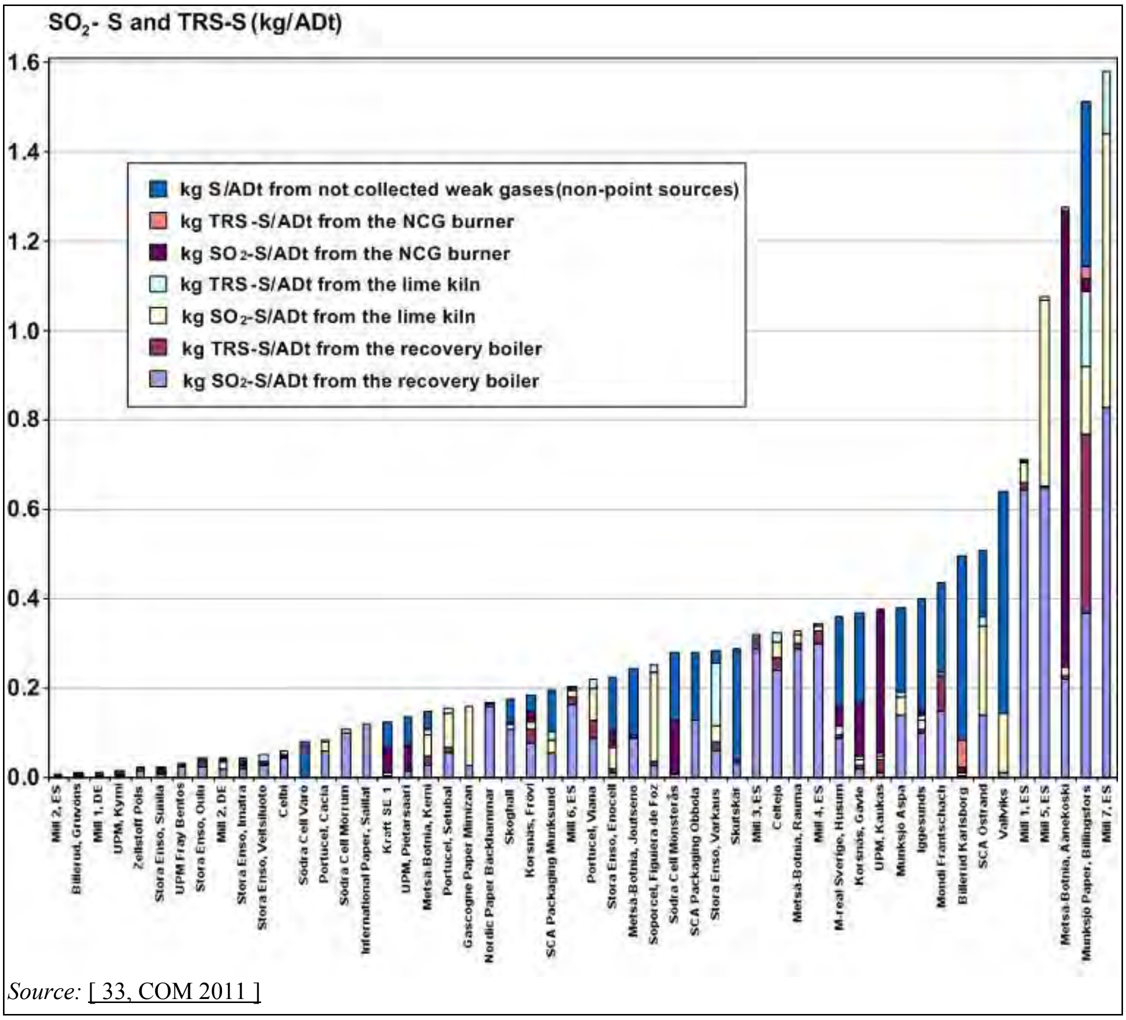
Name of mill	Condition in the permit (kg active chlorine/t bleached pulp)	Measured values in 2008 (kg chlorine/t bleached pulp)	Remarks
M-real, Husum	0.1 as annual average	0.01	6 400 kg/year
Billerud, Skärblacka	0.25	0.15	
Billerud, Gruvön	100 kg/day (approx. 0.1 kg/t bleached pulp)	5 kg/day (approx. 0.005 kg/t bleached pulp)	
Korsnäs	0.18	0 – 0.4	4 times/year after scrubber, 146 t/year
Skoghall	50 kg/day annual (approx. 0.11 kg/t bleached pulp)	3 000 kg/year, 8.5 kg/day (approx. 0.02 kg/t bleached pulp)	
Source: Swedish EPA, 2008			

The data given in Table 3.16 come from the obligatory annual reporting and permits of the mills. The figures cover all emissions from the plant, normally measured in ventilations from the bleach plant and from chlorine dioxide production after scrubbers. Chlorine compounds (Cl_2, ClO_2) that can be detected in the bleaching chemical preparation area and in the ventilation vapours of the bleach plant are measured periodically.

3.2.2.6.7 Total process emissions

3.2.2.6.7.1 Total sulphuric emissions from the process

In Figure 3.29, the total sulphuric emissions (SO_2-S and TRS-S) from all processes are compiled for all European pulp mills that participated in the data collection carried out by the EIPPCB. Point sources considered include the recovery boiler, the lime kiln and the dedicated NCG burner. The total process emissions exclude emissions from auxiliary boilers or other steam and power plants. The emissions data shown in Figure 3.29 include all mills that completed the questionnaire launched by the EIPPCB in February 2011.



Source: [33, COM 2011]

Figure 3.29: Total S emission load (as kg S/ADt) from major processes (recovery boiler, lime kiln, NCG burner) including uncollected or untreated weak gases

It is clear that the mills with the best performance achieve low-sulphuric emissions from all potential emission sources including non-point sources. These mills have found solutions to keep overall S emissions low without shifting sulphuric emissions from one emission source to another.

Differences seem to exist between mills and countries in Europe with regard to reporting of emissions of uncollected and/or untreated non-condensable gases (NCG). Reported emissions may include uncollected weak gases (Swedish mills) or collected but untreated weak gases, which however are bypassed in the event of failure of the gas treatment system and recorded separately (Finnish mills).

At modern mills that apply effective collection systems, diffuse emissions from nearly all production process sources are collected and incinerated and significant diffuse emissions do not occur in practice. The exceptions are those streams that are not considered worth collecting because of their negligible sulphur content and those resulting from momentary failures of the gas treatment system during which the gas destruction system is bypassed and collected NCG are released untreated via stack.

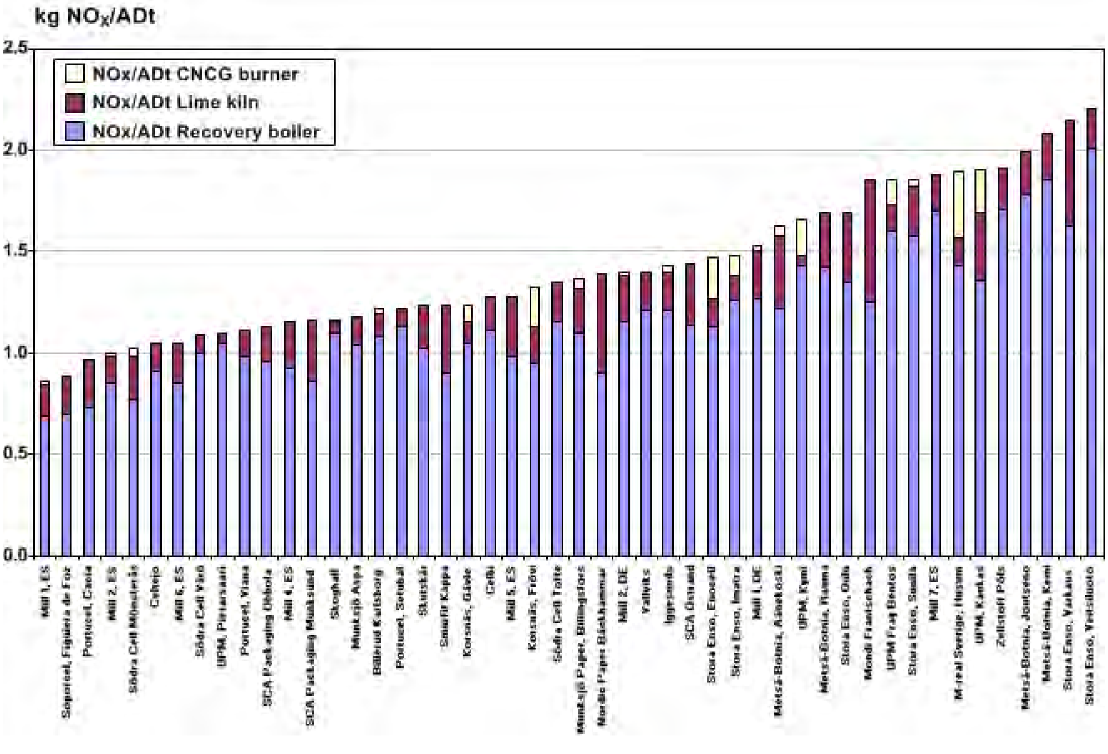
There are other kraft pulp mills in Europe whose collection and incineration systems for weak gases are still inadequate, causing higher diffuse sulphuric emissions from the mill area even during normal operating conditions. Typical sources are tank areas at mills with such a disperse layout that technologically and economically viable collection applications are more difficult to implement in practice.

Figure 3.29 shows that point sources from the main processes (recovery boiler, lime kiln, dedicated burner for odorous gases) may release lower sulphuric emissions than diffuse sources. Uncollected mostly weak NCG and emissions from bypassing the gas destruction system for malodorous gases in case of failures can contribute a high percentage of the total sulphur emission of the mill due to the low-sulphur emissions from point sources during periods of normal operation.

Normally, uncollected S emissions cannot be accurately measured but are approximated using different methods, see Section 2.2.2.2.6.

3.2.2.6.7.2 Total NO_X emissions from main processes

In Figure 3.30, NO_X emissions from all processes are compiled for a number of European pulp mills that participated in a data collection carried out by the EIPPCB in February 2011. Point sources considered include the recovery boiler, the lime kiln and the dedicated NCG burner. The total process emissions exclude auxiliary boilers or other steam and power plants.



Source: [33, COM 2011]

Figure 3.30: Total NO_X emission load (as NO_2/ADt) from major processes (recovery boiler, lime kiln, NCG burner)

Expressing emission levels as specific loads in kg NO_2/ADt
When expressing specific emissions for pulp manufactured from different wood species, it has to be taken into account that for the same amount of wood, some mills produce more pulp than others (higher yield). For NO_X this leads to inequality between mills. A study [226, Vakkilainen et al. 2005] concluded that large modern pulp mills that use the same specified level of technology but different wood species for pulping (eucalyptus and mixed Scandinavian wood) produce different NO_X emissions. In practice, the best eucalyptus mills produce specific NO_X loads of around 0.2 kg NO_2/ADt lower than the best comparable Nordic softwood mills because the pulp yield of eucalyptus is higher than for Nordic mixed wood. This should be borne in mind when comparing BAT-AELs expressed as specific loads (kg pollutant/ADt).

The same applies for unbleached kraft pulp. For unbleached pulp, the yield is higher than for bleached pulp, the amount of generated black liquor and the corresponding flue-gas flow lower and thus the product-specific emission load per tonne of pulp lower than for bleached pulp.

3.2.2.7 Solid waste

The production of kraft pulp generates various fractions of solid waste: inorganic sludge (dregs, green liquor sludge and lime mud) from the chemical recovery; bark and wood residues from wood handling; sludge from effluent treatment (inorganic material, fibres and biological sludge); dust from boilers and furnaces; rejects (mainly sand) from the wood handling; and ashes and miscellaneous material (like building material). Many organic substances, which might be considered waste products, are burnt for energy recovery. This normally includes bark and wood residues and could include water treatment sludge.

Dregs and lime mud are separated from the chemical recovery cycle in order to keep the amount of inert material and non-process chemicals in the cycle at an acceptable level and thus secure high reaction rates in the chemical recovery system.

Bark and wood residues from wood handling is normally burnt for energy recovery. Wood ash from bark boilers contains nutrients taken from the forest with the wood raw material and this ash can be suitable as a fertiliser as long as it is not contaminated, e.g. by metals like Hg, Cd and Pb although these come from the wood itself. The leaching of heavy metals from the recycled ashes spread to forest or agricultural land might be a drawback of these measures.

Sludge from waste water treatment is one of the main groups of residues. A large amount of sludge is generated in primary treatment and in biological treatment with the activated sludge method. Aerated lagoons generate only small amounts of excess sludge. Chemical flocculation produces a considerable amount of sludge. Biological and chemical sludge has poor dewatering properties.

The sludge is usually thickened before being dewatered in a filter press, screw press or in a vacuum filter. Often excess sludge from biological waste water treatment is mixed with primary sludge and bark sludge before dewatering. Inorganic and/or organic chemicals are used to improve the dewatering of sludge by forming larger flocs. Mixed sludge can be dewatered to 25 – 35 % dryness with filter presses and to 40 – 50 % with a screw press using steam in the pretreatment stage.

In sludge burning, the net energy production is around zero or negative if the dry solids content in the sludge is below 40 % and if the sludge contains a high amount of inorganic material. The use of auxiliary fuel is necessary to maintain good burning conditions unless the sludge is mixed with bark and other wood waste material. Burning reduces the volume of waste and the inorganic content remains as ash, which is normally transported to a landfill site.

Sludge from chemical precipitation cannot be burnt alone without the use of auxiliary fuel because of the high content of inorganic matter and water. The sludge is therefore often transported to a landfill site. Sludge from flocculation with only synthetic organic polyelectrolytes is suitable for incineration.

Sufficiently qualified and comparable data on waste generation are limited. In Table 3.17, available data for various types of waste generated in a kraft pulp mill are given.

Table 3.17: Average waste generation in kraft pulp mills in kg dry solids/ADt

Type of waste	kg dry solids/ADt of pulp
Waste water treatment sludge	10
Wood ash	9 (*)
Other ashes	14 (*)
Fibre	5
Wood waste	6
Dregs, grits and green liquor sludge	10 – 20
Lime enriched with non-process elements	10 – 20
Hazardous waste	0.2
Total	**60 – 80**

NB:
'Wood ash' is fly ash and dust from the incineration of wood material (e.g. from the bark boiler).
'Other ashes' are ashes from fuels used in energy production other than wood and black liquor.
(*) Values for ash/ADt are higher if additional biomass from external sources is used as complementary fuel.
'Wood waste' is bark, chips, sawdust, wooden packages, etc.
Source: [Finnish BAT Report, 1996], with changes proposed by experts from the TWG.

Data on solid waste in Swedish mills (expressed as dry solids or DS) are reported below.

Green liquor sludge, dredges and lime mud
These wastes are often mixed and it is very difficult to give separate figures. In total, the amount varies roughly between 10 and 60 kg/t of pulp with an average of about 30 kg/t of pulp (SEPA 4 869). The composition in such a mixed waste varies as well. In Report 4 from the project 'Miljö 95/96' data for a number of samples are given. The following averaged data are calculated for green liquor sludge with different amounts of lime mud.

Table 3.18: Average composition of green liquor sludge with different amounts of lime mud

Lime mud (%)	Dry solids (%)	Ash (%)	Organic content (%)	Tot-N g/kg DS	Tot-P g/kg DS	Tot S g/kg DS
<2	45	62	20	0.4	0.6	23
75	59	62	6.5	<0.4	2.8	6.3

The figures are divided into two groups: one with almost no lime mud (<2 %) and the other with a lot of lime mud (about 75 % on average).

Metal concentrations are also reported for the same samples. In Table 3.19 averaged values are shown.

Table 3.19: Average metal concentrations in green liquor sludge with different amounts of lime mud

Lime mud (%)	Ba	Cd	Co	Cr	Cu	Hg	Ni	Pb	Sr	Zn
<2	430	16	9.2	75	90	0.07	60	18	330	2 300
75	310	11	5.3	85	96	<0.10	29	11	290	1 000
NB: All values expressed as mg/kg dry material.										

In Sweden, green liquor sludge is normally dried on drum filters with a precoat layer of lime mud given a DS of 30 – 70 %. If centrifuges are used the DS is about 8 – 20 % (see Report 4 of Miljö 95/96). The sludge is normally landfilled.

Ashes, slags, particulate matter (e.g. from electrostatic precipitators)
According to SEPA 4 869, the amounts for kraft pulp mills are between about 5 and 45 kg/t of pulp.

Wood yard waste to landfill
The amounts vary between 1 and 20 kg/t of pulp. This waste mainly consists of bark, sand and stones (SEPA 4 869).

Rejects from screening/fibre rejects
The limited amount of data in SEPA 4 869 shows figures between about 2 and 20 kg/t of pulp.

Sludge from biological treatment
At kraft pulp mills with aerated lagoons the amount of sludge is very small, usually <1 kg of DS/t of pulp (from Report 4). Biological treatment in activated sludge plants generates higher amounts of sludge.

3.2.2.8 Noise

The debarking plant generates noise that can be controlled by carefully insulating the debarking house. There are several other sources of noise like chipping, fans, engines, stacks and steam vents. Trucks and other vehicles used at the plant can cause noise in the vicinity of the mill. For further details on noise, the reader is referred to Section 2.9.13.

3.2.2.9 Emissions to soil and groundwater

If preventive control measures for the storage and handling of chemicals are in place, and are well-maintained and controlled, pulp and paper mills should not usually release hazardous substances to soil and groundwater.

For measures to prevent hazardous emissions to soil and groundwater from the storage and handling of chemicals or after the cessation of the activities, the reader is referred to Section 2.9.2.3 'Safe storage and handling of basic chemicals and chemical additives' and Section 8.1.10 'Prevention of pollution risks from decommissioning'.

3.3 Techniques to consider in the determination of BAT

This section describes techniques (or combinations thereof), and associated monitoring, considered to have the potential for achieving a high level of environmental protection in the activities within the scope of this document. The techniques described will include both the technology used and the way in which the installations are designed, built, maintained, operated and decommissioned.

It covers environmental management systems, process-integrated techniques and end-of-pipe measures. Waste prevention and management, including waste minimisation and recycling procedures are also considered, as well as techniques that reduce the consumption of raw materials, water and energy by optimising use and reuse. The techniques described also cover measures used to prevent or to limit the environmental consequences of accidents and incidents, as well as site remediation measures. They also cover measures taken to prevent or reduce emissions under other than normal operating conditions (such as start-up and shutdown operations, leaks, malfunctions, momentary stoppages and the definitive cessation of operations).

Annex III to the Directive lists a number of criteria for determining BAT, and the information within this chapter will address these considerations. As far as possible, the standard structure in Table 3.20 is used to outline the information on each technique, to enable a comparison of techniques and the assessment against the definition of BAT in the Industrial Emissions Directive.

This section does not necessarily provide an exhaustive list of techniques which could be applied in the sector. Other techniques may exist, or may be developed, which could be considered in the determination of BAT for an individual installation.

Table 3.20: Information for each technique described in this chapter

Headings within the sections
Description
Technical description
Achieved environmental benefits
Environmental performance and operational data
Cross-media effects
Technical considerations relevant to applicability
Economics
Driving force for implementation
Example plants
Reference literature

3.3.1 The relevance of the wood species when determining BAT for kraft pulp mills

In Europe, wood for kraft pulping can be distinguished into softwood, hardwood and as a speciality of the latter, eucalyptus. To a certain extent, the type of wood used for pulping may influence the yield, the applied processes and techniques, the process efficiency and the emission levels associated with BAT.

There are mills that use either only softwood or only hardwood; others use softwood and hardwood alternately in the same production line. The design of the production process and recovery line is adapted to this situation and the efficiency of the different processes may be affected (at least during the changeover period).

3.3.1.1 Environmental issues specific to eucalyptus-based kraft pulp-making

The use of eucalyptus wood is especially significant in the production of bleached paper pulp. Six mills in Spain produce 1.5 million ADt/year of bleached eucalyptus pulp and a further six in Portugal produce 1.83 million ADt/year, which together account for 12 % of the total kraft pulp output in CEPI represented countries.

Emissions to water

The most significant factors with regard to bleached pulp mill emissions to water are the degree of delignification achieved before the pulp enters the bleaching section (kappa number), efficient pulp washing to reduce the carry-over of black liquor with the pulp, and the bleaching sequences, bleaching chemicals used and the extent of (partial) closure of the water circuits in the bleach plant. Although these techniques generally do not differ significantly when comparing eucalyptus-based pulps with other hardwood and softwood pulps, lower emission levels are achieved by eucalyptus-based pulp mills. For example, the best eucalyptus kraft pulp mills achieve a COD emission load of around 5 kg COD/ADt, a value which is not achievable by the best softwood-based kraft pulp mills; these achieve around 7.5 kg COD/ADt (50 % higher). The use of extended modified cooking and oxygen delignification with eucalyptus wood provides a kappa number of between 10 and 13 before the pulp enters the bleach plant, similar to the indexes achieved with other types of wood.

The conventional bleaching sequence used is D-EOP-D, which may or may not be followed by an additional hydrogen peroxide (e.g. UPM Fray Bentos: AD-EOP-D-P) or chlorine dioxide stage (e.g. Aracruz: AD-EOP-D-D). 'A' stands for acid hydrolysis of hexenuronic acids, and 'D' for chlorine dioxide bleaching stage. In a number of mills, ozone-based steps ('Z') in the bleaching sequences of eucalyptus pulp are applied, reducing the ClO_2 load, the OX (organically bound halogens) values in the pulp and the AOX values of the effluents.

Achievable specific organic loads in effluents discharged from eucalyptus pulp mills prior to biological treatment are lower than discharges from softwood-based mills. The best eucalyptus-based mills achieve 15 – 20 kg COD/ADt, the best softwood mills achieve around 30 kg COD/ADt before treatment. This can be explained by the fact that eucalyptus is easier to bleach and has a higher yield than wood species from central or northern Europe. *Eucalyptus globulus* have higher yields of around 51 – 54 % compared to Nordic softwood (44 – 46 %) and hardwood (47 – 49 %). Higher yields lead to lower specific emission load values (e.g. kg COD/ADt of pulp) even if the techniques applied are the same.

The phosphorus content in waste waters from some Iberian eucalyptus-based pulp mills is higher than in the effluents from mills using other types of wood. Even though no phosphorus is added as a nutrient in the biological waste water treatment plant, the P level in discharged effluents is considerably higher compared to production sites using non-eucalyptus forest species. This statement is valid assuming that no flocculants are added for phosphorus removal. For eucalyptus pulp mills using wood from regions with higher levels of phosphorus, the average level discharged with the effluent is 0.12 kg tot-P/ADt after the biological process.

Emissions to air

Emissions to air from recovery boilers or lime kilns do not vary between different types of wood. However, the nitrogen content (% N) in the black liquor needs to be measured when comparing emissions to those from other recovery boilers.

When expressing specific emission loads (kg pollutant/ADt) for pulp manufactured from eucalyptus species, it has to be taken into account that mills pulping eucalyptus wood reach higher yields than those pulping mixed Nordic wood for example. Even if the specified level of technology is the same, eucalyptus mills produce emission loads that are mostly lower than those released from Nordic softwood mills. This should be borne in mind when comparing BAT-AELs expressed as specific loads (kg pollutant/ADt).

Energy
With eucalyptus it seems difficult to achieve concentrations of over 72 % dry solids content in black liquor. However, the recovery boiler of the eucalyptus-based mill in Fray Bentos, Uruguay, runs with 79 % dry solids.

Eucalyptus globulus has a cellulose content of 52 – 58 % and therefore has a low specific wood consumption, between 2.7 and 3.6 m^3/ADt of pulp. These factors mean that the generation of heat when burning black liquor is lower than the heat output produced by burning other types of wood. Heat in the form of high-pressure steam measured at the outlet from the boiler, not counting the air blow, is 12 – 13 GJ/ADt, compared to 15 – 16 GJ/ADt from softwood pulp mills. Of this, 2.0 – 2.5 GJ/ADt are used to produce electricity in the steam turbine. The new Fray Bentos eucalyptus-based mill however reported higher values - around 3.5 GJ/ADt.

Reference literature
[70, González 2011], [73, ASPAPEL/CELPA 2010], [77, Costa et al. 2009], [78, Hostachy 2010].

3.3.2 Dry debarking

See Section 2.9.2.2.

3.3.3 Modified cooking before bleaching

Description
Delignification before the bleach plant is done in digesters and, at many mills, also by use of oxygen delignification. Therefore, the techniques 'Extended modified cooking' and 'oxygen delignification' (see Section 3.3.5) should be considered together because the essential issue from an environmental point of view is the total degree of delignification achieved as a result of the delignification stages before the pulp enters the bleach plant. There should be a balance between the kappa reduction in cooking and in oxygen delignification since the selectivity is much higher in the latter system (see Section 3.3.5). For the mill, it is important to control the various processes so that yield and strength characteristics are optimum for a given lignin content.

In order to decrease the lignin content (lower kappa numbers) in the pulp entering the bleach plant and to reduce the charge of bleaching agents in subsequent bleaching (see Sections 3.3.6 and 3.3.7), several modified kraft processes in both continuous and batch systems have been developed and applied commercially.

The different modified cooking processes are based upon the same principles [19, G.Sousa 2011]. These principles involve a series of chemical and physical processes that are aimed at the improvement of cooking selectivity (yield and viscosity).

- **Low and uniform alkali concentration profile (longitudinal and radial):** High alkali concentrations should be avoided in the initial stages of cooking, preventing excessive carbohydrates dissolution. However, generally, fairly high alkali concentrations should be guaranteed in order to increase the relative delignification rate and prevent lignin condensation.
- **High sulphide concentration in the bulk cooking stage**: Sulphide concentration has a relevant influence over the bulk delignification stage. Thus, the presence of this ion on an

active site is imperative in order to increase the relative delignification rate. This parameter may be controlled by adding sulphide on top of circulation or by impregnating wood with black liquor.

- **Low dissolved lignin concentration and low ionic strength**.
- **Low cooking temperature:** This is especially important in the initial and residual stages of cooking.
- **Longer cooking times:** It is known that longer cooking allows a reduction of alkali charge and/or cooking temperature. Increased cooking times induce a higher cooking selectivity, when compared with alkali or temperature effects. New cooking equipment, with higher capacities, will have higher residence times, which would ultimately benefit cooking selectivity.

Examples for this modified cooking processes are as follows.

(a) Continuous cooking
The state-of-the-art continuous cooking techniques (e.g. Lo-Solids and Compact Cooking) include some of the above-mentioned principles.

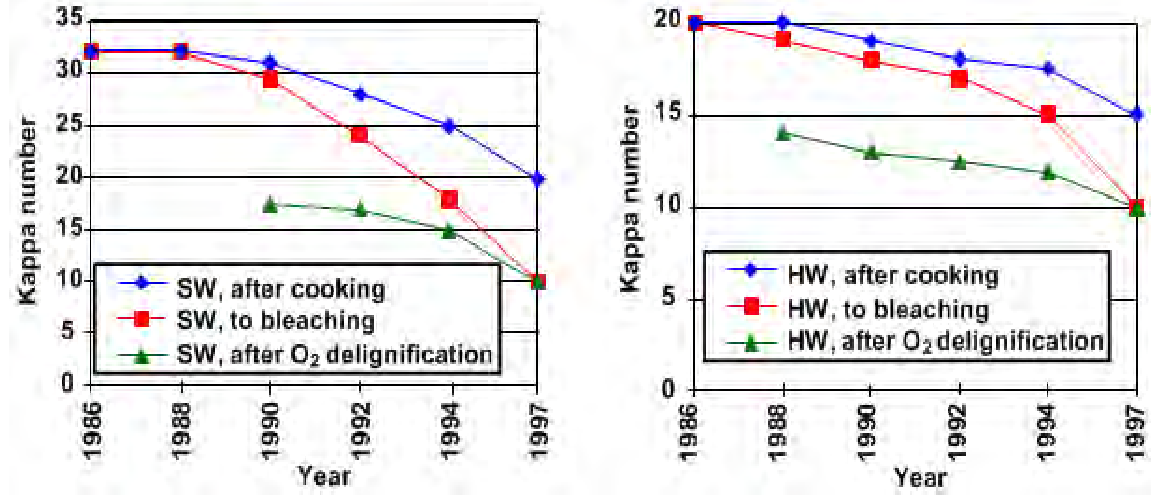
The Compact Cooking method relies on the improvement of the delignification selectivity by maintaining the concentrations of the hydroxide and hydrogen sulphide ions in both the initial and bulk phases as high as possible. Consequently, the reaction of the residual phase proceeds more slowly with the residual lignin and thus a higher pulp yield can be expected. Through black liquor impregnation, the Compact Cooking process improves cooking flexibility. Black liquor impregnation is attained by recycling the final cooking liquor, containing an adequate alkali and sulphide concentration. Potential environmental advantages of this cooking method are higher delignification rate, yield preservation, lower reject content, increased pulp bleachability, lower digester temperature, lower cooking and bleaching chemical consumption.

With the Lo-Solids method, the amount and concentration of dissolved wood solids in the bulk and residual phases are kept to a minimum while maintaining a uniform radial distribution of temperature and pulping chemicals, an even alkali profile along the height of the cooking vessel, minimal concentrations of dissolved lignin at the end of the cooking process, and minimal cooking temperatures. This is achieved by extracting cooking liquor from multiple points of the digester, while replenishing it with fresh liquor in order to maintain the necessary alkali profile and to satisfy the required hydraulic parameters. Potential environmental advantages of this cooking method are a marginal increase of the delignification rate, lower digester temperature and lower cooking and bleaching chemical consumption.

(b) Batch cooking
In the batch cooking systems, processes are based on cooking liquor displacement techniques (e.g. rapid displacement heating (RDH) and superbatch). These systems include a black liquor impregnation stage in order to decrease the heat consumption and the initial sulphide concentration at the same time and to decrease the effective alkali charge. These batch systems have evolved to combine the current technologies into one cooking method. DualC and Continuous Batch Cooking (CBC) are the latest batch cooking technologies. The basic concept of these technologies lies in the preparation of all the process-related liquors in separate vessels. During circulation, the required conditions such as alkali concentrations and temperature are adjusted by continuous addition of cooking chemicals and steam. The digester is filled up with black liquor and then is pressure-impregnated with alkali profiling. After impregnation, hot liquor displacement with alkali profiling and at cooking temperature is implemented for digester heating and cooking. After cooking, the digester is then displaced with cooled wash filtrate and discharged. A potential environmental advantage of this cooking method is improved pulp bleachability.

The lignin content is usually measured as the kappa number with a standardised method. Conventional cooking has its limits regarding how low the kappa number can be brought without deterioration of pulp quality (this kappa number is around 30 – 32 for softwood and

18 – 20 for hardwood). By use of several cooking modifications, the kappa number from cooking can be reduced to a level of 18 – 22 for softwood and 14 – 16 for hardwood, while the yield and strength properties are still maintained. The kappa number reduction depends, among other things, on the modified cooking technology applied and whether a retrofitted or new installation is used. As an example, the kappa trends in Finnish kraft pulp mills until 1997 are shown in Figure 3.31. The trend shown in Figure 3.31 was still valid at the time of writing (2013).



Source: [1, Finnish BAT Report 1997]

Figure 3.31: **Kappa trends in Finnish kraft pulp mills**

Since the late 1990s, the trend in kraft pulping has been to maintain a higher kappa number after cooking because a low kappa number after cooking was associated with reduced wood yield and thus higher costs. An increased kappa number after cooking is compensated by the use of other delignification processes using O_2 to reduce the kappa number that enters the bleaching process. Enhanced delignification after cooking contributes to lower emissions from the bleach plant.

Achieved environmental benefits

The reduction in lignin content before the bleach plant reduces the amount of pollutants discharged while increasing the amount of organic substances going to the recovery boiler. A lower lignin content before bleaching means fewer discharges from the bleach plant of not only organic substances but also nutrients for example. For softwood, one kappa unit corresponds roughly to 0.15 % lignin in the pulp. If the kappa number of pulp from cooking or oxygen delignification (see Section 3.1.6) can be lowered by one unit, the COD released in the bleach plant would be reduced by approximately 2 kg/ADt (COD from TCF bleaching can be as high as about 3 kg COD/kappa number). However, to get a figure for the total discharge from the bleach plant one has to add the COD carry-over from the closed part of the process (see Section 3.3.10).

Environmental performance and operational data

Kappa number reductions of 6 – 7 units for softwood and 4 – 5 units for hardwood have been accomplished without loss of strength properties.

Cross-media effects

Extended cooking affects several elements in the kraft process:

- the consumption of active alkali (NaOH + Na_2S) may slightly increase;
- in modified batch cooking, the energy consumption and blow steam amount decrease in the cooking, but the steam consumption in the evaporation of the black liquor may increase.

From an environmental point of view, extended modified cooking should be assessed together with the O_2 delignification steps because both processes together determine the lignin content to be removed in the bleach plant and thus the emission load.

Technical considerations relevant to applicability
The measure can be applied in new and in existing kraft pulp mills. However, the feasibility of modified cooking techniques has to be evaluated in each individual case.

In continuous cooking systems, the capacity of the plant may decrease with extended cooking.

In batch cooking, modified cooking can be retrofitted in conventional plants, if the digester capacity is large enough. The modifications of an existing batch cooking system can be carried out with additional batch digesters and additional investment without lessening the capacity of the cooking plant.

Economics
No information provided.

Driving force for implementation
Substantial energy savings, improved pulp quality, the reduction of emissions to water and reduced consumption of bleaching chemicals are important reasons for implementing this technique. However, as the most expensive component in pulping is wood, the increase or conservation of yield is also a crucial target for modified cooking.

Example plants
A number of digesters have been retrofitted or rebuilt to use modified cooking techniques.

Reference literature
[1, Finnish BAT Report 1997], [14, CEPI 1997], [19, G.Sousa 2011].

3.3.4 Closed brown stock screening

Description
The water system in the brown stock screening plant can be completely closed, which is a reality for most European mills. With modern wood handling and cooking, less than 0.5 % knots and shives are left in the pulp after cooking. The closing contributes to the reduction of organic compounds in the effluents and they are then recovered and incinerated in the recovery boiler. The idea is to bring the clean water counter-current through the fibre line, which gradually increases the dry solids content of the liquor.

Achieved environmental benefits
The closing contributes to a reduction in organic compounds in the effluents. The screening plant has no discharges to water.

Environmental performance and operational data
Closed screening and brown stock washing are a reality in almost all mills.

Cross-media effects
Energy consumption increases due to the increased need for evaporation.

Technical considerations relevant to applicability
The measure can be adopted in new and existing kraft mills. In a few existing mills, the capacity of the evaporation plant or the recovery boiler may need to be increased to cope with the improved closure of the washing and screening departments.

Economics
The investment required for closed screening is typically EUR 4 – 6 million at new mills and EUR 6 – 8 million at existing mills. Operating costs are EUR 0.3 – 0.5 million per year for a capacity of 1 500 ADt/d.

An important development has taken place in screening; today it is possible to screen at higher pulp consistencies than before. The benefits are a lower investment and lower consumption of electrical energy.

Driving force for implementation
The reduction of emissions to water is the main reason to implement the technique.

Example plants
Most plants in Europe.

Reference literature
[14, CEPI 1997].

3.3.5 Oxygen delignification before leaching

Description
After cooking, the fibres still contain some lignin which must be removed before final bleaching. To preserve pulp strength, the lignin must be removed in a selective way with minimum damage to the cellulosic part of the fibres and with minimum yield loss. About half of the remaining lignin in the brown stock can be removed and recovered by adding oxygen to an alkaline fibre suspension.

In oxygen delignification, oxygen, oxidised white liquor and magnesium sulphate are mixed with the pulp at either high consistencies (25 – 30 %) or medium consistencies (10 – 15 %) in a reactor. The oxygen delignification stage has also been called oxygen bleaching (oxygen stages are nowadays also used in the bleach plant and in this report oxygen delignification is used for the processing of unbleached pulp). In order to maintain the sodium balance of the mill, the oxygen stage normally uses the oxidised cooking liquor, where sodium hydroxide is the main alkaline chemical and sodium sulphide has been oxidised to thiosulphate or sulphate in the oxidising process. The delignification reactor is pressurised and the temperature is elevated to about 100 °C.

The oxygen delignification takes place in one or two stages after cooking and prior to bleaching and can achieve a delignification efficiency of 40 % to 70 %. Higher delignification efficiencies normally require two-stage installations [1, Finnish BAT Report 1997].

The waste liquor is sent counter-current to the chemical recovery system. In Figure 3.32 and Figure 3.33 examples of the process layout of single-stage and two-stage delignification processes are given.

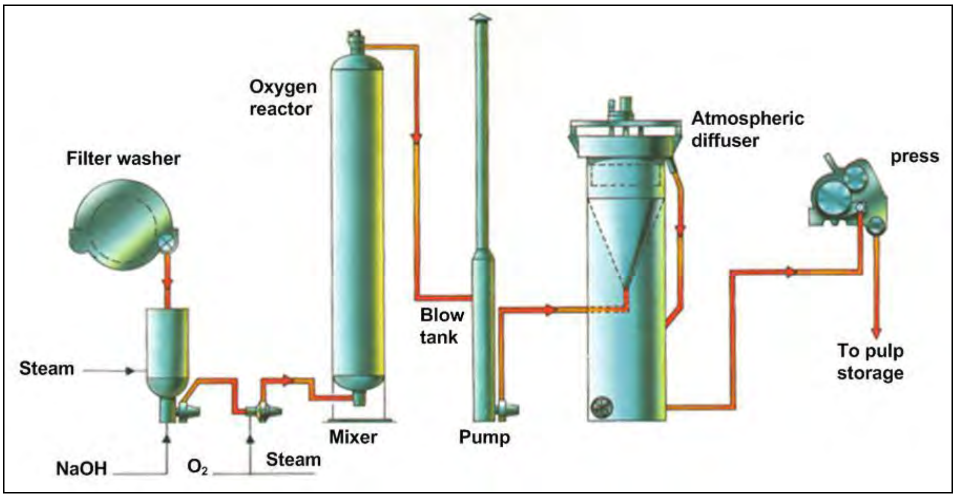


Figure 3.32: Single-stage oxygen delignification

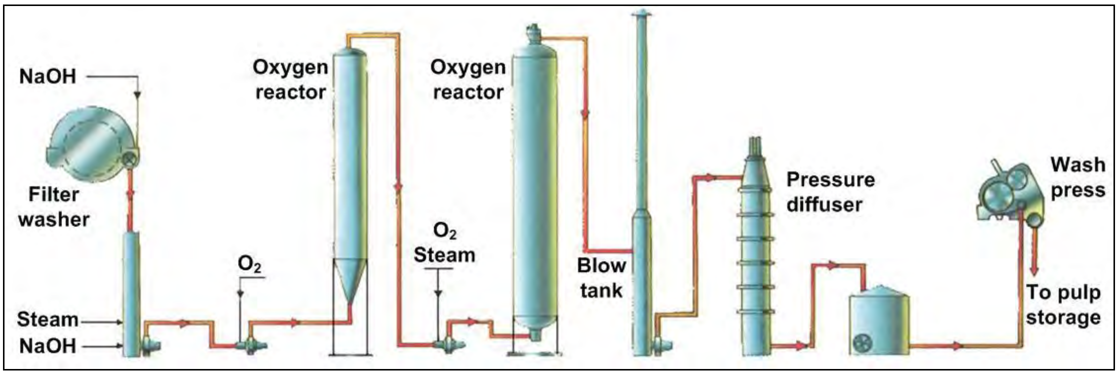


Figure 3.33: Two-stage oxygen delignification

Achieved environmental benefits
The major benefits of oxygen delignification are a decrease in the amount of chemicals in final bleaching and total costs for bleaching chemicals and a decrease in the pollution load from the bleaching plant (COD and chlorinated organic compounds from final bleaching in the case of ECF bleaching).

Environmental performance and operational data
Modern mills are always designed for a combination of modified cooking and oxygen delignification and for the effect on the environment (discharges of COD and AOX) both techniques have to be considered together.

The reduction of kappa number and organic substances and the consumption of chemicals in oxygen delignification are strongly related to the efficiency of the washing equipment between the oxygen stages. The environmental benefits are not achieved without efficient washing (see Section 3.3.10).

The strength properties of oxygen-bleached pulp and conventionally bleached pulp are very similar although oxygen-bleached pulp has a lower average viscosity. No significant differences are seen in the burst factor and tear factor at the given breaking lengths.

According to some mill experiences, an oxygen stage before a softwood bleaching sequence results in more particles and shives.

Cross-media effects
In energy consumption, the measure means slightly increased energy recovery from dissolved organic substances but also a decrease in the heat value of the black liquor from the inorganic compounds.

Technical considerations relevant to applicability
The measure can be adopted at new and existing kraft mills.

The installation of an oxygen delignification phase in an existing kraft mill may decrease the fibre line production, if there is not enough capacity in the whole recovery system.

The additional evaporator steam requirements are 0 – 4 % for high-consistency system and 4 – 10 % for medium-consistency system. The total additional solids loads sent to the recovery boilers are about 70 kg/t for softwood and 45 kg/t for hardwood.

Economics
The investment for an oxygen delignification system is typically EUR 35 – 40 million for 1 500 ADt/d bleached pulp production. Its operating costs are EUR 2.5 – 3.0 million/yr. However, the oxygen delignification will decrease the chemical consumption in bleaching. Oxygen delignification is a typical measure for optimisation programmes in order to decrease the bleaching chemicals by reduction of the kappa number. The net effect is a cost saving which depends on the wood species.

If oxygen delignification is applied, it has implications for the recovery boiler and the lime kiln. At existing mills, additional dry solids loads to the recovery boiler have been reported as being up to 10 % and, more commonly, it is at least 4 – 6 %; and additionally 4 – 6 % more capacity would be required in recausticising and the lime kiln. Should this capacity not be available, it would normally result in a corresponding loss in the production capacity of the whole mill.

Driving force for implementation
The reduction of emissions to water (effluent treatment plant and recipient) is a major reason to implement the method.

Example plants
Numerous plants in Europe and in America.

Reference literature
[1, Finnish BAT Report 1997], [14, CEPI 1997].

3.3.6 Modern ECF bleaching

Description
The target of bleaching is a high and stable brightness. ECF (elemental chlorine free) bleaching is a bleaching sequence without the use of elemental chlorine, i.e. chlorine gas (Cl_2). In ECF bleaching, chlorine dioxide (ClO_2) is usually the main bleaching agent. The lignin removal by bleaching is carried out in several stages, the first two stages primarily releasing and extracting lignin and the subsequent stages removing the lignin residues and finishing the product. A bleach plant consists of a sequence of separate bleaching stages with different chemicals or a combination of chemicals added (see Table 3.21).

The alternative bleaching stages used for minimising the consumption of chlorine dioxide in modern ECF bleaching include one or a combination of the following bleaching stages: oxygen, hot acid hydrolysis (A_{hot}) stage, ozone stages (Z) at medium and high consistency, stages with atmospheric hydrogen peroxide (P) and pressurised hydrogen peroxide (PO) or the use of a hot chlorine dioxide stage (D_{hot}). The final design concept of a bleach plant depends on the priorities with regard to the cost of the chemical products, operating costs, bleaching process yields, operating flexibility and specific process restrictions.

The inclusion of stages like acid hydrolysis, pressurised peroxide, peracetic acid and/or ozone in the bleaching sequences aim at reducing environmental impact (low ClO_2 charge, low effluent volume, low COD emission load from the bleach plant) and allow for the partial closing of the waste water circuit from the bleach plant (see Section 3.3.8). These bleaching sequences satisfy demands for pulp quality and bleach plant economy and result in the bleaching process having a low environmental impact.

ECF bleaching is different for softwood and hardwood. Generally, to reach a certain brightness target, hardwood requires fewer chemicals than softwood, which usually means that the number of bleaching stages can be lower.

Examples of modern bleaching sequences are listed in Table 3.21. The list is not exclusive and other bleaching sequence options may exist or be developed. All of them are a combination of stages and processes that seek to optimise the bleaching process producing the best pulp quality (depends on species and final application) and the overall impact of the process by reducing energy and water consumption and the impact of the liquid effluent.

Table 3.21: Modern pulp bleaching sequences

Modern bleaching sequences			
O/ODEDP	O/OADED	O(OPDQ(PO)	OmPZPZP
O/ODED	O/OZEDD	OQ(PO)(DQ)(PO)	O/O(Q)OP(Paa/Q)PO
O/ODEDD	O/OADPZP	OQXOP/ODEPDPaa	
O/OADEDP	O/OZDP	O/O(Q)OPDPO	

NB: Abbreviations used are given below:
A = Acid wash to remove metal element from pulp
D = Chlorine dioxide
E = Alkaline extraction
EO = Alkaline extraction reinforced with oxygen
EP = Alkaline extraction reinforced with hydrogen peroxide
EOP = Alkaline extraction reinforced with oxygen and hydrogen peroxide
mP = Modified peroxide
O = Oxygen
P = Hydrogen peroxide (H_2O_2)
Paa = Peracetic acid
Q = Chelating agent
X = Xylanase
Z = Ozone
ZD = Ozone and chlorine dioxide added sequentially in same stage.
Source: Finnish Environment Institute

The alkaline (E) stages can be reinforced with oxygen or peroxide or both. The oxygen stage (O) is normally carried out in one or two stages. The D stage can also be carried out instead of the Paa/Q stage.

The bleaching sequences implemented in the latest designs of eucalyptus-based pulp mills are shown in Table 3.22.

Table 3.22: Modern bleaching sequences of eucalyptus-based kraft pulp mills

Eucalyptus-based kraft pulp mills	Bleaching sequence
Veracel	AD_0 EOP D_1 P
Aracruz C	AD_0 EOP D_1 D_2
Ripasa	D_{hot} PO D_1
UPM Fray Bentos	AD EOP D P
Ence-Navia	D_0 EOP D_1
Valdivia Arauco	D_0 EOP D1 D_2
Nueva Aldea	D_{hot} EOP D_1 D_2
Santa Fe CMPC	AD_0 EOP D_1 D_2
Source: [73, ASPAPEL/CELPA 2010]	

Acidic stage (A)

All pulps contain hexenuronic acids (HexA) and they are formed during the cooking process from xylanes. HexA contents in softwood and hardwood pulps are 20 – 30 mmol/kg and 40 – 70 mmol/kg respectively, in some eucalyptus pulps even up to 85 mmol/kg. HexA consume bleaching chemicals such as chlorine dioxide, ozone, and peracetic acid. Approximately 10 mmol/kg of HexA corresponds to one kappa number. HexA can be removed through mild acid hydrolysis (pH 3 – 3.5, temperature 85 – 95°C and time 120 – 180 min) which results in bleaching chemical savings. The extent of the savings and the economic viability of adopting this process (new tower and washer stage) is dependent on the HexA content of the pulp and effective chemicals reduction without yield losses and degradation of pulp quality [24, Furtado 2001]. The first whole bleaching sequence where an A stage was combined with bleaching was applied was at Aracruz pulp mill in 2002 (Brazil), and later also in other South American mills using high HexA content eucalyptus pulps. The A stage is applied without interstage washing before the chlorine dioxide stage (D_0), or the initial ozone stage (Z) but in this last configuration with interstage washing.

Chlorine dioxide has the highest selectivity among technical bleaching chemicals. Bleaching with only chlorine dioxide in the first bleaching stage means that the total charge of effective chlorine has to be increased and oxygen and hydrogen peroxide are more extensively used in the extraction stages.

More recently, a chlorine dioxide stage with a high temperature (typically above 90ºC) and long retention time (D_{hot}) has been applied, resulting in faster delignification reactions of chlorine dioxide. In this stage, chlorine dioxide reacts first and fast with pulp lignin and then the pulp is left to be subjected to the acidic hydrolysis conditions that promote the removal of HexA, i.e. a long time (approximately 2 hours), temperature above 90 ºC and low pH [20, Pikka 2007].

Peroxide can be applied in several positions both in ECF and TCF and bleaching sequences (see Section 3.3.7). The bleaching process optimisation is conducted to give the best performance both in terms of pulp quality and bleaching costs.

Ozone bleaching is used for both ECF and TCF pulps (see Section 3.1.12.2).

Enzymes (e.g. xylanase) were reported to be used on an industrial scale to enhance bleaching performance by at least three mills in Canada. [211, Technical University of Denmark and Novozymes 2007]

Achieved environmental benefits

ECF bleaching is capable of reducing 2,3,7,8-TCDD and 2,3,7,8-TCDF to undetectable levels. However, the complete elimination of dioxins in ECF-bleached effluents is a question of kappa number and purity of ClO_2. With a high kappa number and impure ClO_2 (i.e. high concentration of Cl_2) the probability of forming dioxins increases. Modern ECF bleaching is also capable of preventing chlorophenols and chloroform formation and reduces chlorinated organic compound

(AOX) formation. Also refer to Section 3.1.7 ´Discussion about modern ECF versus TCF bleaching'.

Environmental performance and operational data
The production of ECF pulp is common practice in pulp mills in Europe. All mills combine the available stages and processes in order to optimise the bleaching process producing the best pulp quality and yield (depends on species and final application). However, the overall impact of the bleaching process can be lessened by reducing energy and water consumption and the impact of the liquid effluent. See also Section 3.3.8.

ECF pulp mills that have a low kappa number when the pulp enters the bleach plant and use one or two ClO_2 stages combined with other bleaching agent stages reach levels of organochlorinated substances of <0.2 kg AOX/ADt. Some of these mills with minor charges of chlorine dioxide use the term 'ECF-light' to describe a characteristic of the mill although this term is not well-defined in the industry.

More data on the final effluent after biological treatment are presented in Section 3.3.13.

Cross-media effects
No significant effects.

Technical considerations relevant to applicability
Generally applicable. In existing mills, bleaching strategy improvements must fit to existing process equipment that will continue to be used, relocated and supplemented by new process equipment.

Economics
Table 3.23 shows the specific operating costs of the main bleaching chemicals used for eucalyptus pulp (other costs are not included) in a number of alternative bleaching sequences evaluated for different air dry brightness levels. All the cost values were calculated for consumption estimated according to laboratory test results. The following bleaching chemicals values were used as a basis for the operating cost calculation: USD 0.342/kg NaOH; USD 0.8/kg ClO_2, USD 0.08/kg H_2SO_4; USD 0.75/kg H_2O_2; USD 0.1/kg O_2; USD 1.5/kg O_3; USD 0.23/kg $MgSO_4$.

Table 3.23: Specific operating costs of main bleaching chemicals used in alternative bleaching sequences evaluated for different brightness levels of air dry kraft pulp

Alternative bleaching sequences	Bleaching chemical cost, USD/tonne oven dry pulp				
Air dry Brightness, % ISO	**91**	**92**	**93**	**93.5**	**94**
D(EOP)DP (reference)	26.01	27.15	28.97		
D(EOP)DP (excessive washing)	25.41	25.99	28.06		
D(EOP)D(PO)	20.51	22.49			
Dhot(EOP)DP		19.72	22.16	25.04	
Dhot(EOP)D(PO)		19.01	20.41	20.92	
AhotD(EOP)DP	19.25	19.78	20.95	21.48	
Ahot(ZhcD)(EOP)DP			25.25	26.05	26.61
Ahot(EOP)(ZhcD)P	23.30	26.86	28.19		
AhotZhcDP	17.63	23.80			
(ZmcD)(EOP)DP			24.50	26.40	27.05
ZmcD(EOP)DP			25.16	25.42	26.30
D(EOP)ZhcP	27.17				
D(EOP)(ZhcD)P		21.50	23.40		

NB: Abbreviations used are given below:
A = Acid wash to remove metal element from pulp
D = Chlorine dioxide
EOP = Alkaline extraction reinforced with oxygen and hydrogen peroxide
PO = Pressurised peroxide bleaching
Q = Chelating agent
Z = Ozone
ZD = Ozone and chlorine dioxide added sequentially in same stage.
hc = high consistency; mc = medium consistency.

Source: [77, Costa et al. 2009]

Driving force for implementation

The reduction of adsorbable organically bound halogens emissions to water (effluent treatment plant and recipient) is the main reason to implement the method.

Example plants

Most plants in Europe and the world apply ECF bleaching. Many mills have invested in low environmental impact ECF bleaching sequences during the last decade. [78, Hostachy 2010] lists 21 kraft pulp mills in the world using ozone bleaching in their fibre line for example.

Reference literature

[20, Pikka 2007], [24, Furtado 2001], [72, R.Campo et al. 2009], [77, Costa et al. 2009], [78, Hostachy 2010], [211, Technical University of Denmark and Novozymes 2007].

3.3.7 TCF bleaching

Description

Totally chlorine free (TCF) bleaching is a bleaching process carried out without any chlorine-containing chemicals, thereby avoiding the generation of organically bound chlorine in the pulp and waste water stream. In TCF bleaching, hydrogen peroxide (P) together with ozone (Z) or peracetic acid (Paa) are the most commonly used chemicals. Provided that the pulp has a low enough kappa number after cooking and oxygen delignification, i.e. before the pulp enters the bleach plant, and that transition metals (e.g. Mn^{2+}) have been removed in the necessary chelating stages (Q stages), it is possible to attain full market brightness with peroxide as the sole bleaching chemical. However, the dose-response curve for brightness versus peroxide consumption is quite shallow at top brightness, which means that even small disturbances in the incoming kappa number can result in rather high bleaching costs and the downgrading of the pulp because of low brightness.

One possible option of reducing the hydrogen peroxide consumption is to introduce an ozone stage into the sequence in a position before the peroxide stage (ZQP). Ozone bleaching is also used for ECF bleaching (see Section 3.3.6). The main purpose of using ozone is to provide more delignification power. Ozone activates the fibres towards peroxide and this results in greater brightness and lower peroxide consumption. Ozone is very efficient to reduce the amount of peroxide required to obtain even very high brightness levels. A drawback with ozone is that, in larger charges, it has a tendency to attack the cellulose chains.

Ozone is generated by means of silent electrical discharges in a stream of oxygen gas. Ozone bleaching (O_3) requires a high investment due to the high costs of ozone generators and auxiliary equipment for ozone generation. Since the ozone concentration in oxygen will only be about 12 – 16 %, fairly large volumes of oxygen are required. Thus, the operating cost is rather high due to the relatively high cost of oxygen (needed for ozone generation) as well as to the high power consumption. On the other hand, the efficiency of ozone is much higher than for other bleaching chemicals (e.g. it has about twice the oxidising potential of chlorine dioxide).

Peracids have now become commercially available in the form of, for example, peracetic acid (Paa). This bleaching chemical is a valuable complement in a stage preceding hydrogen peroxide where it can replace ozone. Full brightness can be achieved even when the unbleached pulp has a slightly higher kappa number than the very lowest. The drawback with peracetic acid is its still rather high cost.

Examples of different TCF bleaching sequences are listed in Table 3.24.

Table 3.24: Bleaching sequences for TCF softwood and hardwood kraft pulping

TCF/Softwood	TCF/Hardwood
Q(EP)(EP)(EP)	QPZP
Q(OP)(ZQ)(PO)	Q(OP)(ZQ)(PO)
Q(EOP)Q(PO)	Q(EOP)Q(PO)
Q(OP)ZQ(PO)	Q(OP)ZQ(PO)
Q/OP/(Q+Paa)/PO	O/OZPZP
O/O(Q)OP(Paa/Q)PO	OmPZPZP

NB: Abbreviations used are given below:
Q = Acid stage where the chelating agent EDTA or DTPA has been used for the removal of metals
EP = Extraction stage using NaOH with the subsequent addition of an H_2O_2 solution as a reinforcing agent
EOP = Alkaline extraction bleaching stage using sodium hydroxide with the subsequent addition of oxygen and hydrogen peroxide solution as a reinforcing agent
EO = Extraction stage using NaOH with subsequent addition of gaseous oxygen as a reinforcing agent
P = Alkaline stage with H_2O_2 as liquid
Z = Ozone bleaching using gaseous O_3
PO = Pressurised peroxide bleaching.

The first TCF bleaching sequence was based on peroxide under alkaline conditions and an extensive use of hydrogen peroxide is still the main feature of all TCF bleaching sequences. Decomposition of peroxide is catalysed by certain metal ions which have to be removed in an acidic stage before the peroxide stage.

Peroxide can be applied in several positions or several different ways:

- reinforcement of a mild initial oxygen stage (low or moderate charge): OP
- reinforcement of alkaline extraction stages (low charge): EP
- final brightness adjustment in high-density storage towers (low charge): P
- separate delignification/bleaching stage (high charge): P
- separate pressurised delignification/bleaching stage (high charge): PO.

Pretreatment of the pulp with a suitable electrophilic agent before peroxide bleaching may 'activate' the fibres and improve their response to peroxide. Ozone can promote this kind of effect.

Ozone has become the most common complements to peroxide in TCF bleaching sequences. The main purpose of using ozone is to provide more delignification power. Ozone activates the fibres towards hydrogen peroxide and these result in a greater brightness and a somewhat lower hydrogen peroxide consumption. On the other hand, the selectivity of ozone is poor. Excessive application, too high a temperature or application of other unsuitable treatments may lead to serious cellulose degradation. Ozone should preferably be applied under acidic conditions (pH ~2 – 3). Too high a temperature (>70 °C) impairs the selectivity. High pressure increases the solubility of ozone in the aqueous phase during bleaching (dissolved ozone is claimed to be less aggressive to the carbohydrates than ozone in the gas phase). Pulp consistency is an important parameter in ozone bleaching. Installations for ozone bleaching operate under medium consistency (8 – 15 %) or high consistency (>30 %) conditions.

If ozone is applied, a new on-site chemical manufacturing unit is necessary because of the rapid decomposition of ozone in transportation or storage. The operating costs of TCF pulping are usually somewhat higher than those of ECF pulping.

Achieved environmental benefits

In TCF bleaching the formation of AOX is not detectable. In TCF mills the use of ozone and other chlorine free bleaching chemicals makes it less complicated to close up the filtrate streams from washing stages (see Section 3.3.8). In addition to preventing environmentally damaging waste water streams where the latest technology is applied, this technique also allows TCF mills to reduce the fresh water demand from approximately 25 – 50 m^3/ADt to 10 – 20 m3/ADt. By eliminating chlorine from the bleaching process, TCF bleaching also eliminates the environmental risk inherent in the storage of chlorine and preparation of chlorine dioxide.

At modern kraft pulp mills, from an environmental point of view the focus should be less on the ECF or TCF bleaching technique and more on the combination and efficiency of a set of techniques such as optimised cooking, bleaching and washing processes, an efficient waste water treatment and the overall impact of the mill (raw materials, energy and water consumption, impact of the liquid effluent). Also refer to Section 3.1.7 ´The discussion about modern ECF versus TCF bleaching'.

Environmental performance and operational data

TCF bleaching is now a well-established technology. Many mills in Europe have the possibility to produce TCF pulp in separate campaigns instead of ECF pulp depending on the market demand. A few mills manufacture TCF pulp only. Slightly higher production costs and no improvement in the product quality have however limited the demand, and the share of TCF pulps has not increased.

TCF mills discharge virtually no chlorinated organics (no formation in bleaching).

Cross-media effects

At the time of writing (2013), there are no significant differences in chemical and energy consumption when comparing an ECF and TCF alternative. Even if the bleaching operation has a slightly higher energy consumption, the overall energy performance of a TCF mill is no higher than that of an ECF mill.

Technical considerations relevant to applicability

Generally applicable to kraft mills. Ozone bleaching is related to the production of TCF pulps and in a few cases it is also used for ECF bleaching.

In existing mills, a chelating stage, a new oxygen stage and a washer are usually needed to convert the ECF bleaching sequence to TCF. If hydrogen peroxide or ozone stages are used, two new bleaching towers are used and the bleaching filters are reconstructed. Ozone bleaching requires ozone generators and reactor.

In new greenfield mills, fewer modifications and lower investments are required but operating costs are likely to be in the same order of magnitude.

Economics
The investment required for peroxide bleaching at new mills with a 1 500 ADt/d production rate is EUR 7 – 8 million, at existing pulp mills the costs are EUR 2 – 5 million depending on the materials of the existing bleaching equipment. If the materials tolerate hydrogen peroxide, the costs are EUR 2 – 3 million. Operating costs with peroxide bleaching are considerably higher than with ECF bleaching due to the higher chemical costs, EUR 18 – 21 million/yr.

If both ozone and peroxide bleaching are applied, the investment required is higher. The investment for a 1 500 ADt/d ozone bleaching system is EUR 12 – 15 million. Corresponding operating costs are EUR 1.8 – 2.1 million/yr.

Driving force for implementation
The AOX emissions to water are reduced and chlorine-organic compounds are not formed in the TCF bleaching. Also, the increased public awareness of the environmental and health effects of persistent organically bound chlorine compounds since the 1980s and a regulatory response to this issue in many jurisdictions have been the primary drivers of TCF bleaching implementation. By eliminating the production of such compounds in the bleaching process, TCF bleaching offered both legal compliance and filled an emerging demand in environmentally aware markets. In addition, the adoption of a precautionary approach to environmental issues was also a driver of TCF implementation.

Example plants
A few plants in Europe and elsewhere in the world, e.g. SCA Östrands, Södra Cell mills in Mönsterås, Mörrum and Värö.

Reference literature
[1, Finnish BAT Report 1997], [14, CEPI 1997], [16, CEPI 1998], [131, SEPA report 1997], [257, Soedra 2009].

3.3.8 Partial process water recycling in the bleach plant

Description
Some pulp mills have adapted their bleaching technology to partially close the waste water circuits of the bleach plant. The filtrates from bleaching stages that are suitable for water recycling are returned to processes where the water and chemicals can be useful. The return of filtrates and the recycling points should be studied carefully to avoid incrustation in bleaching, mainly with carbonates and oxalates.

A prerequisite for partial bleach plant closure, i.e. the recycling of the filtrates to the chemical recovery, is to reduce the water flow through the bleach plant. This can be achieved by leading the bleaching filtrates counter-currently from the last bleach stage through the sequence via the oxygen stage washing apparatus to the brown stock washer. To increase the closure of the bleach plant, extra storage capacity for internal waters and a rebuild of the water distribution system and efficient pulp washing equipment are necessary.

At the time of writing (2013), the problems associated with the increased concentration of organic and inorganic substances (the so-called non-process elements) in partially closed water circuits are the major hurdle to further reduce water consumption in the bleach plant.

The problems associated with closing water circuits – not only in the bleach plant – are as follows [18, RAIZ 2011].

- Increased Cl and K content in the recovery boiler ash causing plugging and increased corrosion of this equipment. Leaching and evaporation/crystallisation of recovery boiler ash have been implemented on an industrial scale.
- Increased inert content in the lime circuit due to the phosphorus build-up in this circuit.
- Increased deposit formation and scaling, mainly in bleaching equipment due to the increased concentration of Ca, Ba, C_2O_4, CO3 and SO_4 on bleach pulps and filtrates.
- Increased bleaching chemicals consumption as a result of increased organic carry-over on pulps.
- Reduction of selectivity of some oxidant agents as a result of the increase of transition metals concentration.
- Decreased pulp quality as a consequence of 'pitch' deposit or others.

Calcium is present in the pulp and during all oxidative bleaching a substantial amount of oxalic acid is formed. When an alkaline filtrate is used as wash water on a pulp from an acidic stage or is mixed with an acidic filtrate where calcium is dissolved, there is a risk that solid calcium oxalate precipitates. The tendency for calcium oxalate to precipitate increases with higher concentrations of calcium and oxalate, i.e. the more the water system is closed or the filtrates are recycled, the higher the risk of precipitation or scaling. This problem still awaits a solution. It is almost impossible to reduce the discharge from the bleach plant below 10 – 15 m^3/ADt.

Further water reductions are dependent on the existence of effective and industrial implemented kidneys to purge the system of calcium, oxalate or disturbing 'non-process elements' such as K, Cl or phosphorus that may impair the bleaching process, the technical equipment, the chemical recovery cycle or the pulp quality.

There are references to the following processes working as selective kidneys in the bleach plant:

- ionic exchange with fixed bed resin;
- evaporation;
- membrane filtration;
- chips leaching.

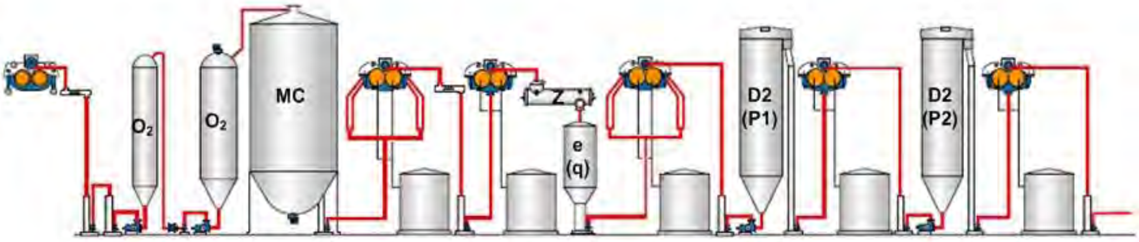
These kidney technologies are not yet fully developed or implemented at full mill scale. They are still either at laboratory or pilot scale or being investigated as a demonstration project. None of the proposals so far were able to provide a complete and integrated solution to the problem. For instance, membrane filtration barely deals with ions, ion exchange cannot reduce the organic substances that are recirculated in the closed water circuits, etc.

Therefore, a completely closed bleach plant is not considered an available technique. But it is possible to carry the filtrates in two counter-current streams, one acidic and one alkaline. The alkaline water may be used for washing the pulp in the unbleached part of the process. This will result in a significant reduction of flows and discharges from the bleach plant compared to conventional systems.

Achieved environmental benefits
The measure results in the reduction of COD loads and flows. The performance achieved is highly dependent on the wood species, water quality, bleaching sequence, washing equipment and overall process design.

Environmental performance and operational data
Figure 3.34 shows an example of a recently retrofitted bleach plant that is designed to process bleached softwood pulp or, alternatively, bleached hardwood pulp with low effluent flow and load. The chemicals applied to pulp in the O_2 delignification and ozone stages and the material

removed from the pulp in the brown stock washing area are compatible with the black liquor recovery system. Therefore, filtrate from the wash press after the ozone stage is utilised for full counter-current washing through the post-oxygen wash press and brown stock washers, and sent to the recovery area to be evaporated and burnt in the recovery boiler.



Legend:
O_2 = Oxygen delignification
MC = Medium Consistency
Z = Ozone reactor
e = Alkaline extraction stage; alternatively (q)
(q) = Chelatant stage as process alternative (for TCF bleaching)
D1 + D2 = Chlorine dioxide stages 1 and 2
(P1) + (P2) = Hydrogen peroxide stages 1 and 2 as alternatives
Letters in brackets refer to process alternatives to ECF: 'ECF-light' or TCF

Source: [72, R.Campo et al. 2009]

Figure 3.34: **Example of a bleach plant concept with low effluent volume and COD load**

In this example, the total bleach plant effluent volume is maintained at a very low level, approximately 6 – 8 m^3/ADt in ECF and 4 – 6 m^3/ADt in TCF, with COD about 17 kg/ADt and 18 kg/ADt, respectively.

A modern ECF bleaching plant with a counter-current washing system normally uses a waste water flow in the order of magnitude of 15 – 20 m^3/ADt. Further closure of the bleach plant filtrates should be based on the balances of 'non-process elements' (NPE) including chloride and potassium, the Na/S balance and the energy balance of the mill.

One TCF mill in Sweden reports achieving a water effluent of 10 m^3/ADt for continuous production with water presses and a fluidised biobed carrier (FBBC) in secondary treatment.

Cross-media effects

Dissolved organic substances from the bleach plant effluents are led via the evaporation plant to the recovery boiler. This requires additional capacity and energy consumption in the evaporation plant. On the other hand, energy and space for external treatment may be saved and less excess sludge generated.

Technical considerations relevant to applicability

Applicable in both new or existing mills. The extent of closing water circuits in the bleach plant also depends on the quality of the fresh water source, the type, number and capacity of the pieces of washing equipment, the designed existing bleaching sequence and, due to its cross-media effects in other process areas, also on the capacity of the recovery boiler part of the mill to deal with possible problems (e.g. K and Cl accumulation in the recovery boiler). A prerequisite for partial bleach plant closure is a sufficient capacity in the evaporators and recovery boiler. It should be noted that the evaporation of bleach plant effluents is easier to apply in the case of TCF bleaching. For safety reasons, in ECF bleaching there is an elevated risk of chloride corrosion in the recovery boiler at the development stage it is at the time of writing (2013).

Economics
Considerable investment is required. A rebuild of the water distribution system in the bleach plant including extra storage for internal waters is necessary. In some cases, investments in retrofitting or adapting of bleaching sequences, the water system control system and the efficiency and number of washers will be required. The decision on the best sequence for circuit closing depends on the achieved bleaching results and operating costs. No specific cost data are available.

Driving force for implementation
Environmental requirements from competent authorities.

Example plants
Södra Cell mills in Mönsterås, Mörrum and Värö (SE), Celtejo mill, (PT), Mercer Stendal and Rosenthal kraft pulp mill (DE), many others.

Reference literature
[18, RAIZ 2011], [72, R.Campo et al. 2009], [193, Axegård et al. 2003].

3.3.9 Effective spill monitoring and containment with a suitable recovery system

This measure is connected to the measures described in Section 3.3.12, 'Use of sufficiently large buffer tanks'.

Description and achieved environmental benefits
Efficient collection of spillages is crucial for both the weak liquor from the washing of unbleached pulp and for strong liquor from the evaporation plant in order to avoid the accidental discharge of highly concentrated and sometimes toxic effluents. These process liquors may cause peak emission loads and occasionally upsets in the biological effluent treatment.

Pulping liquor may escape from the seals on brown stock washers, pumps and valves in liquor service, from knotters and screens, sewered evaporator boil-out solutions, and other intentional liquor diversions during maintenance, start-ups and shutdowns. Liquor is also lost in spills resulting from process upsets, tank overflows, mechanical breakdowns, operator errors and construction activities.

A spillage prevention and control system should be designed around the following concepts:

- conductivity or pH monitoring at strategic locations to detect losses and spills (spill control system which makes prevention of spillage and monitoring possible);
- collection of diverted or spilled liquor at the highest possible liquor solids concentration;
- return of collected liquor and fibre to the process at appropriate locations;
- prevention of spills of concentrated or harmful flows from critical process areas (including tall oil and turpentine) from entering the biological effluent treatment or from contaminating clean water sewers.

The general concept for efficient recovery also requires the contaminated effluent sewers to be arranged so that most of the spills, contaminated sealing waters or floor washing in key areas (pulp cooking, washing and screening, used liquor storage and evaporation, cooking liquor preparation) are collected in sumps and pumped either directly or via an intermediate tank into an appropriate liquor storage tank. The need for such recovery must, typically due to economic reasons, be limited to areas where the mixed spill concentration is at least 2 – 3 % dry dissolved solids. Floor washing and sealing water in these collection areas dilute the recoverable stream so care must be taken not to dilute process liquors too much.

Inside product areas, such as tall oil plants and turpentine recovery systems, care should be taken to prevent spills from going to the external treatment. Soap and turpentine contain substances that may cause toxic effects in the biological treatment.

A single line kraft mill would need up to five collection sumps equipped with conductivity-activated recovery pumps. Moderately complex mills would require up to 9 and complex mills up to 12 collecting sumps.

Environmental performance and operational data
Liquor spill and overflow containment in the process and establishment of relevant management policy in chemical production have been found to be beneficial and necessary both from an economic and environmental point of view. This matter has been solved efficiently in many mills with fairly simple methods.

A general analysis has indicated that with good process management and properly designed spill containment, recovery and having 5 – 10 % extra capacity in the evaporation plant a reduction in effluent load of 3 – 8 kg COD/ADt can be reached in comparison to mills with no or inefficient spill recovery and poor process stability. In total, spills can be less than 2 kg COD/ADt.

Cross-media effects
In order to handle the collected spills, 5 – 10 % more evaporation capacity would be needed. This would also consume 5 – 10 % more steam. However, the collection of spills means recovering energy and chemicals when they are burnt in the recovery boiler.

The need for extra capacity and excess energy exists only during mill upsets, so not during significant operating times. If continuous excess evaporation of spills is needed then tail units can be added to the evaporation plant, with investment but no additional steam usage (like at the Kotka mill, FI).

Technical considerations relevant to applicability
Applicable to both new and existing mills. However, the effective spill control system is easier to install when designing and building new installations rather than when retrofitting old mills.

For existing mills the separate collection and reintroduction in the process is sometimes impossible for the existing layout. In these cases, measures like a final treatment of collected spills in the waste water treatment plant are an alternative.

Economics
The investment required for spill liquor handling systems at a kraft mill producing 1 500 ADt/d pulp mill is EUR 0.8 – 1.5 million. If the evaporation plant needs to be expanded with 0.8 m^3/ADt, an additional cost of EUR 4 – 6 million will be required. The operating costs of the system are estimated to be EUR 100 000 – 400 000 per year, but can vary considerably between new and existing mills. With new mills, there is generally more excess heat and the operating costs are in the lower part of the range.

Driving force for implementation
Reduction of discharges of COD and inorganic process chemicals.

Example plants
Numerous mills around the world.

Reference literature
[140, Tappi proceedings 1996], [131, SEPA report 1997].

3.3.10 Efficient brown stock washing

Description
Poorly washed pulp entrains part of the organic and inorganic material dissolved in the reactions of the previous stage (carry-over).

The objective of brown stock washing is to separate the pulp fibres as completely as possible from dissolved organic and inorganic chemicals before the pulp enters the bleach plant, thereby recovering as much of the cooking chemicals and dissolved organic substances as possible. In the bleach plant, efficient washing is crucial to effectively remove most dissolved material between bleaching stages because this material would otherwise consume chemical reagents in order to be neutralised.

The washing stage consists of a combination of successive dilution and thickening or displacement. In practice, each combination of washing equipment makes use of these methods in different proportions. There is a variety of pulp washing equipment available, the most typical being vacuum or pressurised drum filters, Fourdrinier-type washers, atmospheric and pressurised diffuser washers and wash presses. Of these, the wash presses and pressurised drums or diffuser washers represent the best performance. With the increased discharge consistency of the pulp, the quantity of contaminated water carried by the pulp is reduced. The washing of the kraft pulp can be supported by the application of gaseous carbon dioxide.

As the washing is never 100 % efficient a certain amount of chemicals and pollutants (carry-over) is transported with the pulp into the bleach plant. In turn, this material consumes chemical reagents for its neutralisation, resulting in an increase in total chemical consumption in bleaching and consequently higher emission loads.

Achieved environmental benefits
Reduced consumption of bleaching chemicals, reduced emissions to water from the bleach plant.

Environmental performance and operational data
The washing loss after a conventional drum washing or press washing system is around 5 – 10 kg COD/ADt to enable the following process stages to operate satisfactorily. The remaining substances are adsorbed on or enclosed in fibres. Comparing filters and presses, the outgoing pulp consistency increases from roughly 10 – 15 % using filters to 25 – 35 % using wash presses, and the water content decreases from 6 – 10 m^3/ADt to 2 – 3 m^3/ADt, and the wash liquor demand decreases from about 9 m^3/ADt to about 4 m^3/ADt. The level of COD carry-over is more related to the number of washers and their operation than the type of washer (i.e. filters or presses). Washing stages in series can reach a recovery efficiency of black liquor of up to 96 – 98 %.

When efficient washing takes place in brown stock washing, i.e. before oxygen delignification, oxygen consumption is reduced.

Efficient washing prior to the first bleaching stage reduces the carry-over of organics to bleaching and results in reduced emissions of AOX and COD discharged to the mill sewer. Reducing the washing carry-over effect between bleaching stages results in a reduction of chemical consumption in bleaching.

Standardised methods exist for measuring this carry-over which is often denoted as 'washing loss'. Washing losses were originally measured as the sodium sulphate content in the pulp. As this loss of make-up chemical has become less important, the washing loss is normally measured as COD removable by washing, using SCAN CM-45:00 [36, SCAN 2000] or similar.

Cross-media effects
No significant negative effects.

Technical considerations relevant to applicability
The measure can be adopted in new and existing kraft mills.

For practical reasons, the installation of a complete set of new washing equipment may be preferable to modification of the existing washing system.

A closed washing system increases the importance of the collection of temporary spills. The outgoing washing liquor contains both organic and inorganic substances. Washing waters withdrawn from the process are disposed of via external treatment.

Economics
The investment required typically ranges from EUR 4 million to 6 million at new mills and from approximately EUR 2 million to 4 million for existing mills. No major additional operating costs are involved.

Driving force for implementation
Reduction of the impurity concentration in the pulp and reduction of emissions to water are the main reason for implementing efficient washing systems.

Example plants
Numerous plants in Europe.

Reference literature
[36, SCAN 2000], [75, Pöyry 1997], [76, Pöyry 1998].

3.3.11 Stripping the contaminated (foul) condensates and reusing the condensates in the process

Description
Condensates can be classified as follows.

- Primary condensates: live-steam condensates that are normally clean enough to be reused as boiler feedwater (after polishing).
- Secondary condensates: contaminated steam condensates that are flushed from black liquor, pulp suspensions, etc. Only the dirtiest part of the condensate is stripped.

Condensates originate from the process vapours from digesters and the evaporation plant. In total, about 8 – 10 m^3/ADt of total condensates are formed with a COD load of about 20 – 30 kg/t and 7 – 10 kg/ADt of BOD_5. Normally, about 1 m^3/ADt is heavily polluted, 4 m^3/ADt moderately polluted and 4 m^3/ADt with a low level of contamination.

The COD is mainly methanol (5 – 10 kg/ADt) with some ethanol and a number of organic sulphuric compounds (1 – 2 kg/ADt of TRS), 1 – 2 kg of turpentine and inorganic nitrous compounds. Furthermore, foul condensate contains ketones, terpenes, phenolics, resin and fatty acids and various dissolved gases. A large proportion of nitrogen discharged from a kraft pulp mill is contained in condensates.

About 1 m^3 of condensate per tonne of pulp has a COD concentration of 10 – 20 kg. The level is higher in condensates from hardwood pulp than from softwood. These strong condensates are normally treated in a stripper where the removal efficiency for most compounds is over 90 % depending on the pH. Stripping systems usually remove malodorous gases (TRS) and COD-contributing substances at the same time. Stripped condensates after treatment can be 1 – 1.5 kg

COD/m^3 of condensate. The stripped gases can be inserted into a CNCG treatment system and handled appropriately, i.e. incinerated in a dedicated burner, the recovery boiler or the lime kiln.

About 7 – 9 m^3 of weaker condensates (with medium and low contamination) are formed with COD ranging from 0.5 – 2 kg COD/m^3, containing a total of about 8 – 12 kg of COD/t of pulp.

Alternatively, moderately contaminated condensates can be stripped in a system linked to the evaporation plant, thereby effecting treatment without any substantial additional use of energy. In this way, the total COD load before any reuse is reduced to about 5 kg/t, a reduction of about 50 % compared to only treating the most contaminated condensates.

The stripping column can be a separate piece of equipment or it can be an integrated part of the evaporation plant. The condensates are fed to the top of the stripping column. Steam or vaporised condensate rises from the bottom of the column in a counter-current direction to the foul condensate. The overhead vapour from the stripping column is sent to a reflux condenser where it is partly condensed. The purpose of the reflux condenser is to condense some of the water and to increase the concentration of volatile material in the gases leaving the condenser. The non-condensable gases from the condenser contain the majority of the volatile compounds that are stripped in the stripping column. They are led to incineration where the organic and TRS compounds are destroyed by thermal oxidation.

Cleaned condensates are free of metals and therefore are particularly useful for washing in the bleach plant when aiming at closing up this part of the process. They can also be reused in brown stock washing, in the causticising area (mud washing and dilution, mud filter showers), as TRS scrubbing liquor for lime kilns or as white liquor make-up water. This means that some condensates will be used in closed parts of the process and will not be discharged to waste. Other condensates will be used in open parts, e.g. the bleach plant, and end up in the effluent together with those condensates which are not reused but discharged directly to waste.

Achieved environmental benefits

Reduction of fresh water consumption, reduction of the organic pollution load to the waste water treatment plant, reduction of reduced sulphur compound (TRS) and methanol emissions to air.

Environmental performance and operational data

The stripping of contaminated condensates is common in most mills. When the stripping system is used for the removal of high levels of methanol, the condensates from the stripping column are relatively clean and can be reused in the pulp mill for applications such as brown stock washing (see Section 3.3.10).

The basis for the design should be the minimisation of the flow to the stripping system by segregating the condensates in order to reduce the required investment. In the evaporation plant, the first liquor vapour condensate can be split into two fractions. The surface condenser can be split into two units or two condensing steps. The blow vapour from a batch digester can be condensed in two steps. Secondary steam can be used as the main steam source for the stripping column.

The best place to reuse the condensates is pulp washing, either in the last washer or on the decker in a mill with a closed screen-room water system. The typical wash water demand is 10 – 13 m^3/ADt. The evaporator-area and digester-area condensate available for reuse can amount to 6 – 9 m^3/ADt, which is the amount of potential water savings. In total, the stripping of only the heavily polluted condensates would result in 4 – 6 kg COD/ADt while with stripping of the moderately contaminated condensates about 3 – 5 kg COD/ADt can be achieved. However, condensates discharged to effluent treatment are mostly readily biodegradable. TRS removal is about 97 % from the condensate, and methanol removal about 92 %.

Cross-media effects

When steam stripping is used, the non-condensable gases (NCG) have to be incinerated separately in order to avoid the release of concentrated TRS gases into the atmosphere. This is discussed in more detail in Sections 3.3.16.2 and 3.3.16.3.

When the stripping of concentrated, contaminated condensates is applied the load to the waste water plant will be reduced and, if there are difficulties to meet the permit conditions, new investments in the effluent treatment plant may be avoided. This also means that less energy is needed for aeration and less energy and chemicals in the sludge treatment.

When combining the recovery of clean condensates and stripped condensates, fresh water consumption may be decreased by 6 m^3/ADt. Because the condensates are hot, part of the energy used in the stripping column can be saved.

Fugitive TRS emissions from waste water treatment plants can be reduced by the steam stripping of condensates which removes TRS compounds from foul condensates.

As the stripper off-gases contain 8 – 12 kg/ADt of methanol, there is the potential to save fuel oil or natural gas, provided that the stripper gas can replace the fuel.

The stripping of condensates reduces the low level emissions of TRS compounds from foul condensates. The TRS compounds include hydrogen sulphide, methyl mercaptan, dimethyl sulphide and dimethyl disulphide. These emissions are partially responsible for the foul odours from a kraft mill.

Technical considerations relevant to applicability

Steam stripping is a viable in-plant treatment method for reducing COD and odour from kraft mill foul condensates. The process can be applied at both new and existing kraft mills. The condensate stripping column can be separate or it can be integrated into the evaporation plant. In the former case, live steam would be required whereas in the latter case, secondary steam from evaporator effects can be used. However, thermal oxidation of the vapours from the stripper system is necessary. Lime kilns, power boilers and separate TRS incinerators can be used for this purpose.

Economics

The investment required for the stripper system at a 1 500 ADt/d kraft pulp mill is about EUR 2.0 – 2.5 million. Additional investment may be required to increase the capacity of the evaporation plant of the mill, but this depends very much on the existing evaporation plant configuration. Retrofitting costs can vary between EUR 1 million and 4 million.

The operating costs of condensate stripping consist mainly of the cost of steam used in stripping and maintenance. If the stripper is operated separately from the evaporation plant, the operating costs are significantly higher due to the demand for fresh steam. The costs are about EUR 0.6 – 0.7 million/yr. If the stripper is connected between the evaporation stages, the operating costs are lower, around EUR 0.3 – 0.4 million/yr.

Driving force for implementation

The majority of kraft pulp mills in Europe carry out steam stripping of contaminated condensates from the cooking and evaporation plant. The stripping of contaminated condensates efficiently removes its odorous components. Stripped condensates may be reused in unbleached and bleached pulp washing and in causticising processes thus achieving reduced water consumption.

Example plants

Numerous mills in Europe.

Reference literature

[126, Sebbas 1988].

3.3.12 Use of correctly dimensioned buffer tanks for the storage of concentrated or hot liquids from the process

This measure is connected to the measure discussed in Section 3.3.9.

Description

For prevention of peak loads and occasional upsets in the effluent treatment process, containers for cooking and recovery liquors and dirty condensates should have a storage capacity exceeding normal operating volumes by at least 30 %. Clean streams are diverted from potential spill areas to avoid dilution of recovered process liquors.

The volumes available to control these weak and strong liquors from sulphate or sulphite production especially in start-up, shutdown or upset conditions are crucial. A basic demand for storage volumes is caused by the liquor concentration, measured as dry solids content. For instance, in an old kraft pulp mill the weak black liquor concentration can be 8 % and the strong liquor concentration 60 % as opposed to 16 % and 75 % in a modern mill. This means that proportionally the storage volumes must be considerably larger in mills with low-efficiency washing of unbleached pulp or standard evaporation plants without liquor concentrator units.

The additional volume required above the normal level must be able to contain peak process flows of a few hours due to operational disturbances. The volume must further be large enough so that enough weak liquor can be stored, that the evaporation plant can operate normally despite a short shutdown in cooking and washing or that a part of a multi-line or a single-line evaporation plant can be shut down briefly for maintenance. The storage volume must also be large enough to store enough strong liquor so that problems or short-lived production cuts in the recovery boiler can be solved without decreasing evaporation throughput or so that the evaporation plant can be shut down briefly for maintenance.

Existing mills considering the implementation of oxygen delignification must assess their weak and strong liquor storage and evaporation plant capacity, because this process step is likely to increase the amount of water going through evaporation.

Liquors after the recovery boiler and with additional process steps reformed to fresh cooking liquor are free of organics but have a very high pH value. These liquor tanks also need buffer capacity for short-lived peak flows or, for instance, for shutdowns in connected process units such as liquor filters. These liquors, if sewered out to the effluent treatment plant, cause pH shocks which, if poorly controlled before biological treatment, result in upsets.

Achieved environmental benefits

Reduction in the discharge of concentrated or hot process streams towards the biological effluent treatment plant prevents the potential upset of the active biomass and severe disturbances to the plant performance.

Environmental performance and operational data

There are many ways to solve liquor spills and overflow containment in the process. The limitations to efficient implementation of these measures come from mill-specific process bottlenecks, typically in pulp washing and screening or evaporation.

The risk of upsets in an external treatment plant is reduced when accidental discharges of the incoming stream, which has a high organic and sometimes toxic load or a continuously high or low pH, can be avoided. The effect on hydraulic loading is not as pronounced except in mills where the washing and screening water system is open.

Conductivity probes are suitable for detecting and evaluating mill liquor spills, because in many cases a conductivity-liquor concentration correlation for each specific stream can be established. In low-concentration streams with varying pH, an on-line pH probe is standard.

Hot streams needing specific monitoring in the sewer can be readily monitored with on-line temperature probes.

Cross-media effects
Changes in liquor and hot liquid tanks and the operation of an effective spill control system often require changes or improvements in other equipment, especially in pulp washing or evaporation. The handling of hot liquids requires 5 – 10 % more energy in the evaporation plant.

Technical considerations relevant to applicability
The optimisation of the necessary buffer storage capacity for hot or concentrated streams is applicable for both new and existing mills. These measures not only help to maintain valuable process chemicals in the production process and improve the process economy, but also considerably affect the environmental performance of the mill. In existing mills the solution to efficient process stream containment also lies in the key process equipment itself. Thus the building of buffer storage and spill containment vessels should be done in conjunction with the evaluation of other cost-effective improvements, especially in pulp washing and screening, evaporation and liquor filtering.

Economics
The investment required for 1 500 ADt/d pulp production is about EUR 0.8 – 1.0 million for two 3 000 m^3 storage tanks including the necessary piping, insulation and pumps with electrical power and process control.

Recovery of concentrated process liquors allows for recovering fuel (e.g. black liquor) or the reusable chemicals that these streams may contain.

Driving force for implementation
These measures are promoted for environmental and process safety reasons.

Example plants
Most mills around the word.

Reference literature
None provided.

3.3.13 Aerobic biological waste water treatment

Description
See Section 2.9.11.2.1

In most cases, effluents from kraft pulp and paper mills are treated with aerobic methods. The activated sludge process is most commonly used. Some mills run moving bed biofilm reactors (MBBRs) as a stand-alone technique or combined with activated sludge plants. Aerated lagoons are also still in use in a few cases.

Achieved environmental benefits
Reduction of emissions of organic matter (COD, BOD), AOX, phosphorus, nitrogen and chelating agents to water.

Environmental performance and operational data
To reduce emissions, many kraft pulp mills first developed towards more and more closed processes where most of the liquors, spillages and wash water are recovered and recycled to the recovery island of the mill thus preventing the chemicals and concentrated organic substances from being released with the process water.

Activated sludge plants in kraft pulp mills have a retention time of about 15 – 48 hours.

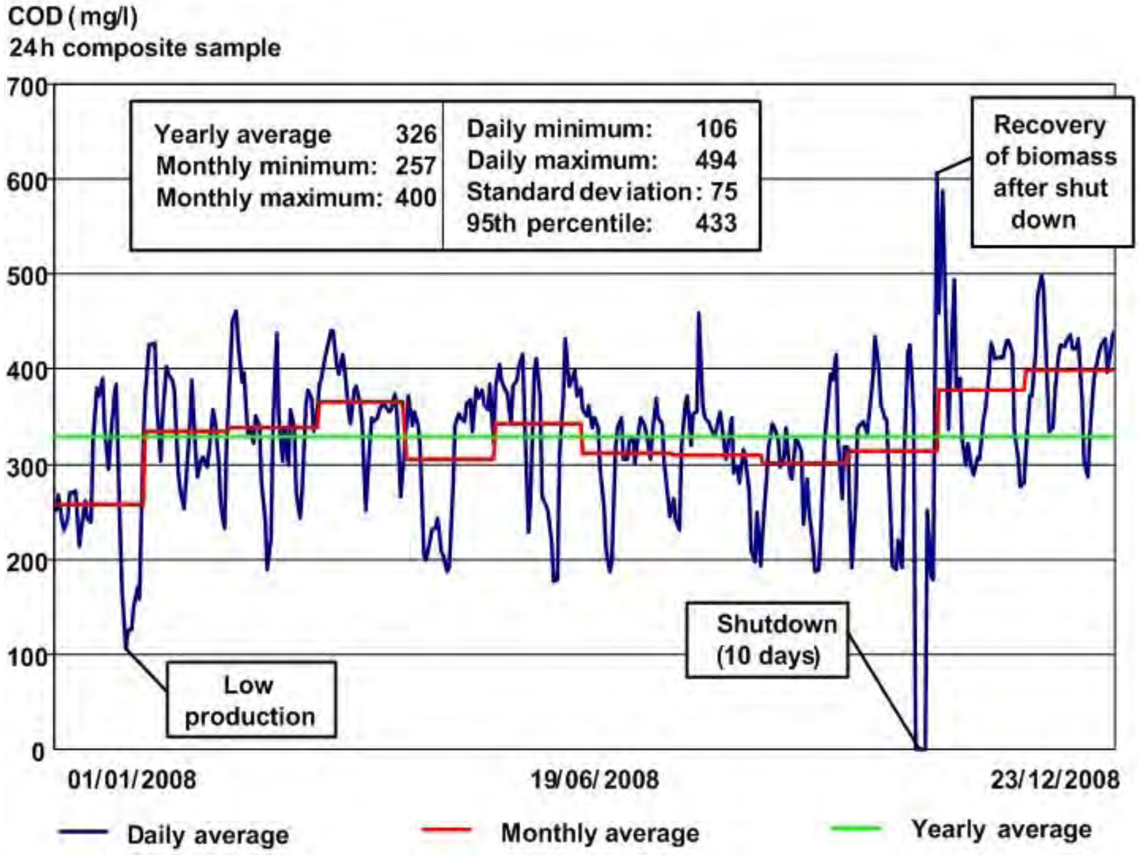
Treatment efficiencies vary and depend on effluent type, plant design and operating conditions. Typical values are within the ranges of 85 – 98 % for BOD_5 removal and 65 – 75 % for COD removal. AOX reduction is in the range of 40 – 65 %, and phosphorus and nitrogen are reduced by 40 – 85 % and 20 – 50 % respectively. The overall efficiency of TSS removal using primary and secondary treatment is about 85 – 90 %.

In the case of disturbances or if some of the running parameters are moving away from the target level, the BOD concentration in effluents increases above 25 mg/l. Adjustment of the operating parameters and/or analysis of the biomass are appropriate measures to counteract this increase.

In bleached kraft pulp mills with peroxide bleaching stages, EDTA concentrations of around 50 mg/l (24-hour composite sample) are measured in the inflow to the biological waste water treatment plant. Depending on the design and operating conditions of the waste water treatment, EDTA removal rates between almost zero and up to 90 % are reported. If EDTA elimination occurs, in most cases it is unclear whether complete degradation is achieved or only changes in the molecule.

a) Bleached kraft pulp

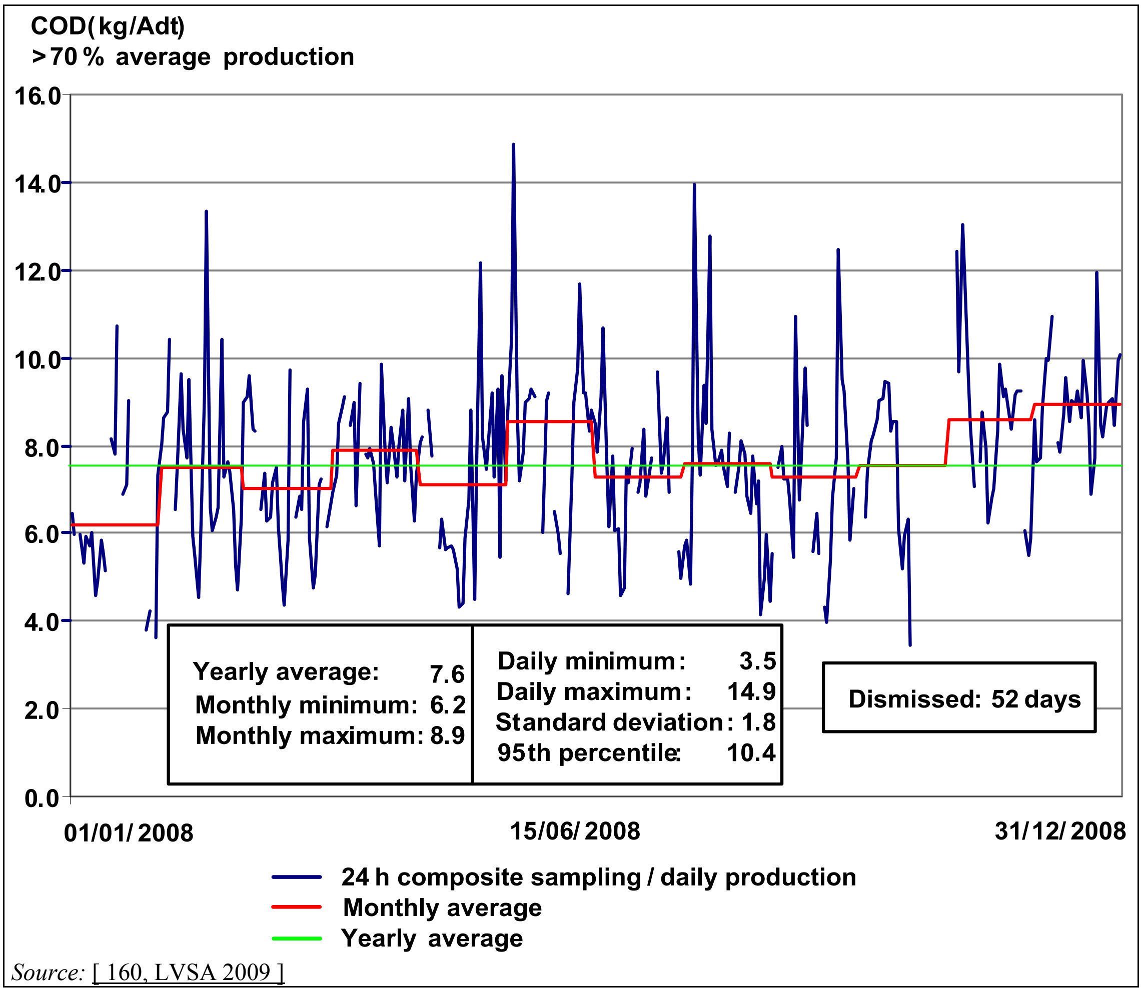
Figure 3.35 shows the variations in the daily average emission values of a mill that manufactures bleached softwood pulp over a complete year. The figure shows the performance of a two-stage moving bed biofilm reactor followed by a low-loaded activated sludge plant (sludge load: <0.1 kg BOD_5/kg DS_{org}) that treats the waste water from the mill. The discharge COD concentration is compiled for three different reference periods (day/month/year). The example represents a mill that has implemented all effluent-related process-integrated BAT and that possesses a well designed and operated biological treatment plant. The flow during the reported year was 26 m^3/ADt on average.



Source: [160, LVSA 2009]

Figure 3.35: COD concentrations of the effluents of a bleached kraft pulp mill after biological treatment for different reference periods

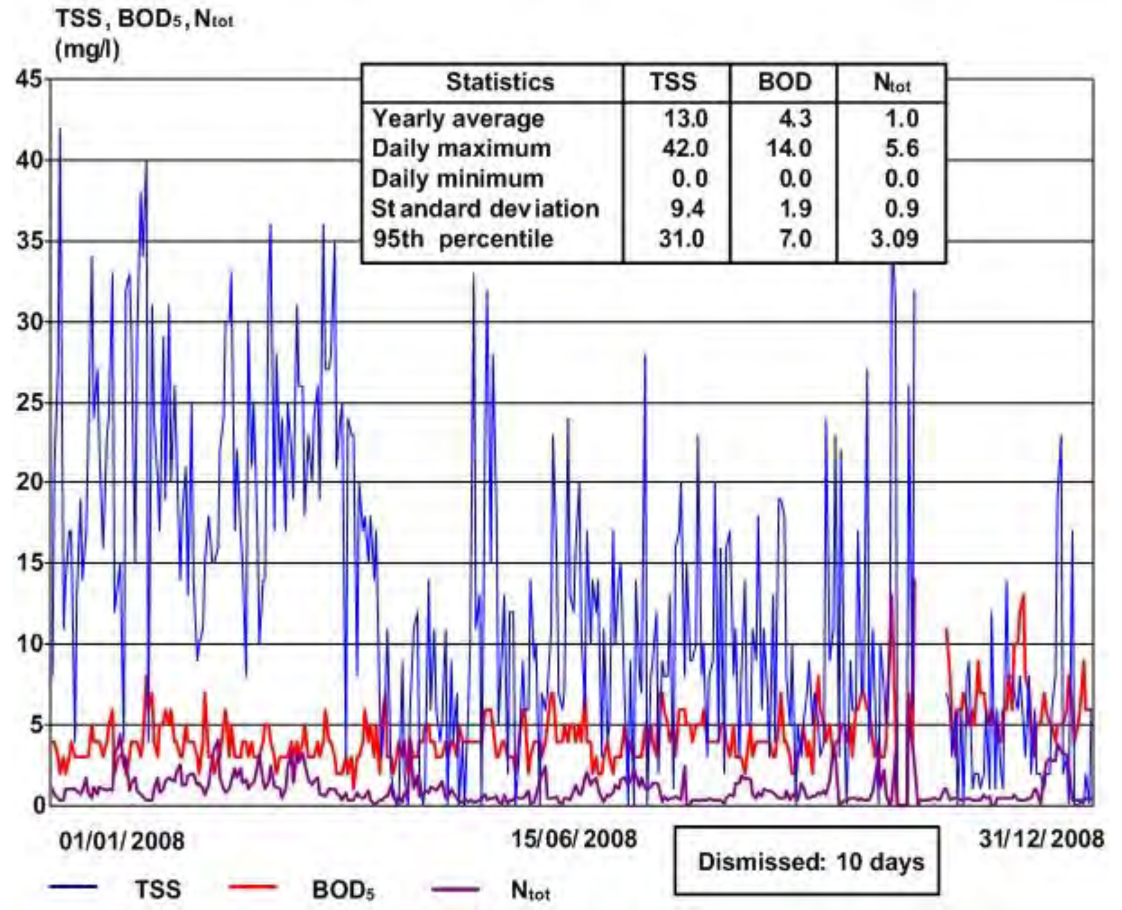
In the pulp and paper sector, it is common to use the daily COD load (kg COD/day) and the daily net production (tonnes of air dry pulp/day) to calculate the specific COD load (kg COD/ADt). The COD load over a complete year is shown in Figure 3.36 for yearly, monthly and daily average periods. It should be noted that for the calculation of the daily average values, the days with a production considerably below the annual average (<70 % of the annual average) have been dismissed in order to reduce the possibly misleading mathematical effect of dividing similar daily COD emission loads by a relatively lower denominator (decreased net production). Not considering this effect may result in drawing inadequate conclusions with regard to the stability of the real performance of the mill. For yearly and monthly averages, this effect is not relevant.



Source: [160, LVSA 2009]

Figure 3.36: COD load of the effluents of a bleached kraft pulp mill after biological treatment for different reference periods

In this case, the treatment plant is operated under nutrient limitation with an influent BOD_5:N:P ratio of 100:0.5:0.1 (conventionally BOD_5:N:P = 100:3 – 5:0.5 – 1). The nutrient limitation was found not to compromise the COD removal, generates less excess sludge and good sludge settleability [159, Steube et al. 2005]. At a hydraulic retention times of 3 hours in the biofilm system and 8 – 9 hours in the activated sludge plant under nutrient-limited conditions, 98 % of the BOD and 70 % of the COD are removed. The effluent TSS is mostly less than 25 mg/l. Low discharge levels of nutrients are achieved: 0.3 mg/l of total P and 1 mg/l of $N_{inorganic}$ as a yearly average. Figure 3.37 shows the achieved daily average concentration levels for tot-N, BOD_5 and TSS over a complete year and also includes a statistical evaluation. tot-N includes only $N_{inorganic}$ compounds.



Statistics	TSS	BOD	N_{tot}
Yearly average	13.0	4.3	1.0
Daily maximum	42.0	14.0	5.6
Daily minimum	0.0	0.0	0.0
Standard deviation	9.4	1.9	0.9
95th percentile	31.0	7.0	3.09

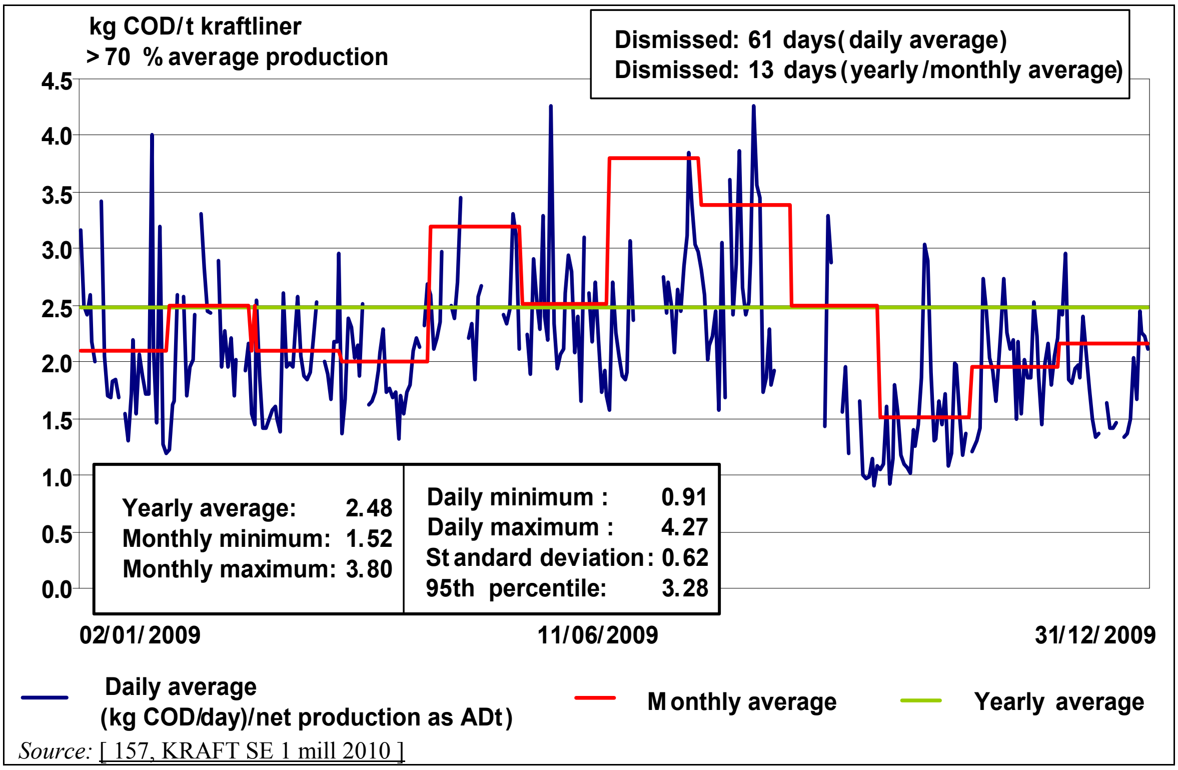
Source: [160, LVSA 2009]

Figure 3.37: TSS, BOD_5, $N_{inorganic}$ concentrations of kraft pulp mill effluents after biological treatment for different reference periods

In this case, EDTA (inflow: 34 – 63 mg/l) is reduced by around 90 % or more achieving effluent concentrations between 0.4 and 7 mg EDTA/l (average 2008: 1.8 mg/l; measured 12 times a year in 24-hour composite samples; method of analysis: DIN 38413-3). In the inflow, on average 50 mg EDTA/l (24-hour mixed sample) are measured.

b) Unbleached kraft pulp

An example of the performance of an activated sludge treatment system for unbleached kraft pulp is shown in Figure 3.38. The integrated pulp and paper mill, KRAFT SE 1, has an annual capacity of 700 000 tonnes of kraftliner, a base paper used in the production of high-quality corrugated board. The mill consists of a sulphate mill with two softwood pulp lines, one hardwood pulp line with a bleach plant, a recycled fibre line and two paper machines. Waste water from the unbleached kraft pulp line occurs only in the event of operational problems. The pulp mill is totally closed regarding black liquor spills, i.e. all black liquor is sent to the recovery island. Other sources of organic matter (COD) are the debarking station, effluents from the bleach plant and the processing paper for recycling line. In July and August, emissions increased above average. Some black liquor from the overflow of storage cisterns had to be sent to the emergency basin from where it was gradually pumped to the biological treatment plant. In the course of the year, the situation could be controlled.



Source: [157, KRAFT SE 1 mill 2010]

Figure 3.38: COD load of effluents for an unbleached kraft pulp mill after biological treatment for different reference periods (KRAFT SE 1)

Table 3.25 compiles the achieved emission levels to water after biological treatment of a selection of well-performing kraft pulp mills in Europe. These mills have implemented both a combination of process-integrated techniques as described in Sections 3.3.2 – 3.3.12 plus primary treatment and an effective biological treatment. The treatment efficiency of these examples is around 70 % for COD. The biological treatment plants are designed and operated mostly as low-loaded activated sludge plants (or comparable systems such as MBBR) with a sludge load of below 0.15 kg BOD/kg MLSS per day and typical retention times in the aeration basin range from about 14 hours up to 2 days. The list of mills is a selection of mills for which data were available or provided and is therefore not intended to be complete. More examples can be found in Section 3.2.2.5.3. In Sweden and Finland the values for BOD are given as BOD_7. All values are yearly average values. A few mills measure total organic carbon (TOC) as a substitute for the parameter COD, or additionally. Where available, these TOC values are presented in the table in square brackets. Values are separated into bleached and unbleached kraft pulp mills. The type of wood used for pulping is also indicated.

Table 3.25: Achieved emission levels to water after biological treatment of a sample of kraft pulp mills in Europe

Example mills (Data source)	COD [TOC] (kg/ADt) and (mg/l)	$BOD_{5\ or\ 7}$ (kg/ADt) and (mg/l)	TSS GF/A (kg/ADt) and (mg/l)	AOX (kg/ADt) and (mg/l)	Tot-N (g/ADt) and (mg/l)	Tot-P (g/ADt) and (mg/l)	Flow (m^3/ADt)	Type of treatment	Remarks
Bleached kraft pulp									
Södra Cell AB, Mönsterås Bruk (Swedish statistics 2007)	8 (286)	0.9 (32)	0.3 (11)	ND	57 (0 2.0)	9 (0.3)	28	Activated sludge with long retention time (>2 d)	Bleached softwood/hardwood, TCF market pulp
Zellstoff Pöls AG (Environmental report 2008)	9.2 [3.9] (250) [106]	0.45 (12)	0.52 (14)	0.11 (3.0)	57 (1.5)	32 (1.3)	36.8	Activated sludge with 14-hour retention time	Bleached softwood, ECF market pulp
Zellstoff Stendal (Questionnaire 2007)	7.6 (247)	0.15 (5)	0.5 (16)	0.05 (1)	100 (1)	20 (2)	31	Two-stage activated sludge	Bleached softwood, ECF and TCF market pulp
Zellstoff- und Papierfabrik Rosenthal (Questionnaire 2007)	6.5 (245)	0.11 (5)	0.3 (12)	0.03 (1.0)	10 (0.27)	10 (0.3)	26.5	Activated sludge	Bleached softwood, ECF and TCF market pulp
Stora Enso Enocell (Finnish statistical data 2006)	14 (378)	0.2 (5)	0.3 (8)	0.19 (5.1)	70 (0.2)	4 (0.1)	37	Activated sludge	Bleached softwood/hardwood, ECF and TCF market pulp
Oy Metsä-Botnia Ab, Rauma mill (Questionnaire 2009)	11.2 (401)	0.38 (14)	0.32 (12)	0.16 (5.7)	50 (1.8)	7 (0.2)	27.9	Activated sludge	ECF market pulp
Metsä-Botnia Joutseno, (Finnish statistical data 2006)	11 (250)	0.2 (5)	0.2 (5)	0.16 (3.6)	120 (2.7)	6 (0.1)	44	Activated sludge	ECF bleached softwood pulp
Södra Cell Värö (Questionnaire 2009)	[4.2] [223]	ND	ND	ND	130 (6.9)	8 (0.4)	18.8	Activated sludge	Bleached softwood/hardwood, TCF market pulp
Celulose Beira Industrial (Celbi), Figueira da Foz (Questionnaire 2009)	8.2 [2.6] (214) [68]	0.5 (13)	0.8 (21)	0.04 (1.0)	160 (4.2)	110 (2.9)	38.4	Activated sludge	Bleached ECF eucalyptus market pulp
Portucel – Setúbal (Questionnaire 2009)	5.1 (259)	0.23 (12)	0.22 (11)	0.09 (4.6)	40 (2.0)	100 (5.1)	19.7	Activated sludge	Bleached ECF eucalyptus market pulp
Soporcel, Figueira da Foz (Questionnaire 2009)	8.7 (323)	0.5 (19)	0.9 (34)	0.11 (4.1)	110 (4.1)	100 (3.7)	26.9	Activated sludge	ECF eucalyptus pulp for integrated production (values refer to pulp mill only)

Example mills (Data source)	COD [TOC] (kg/ADt) and (mg/l)	$BOD_{5\ or\ 7}$ (kg/ADt) and (mg/l)	TSS GF/A (kg/ADt) and (mg/l)	AOX (kg/ADt) and (mg/l)	Tot-N (g/ADt) and (mg/l)	Tot-P (g/ADt) and (mg/l)	Flow (m^3/ADt)	Type of treatment	Remarks
Unbleached kraft pulp									
Nordic Paper, Bäckhammars Bruk (Swedish statistics 2007)	4 (87)	1.5 (33)	0.5 (11)	ND	394 (8.6)	6 (0.1)	46	Biological treatment + chemical precipitation (emissions refer to pulp only)	Unbleached kraft pulp + paper
Portucel, Viana do Castelo (Questionnaire 2009)	2.8 (164)	0.1 (5.8)	0.6 (35)	0.001 (0.05)	90 (5.3)	10 (0.6)	17.1	Activated sludge (values refer to liner/board produced	Unbleached kraft liner board (30 % RCF)
KRAFT SE 1 (Swedish statistics 2007)	2 (105)	ND	0.2 (11)	ND	70 (3.7)	17 (0.9)	19	Activated sludge (values refer to pulp including RCF processing)	Bleached and unbleached kraft + kraftliner (20 % RCF)
NB: ND = no data. [value] = result of TOC analysis Activated sludge (values refer to pulp including RCF processing) Bleached and unbleached kraft + kraftliner (20 % RCF).									

Cross-media effects
Aerobic biological waste water treatment consumes energy (e.g. for aerators and pumps) and generates sludge that normally requires treatment before utilisation or disposal.

Technical considerations relevant to applicability
The technique can be applied to new and existing mills.

Economics
The investment required for a completely new activated sludge treatment plant are approximately EUR 19 – 24 million for a kraft pulp mill with 1 500 ADt/d production, the lower end of the cost range being for an unbleached kraft pulp mill. These costs also include the necessary primary treatment and sludge handling. The corresponding operating costs are EUR 2.0 – 2.6 million/yr.

Driving force for implementation
Protection of water bodies from organics, suspended solids, nutrients and potentially toxic effluents. Legal requirements. Water quality objectives.

Example plants
Many kraft pulp and paper mills in Europe have implemented effective biological treatment systems. There are also numerous plants all over the world that apply it too.

Reference literature
[1, Finnish BAT Report 1997], [75, Pöyry 1997], [131, SEPA report 1997], [157, KRAFT SE 1 mill 2010], [159, Steube et al. 2005], [160, LVSA 2009], [EIPPCB Questionnaires 2007 and 2009], [Swedish statistics 2007], [Finnish statistical data 2006].

3.3.14 Tertiary waste water treatment - chemical precipitation

Description
See Section 2.9.11.3.1.

Achieved environmental benefits
The objective of tertiary treatment is mainly the reduction of emissions of suspended solids, partly non-biodegradable dissolved COD matter and phosphorus. The reduction of suspended matter emissions also reduces the nutrient emissions bound thereto.

Prevention of the disruptive effects of temporary overflows is another benefit of tertiary treatment.

Environmental performance and operational data
No emission data were provided, but under controlled test conditions it is possible to remove 30 – 50 % of the non-biodegradable COD from biologically treated water by efficient and well-functioning chemical coagulation.

Tertiary treatment can be a reasonable solution when the waste water load changes significantly during different seasons and the performance of the secondary treatment (e.g. an aerated lagoon) is poorer compared with a well designed and operated activated sludge plant.

At the SE Varkaus mill, tertiary treatment achieved the following reductions [17, Nurmesniemi 2010]:

TSS	55 %
COD	35 %
phosphorus	60 %
nitrogen	50 %.

At the Varkaus Mill, all sludges are mixed before being dewatered with a screw press and the dried sludge is incinerated at the mill's own power plant.

Cross-media effects

A relatively high amount of chemical sludge, which is more difficult to dewater and handle than biosludge, is generated. Aluminium or iron residues can be found in low concentrations in the treated effluents after chemical precipitation.

Technical considerations relevant to applicability

Applicable to new and existing mills when further removal of organic substances, nitrogen or phosphorus is needed.

Economics

A technical-financial study on tertiary treatment (flotation plant and sand filtration for a capacity of approximately 30 000 m^3/day) indicated investment costs of about EUR 6.6 million and operating costs of about EUR 1.4 million per year (price level: last quarter of 2007).

At the SE Varkaus mill, the investment cost of tertiary treatment after the aerated lagoon was lower compared with the upgrading of the aerated lagoon into the activated sludge plant [17, Nurmesniemi 2010].

General cost information about the flotation plant (tertiary treatment) at the Stora Enso Varkaus mill that produced approximately 600 000 t/yr of pulp, paper and board in 2006 (investment cost from 2002) is as follows:

Investment cost (2002):	EUR 5 million
Dimensioning of the plant:	2 x 30 000 m^3/d (two lines)
Incoming COD:	300 – 600 mg/l
Incoming TSS:	50 – 150 mg/l
Usage of aluminium sulphate:	50 – 400 mg/l.

Annual costs:	EUR 0.5 million, EUR 0.025 – 0.03 per m^3 of treated water
Chemical sludge: (as dry matter)	10 t/d (20 % of the total sludge amount).

Driving force for implementation

The major driving forces are the requirements set in the environmental permits. Usually, tertiary treatment is used when the nutrients, colour or COD of the treated waste waters have to be reduced beyond BAT levels (e.g. for a very sensitive receiving water body) or the disturbance effects of temporary overflows have to be prevented. It is also used to improve the efficiency of waste water treatment (e.g. in the case of aerated lagoons). Low reduction efficiencies for phosphorus and COD in aerated lagoons in wintertime can be improved.

Example plants

Biological treatment plus chemical flotation of waste water from the manufacturing of kraft pulp is used at some plants in Sweden, e.g. Skoghall, Billingfors, Bäckhammar or Iggesund. Several mills in Finland also use tertiary treatment with chemical flotation (e.g. SE Varkaus).

Reference literature

[17, Nurmesniemi 2010], [67, Hynninen 2008].

3.3.15 Collection systems for strong and weak malodorous gases

Description
In efficiently designed and operated gas collection systems it is possible to collect and eliminate malodorous gases almost completely. Collection and incineration can cover more than 99 % of the total production-process-based emissions of gaseous sulphuric compounds.

Useful treatment methods are incineration in the recovery boiler (see Section 3.3.16.1), lime kiln (see Section 3.3.16.2) or dedicated TRS burners (see Section 3.3.16.3). Also, scrubbers are used for cleaning dissolving tank vent gases or for reducing SO_2 emissions from the separate TRS burner, the lime kiln or the recovery boiler. An overview of the efficient layout and operation of these gas collection systems is given below.

I. *Collection of concentrated malodorous gases*

The target is to collect all the concentrated malodorous gases because they have a very high sulphur content, for example a softwood mill operating with an annual production of 600 000 ADt would release over 1 300 t of sulphur to air (approximately 2 – 5 kg S/ADt, see also Section 3.2.2.6.4) or more without proper collection and treatment of concentrated malodorous gases only.

Collection points for the strong gases in the fibre line are:

- digesters from the flash steam condenser
- turpentine decanters
- foul condensate tanks
- turpentine scrubbers
- turpentine storage tanks
- tank fumes.

The collection point in the chemical recovery line is the foul condensate system, e.g. the foul condensate tanks (for example from evaporation and the recovery boiler), the foul condensate stripper and its condensers.

Gas ducts are equipped with water locks which condense some of the gases and also ensure that the gases flow in the right direction. Ejectors feed the gases to incineration (recovery boiler, lime kiln or separate TRS burner). Collection channels are also equipped with droplet separators and flame arresters, which prevent flames from going backwards in channels (as concentrated malodorous gases contain a large proportion of inflammable gas).

Figure 3.39 and Figure 3.40 show two different efficient gas collection systems for strong malodorous gases including major collection points, treatment options and back-up systems.

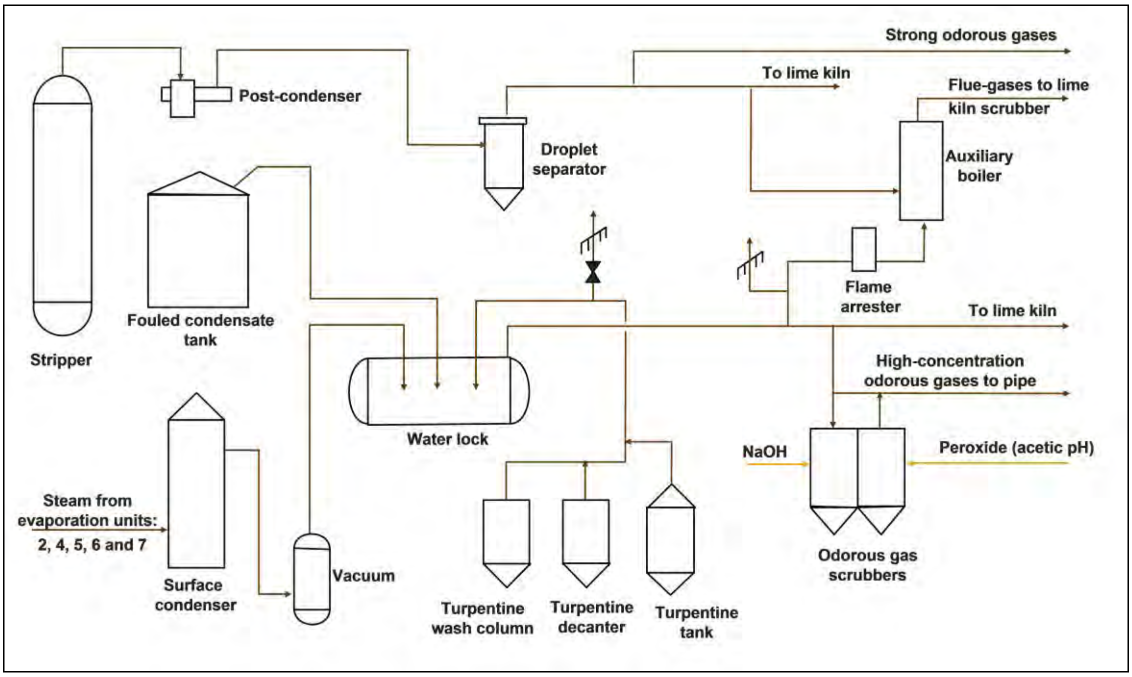


Figure 3.39: **Treatment and collection systems of strong malodorous gases (Botnia Rauma mill)**

Figure 3.40 shows a similar collection and back-up system but the strong gases for incineration are not sent to the lime kiln but to the recovery boiler.

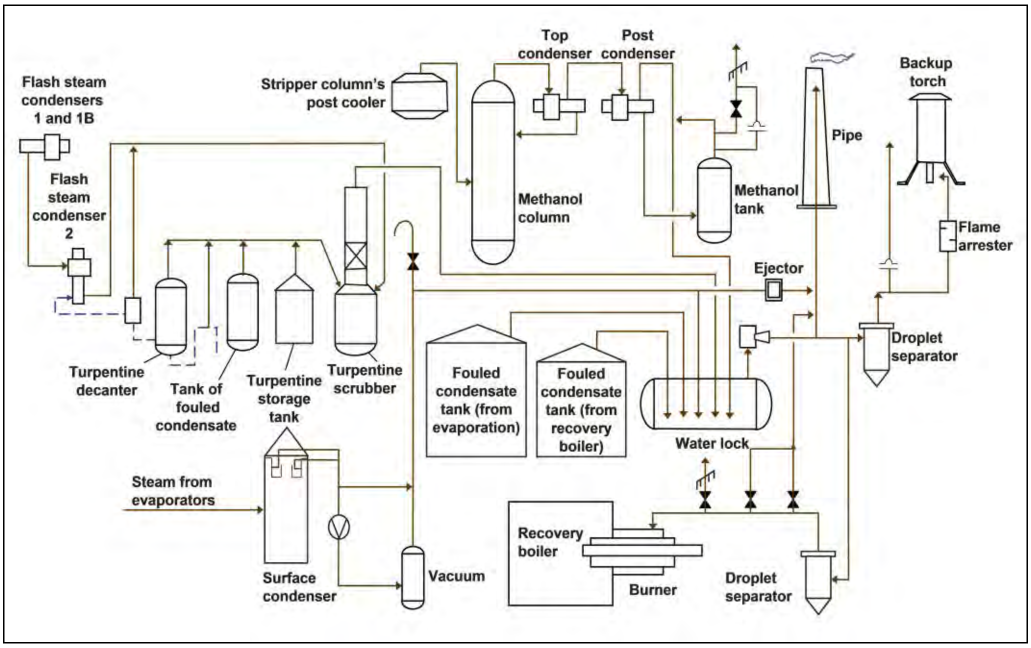


Figure 3.40: **Treatment and collection systems of strong malodorous gases (Botnia Joutseno mill)**

II. *Collection of dilute malodorous gases*

In effective gas collection systems, almost all dilute or light malodorous gases are collected from the fibre line, the chemical recovery island and the causticising plant area.

The collection points for dilute malodorous gases in the fibre line are schematically shown in Figure 3.41.

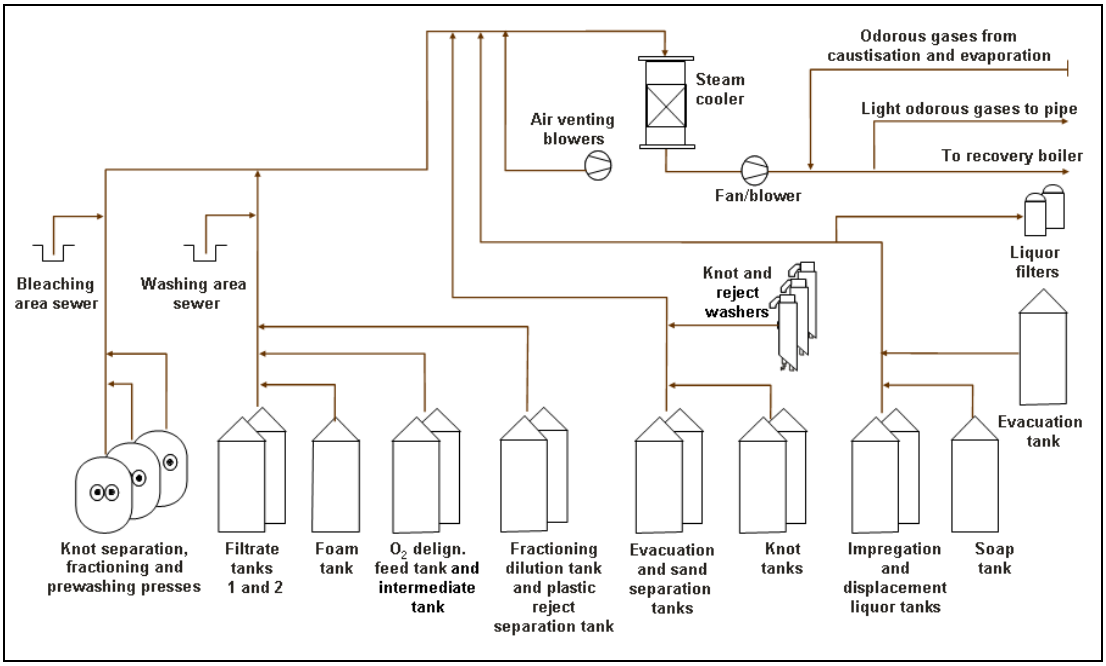


Figure 3.41: **Treatment and collection of dilute malodorous gases in the fibre line (Botnia Rauma mill)**

a) The collection points in the fibre line

The collection points in the fibre line are the digester area, the brown pulp washers (for example diffuser or press washers or drum displacer washers), washer tanks, filtrate tanks, the wash liquor tank, knot return tank, oxygen delignification feed tank, and collection liquor tanks. All these emission sources are connected to the weak gas collection system.

The collection of acidic steam from the bleaching area is not shown in Figure 3.41, e.g. from the chlorine dioxide bleaching towers and the subsequent washers or the SO_2 fumes for chlorine dioxide elimination. In efficient systems, these gases are also collected and treated in a separate scrubber due to the high chloride content which causes a significant corrosion risk in burners.

b) Collection points in the chemical recovery line

The collection points from the evaporation plant and the tall oil production area include a large number of the tank system's gas release points, e.g. the black liquor, strong liquor and condensate tanks, the intermediate liquor, weak liquor, spill liquor and tall oil soap storage tank, the soap equalisation tanks and the tall oil and soap oil tank. Other collection points are the tall oil cooking gas scrubber, the tall oil reactor and the oil separators. Schematically the gas collection system is shown in Figure 3.42. The collected dilute gases are sent to the recovery boiler as combustion air.

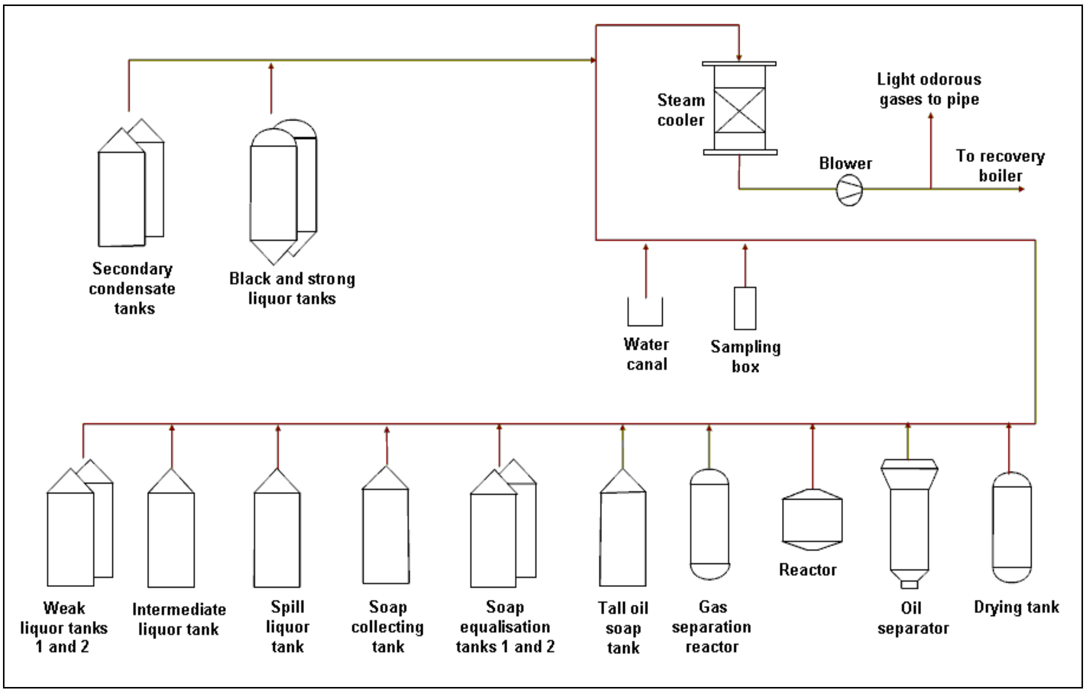


Figure 3.42: **Collection and treatment of light odorous gases from the evaporation area and the tall oil cooking area (Botnia Rauma mill)**

c) Collection points in the causticising plant

A very effective and thorough gas collection system also includes an almost complete collection of all weak malodorous gases in the causticising plant. The causticising fumes have lower malodorous sulphur contents than other sources. Collection points from the causticising plant tank area are green liquor tanks, green liquor dreg filters, dreg tanks, green liquor filters, green liquor filtrate tanks, hot water tanks, green liquor oxidation (if existing) and its steam condenser, lime-slaker and its washer, slaker steam washer, causticisation tanks, lime mud filter, white liquor tanks, lime mud storage tank, dilution water tanks, acid tank, canal ventilation system and heat exchanger before the lime kiln. Only in the newest mills are all low concentration malodorous gases in the causticising plant collected. Typically, causticising fumes have very low malodorous sulphur contents. Collection from the causticising plant tank area is almost as effective as the full collection.

Figure 3.43 shows an example of an efficient gas collection system for the light concentration odorous gases from the causticisation area (Botnia, Rauma, FI).

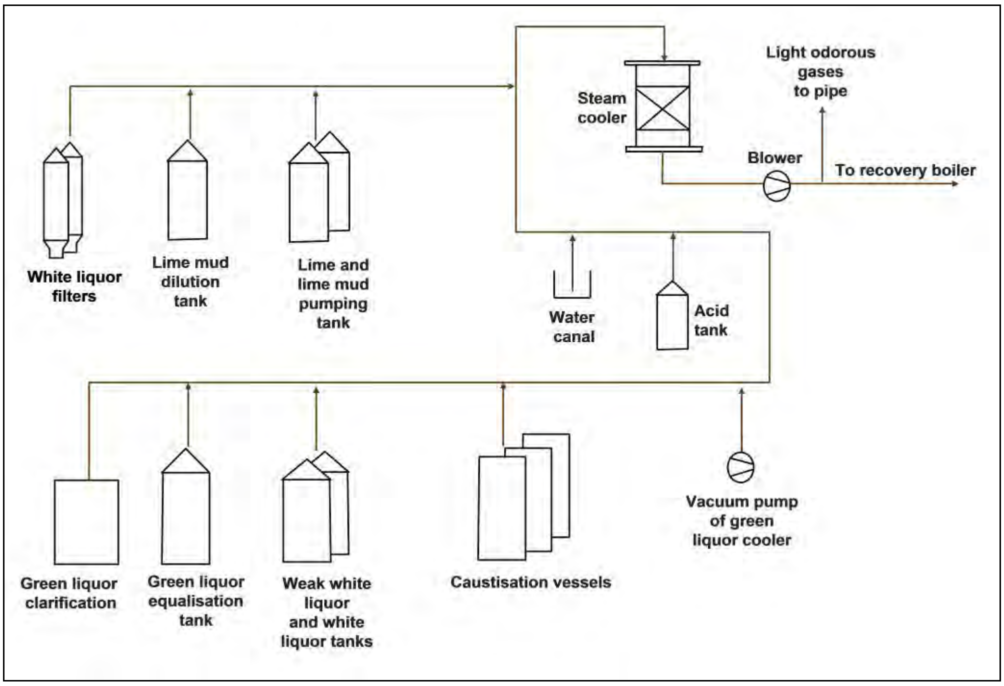


Figure 3.43: **Collection and treatment of weak odorous gases of the causticisation area (Botnia Rauma mill)**

d) Dissolving tank vent gases

The dissolving tank vent gas (DTVG) also contains high amounts of TRS-sulphur and particulates (mainly sulphates). Vent gases have not traditionally been classified as non-condensable gases. However, if the vent gas is sent to the recovery boiler furnace, it must be handled in accordance with the instructions for handling dilute non-condensable gases because of its high moisture content. Often these vent gases were only be treated successfully with scrubbers. Alternatively, DTVG can also be burnt in more recently built recovery boilers and those modified for DTVG incineration, after removing moisture and particulate matter. This technique has been installed in existing recovery boilers in the Varkaus and Rosenthal mills for example (at an approximate cost of EUR 1 – 2 million per mill to install new fans, cooler, ducts and condensate separation).

If DTVG are burnt in the recovery boiler, a fan draws the vent gases from the dissolving tank, a condenser reduces the moisture of the gas and a scrubber reduces the particulate matter. Then the cleaned vent gas is combined with preheated air and a fan blows the air/gas mixture via ducts to the furnace. As an alternative route, the vent gas can be sent through the scrubber and then to the roof.

Achieved environmental benefits

An efficient gas collection and treatment system is essential for both sulphur emission and odour control. It limits the odour nuisance in the neighbourhood. The collection of malodorous gases has a significant impact on improving the air quality. Mills with an advanced collection system for light and highly concentrated malodorous gases can reduce the duration of odour nuisances to <1 % of the operating time.

Environmental performance and operational data

The main target is the almost complete collection and treatment of malodorous gases. Because of the high sulphur and odour content of the strong malodorous gases, these gases should be collected (collection efficiency of >99 %) and treated with the highest availability (>97 %). For strong gases, back-up systems should be in place and be able to start operation as fast as possible, if needed.

Low concentration malodorous gases should be collected and treated from all other points. Normally, low concentration malodorous gases do not have a back-up system for treatment because the odorous effect is not as strong as it is when the higher concentrations of TRS are released. Efficient systems have an automatised monitoring system for the immediate detection of undesired releases which are then reported directly to the control room. Dilute TRS gases should have a high gas collection efficiency (>95 %) and suitable treatment. The availability of the treatment system for light malodorous gases should be over 90 % of the operating hours. Otherwise the nuisance caused by these emissions to the community is significant. Sulphur emissions are significantly lower with an efficient malodorous gas collection and treatment system.

The equipment of the malodorous gas system also has to comply with security regulations, concerning work safety and inflammable liquids and gases. It must be reliable, properly designed (e.g. sufficient blower capacity to reach the targeted suction performance is vital) and operated by specially trained staff. It is essential that the appropriate process design solutions for malodorous gas systems be accompanied by correct and careful operation by the operators of the plant.

Odorous gases contain a significant portion of water vapour. They also contain organic compounds that readily condense in typical operational conditions. It is important to design the collection system in such a way that dirty condensate can be effectively removed and treated. The condensate system needs to be designed so that backflow of air (dry out) during condensate removal can also be eliminated during mill shutdown. Many of the operational accidents occur during mill start-up or upsets through condensate formation and re-evaporation.

Maintenance of the gas collection system is important to achieve the best performance and high availability. In strong gas systems, air leakages may cause gas dilution and the gas-air mixture to become potentially explosive. Therefore gas channels are to be kept in perfect condition. In dilute gas channels the problem is different: in process disturbance situations, gases may accumulate in a high concentration and enter the explosive zone. Under normal operating conditions, the weak malodorous gas system is operated at low pressure. Undesired leakages should be monitored continuously and automatically, e.g. by mini-anemometers for flow rate measurements in the pipe system, shuttle valves and the measurement of temperature changes in case of releases, etc.

One of the most important issues is the capacity of the collection system. A common mistake is to select dimensions which are too small for the collection ducts and process equipment, since normally all mills eventually produce more than the original capacity. Also the blower capacity must be sufficient to hold the whole system under low pressure.

To ensure a high availability of the system, water locks should be large enough so that the gases flow as expected. If not, malodorous gases may enter the wrong places in the process or go directly to air and cause a foul odour. The water level in locks should be monitored continuously.

Scrubbers and their nozzles also need surveillance and maintenance, especially when white liquor is used as a washing liquid (white liquor has a higher solids content than in NaOH). The operation of a scrubber should be monitored with measurements and, depending on the gas, the TRS reduction should be at least 50 %, since dimethylsulphide and dimethyldisulphide do not wash out.

The verification of the effectiveness of the collection system and the operating hours that weak gases are vented out via the stack can be calculated in an accurate way by the process automation of the mill.

Cross-media effects
The efficient collection of malodorous (sulphur-containing) gases may cause a disequilibrium in the sulphur/sodium balance. If excess sulphur accumulates in the process, the excess sulphur may require removal from the process, e.g. by leaching the recovery boiler ash.

Incineration of malodorous gases in the recovery boiler may affect the sulphur and NO_X emissions from the recovery boiler.

Incineration of sulphur-containing gases reduces the carbonate content and pH of the recovery boiler's precipitator ash. The additional sulphur in malodorous gases is first seen as a result of the replacement of carbonate with sulphate in the electrostatic precipitator ash. When the carbonate content becomes low, the remaining sulphur will be in the form of SO_2 in the flue-gases. Before deciding whether to incinerate malodorous gases in the recovery boiler, it would be advisable to study in detail the recovery boiler's capacity to handle the additional sulphur load. Sulphur emissions from the recovery boiler can be reduced by decreasing the sulphidity of black liquors, by increasing the DS content of the concentrated black liquor or by the use of scrubbers.

In stable operation, sulphur emissions are low when incinerating concentrated malodorous gases, provided that the dry solids content of the combustion liquor is at least 72 % and the liquor load is almost full, at a sulphidity of ~40.

If malodorous gases are incinerated with a partial load, the pH and carbonate content of the electrostatic precipitator ash, and the SO_2 content of flue-gases have to be evaluated case by base. A boiler operating continuously at partial load requires higher dry solids than a boiler operating at nominal load or above, in order to secure a trouble-free operation. If the amount of sulphur released with malodorous gases is so large that incineration generates SO_2 emissions, the fouling and corrosion tendency of the boiler due to acid ash salts (low pH) will increase.

Especially concentrated malodorous gases contain nitrogen compounds. These nitrogen compounds consist mostly of ammonia, which is separated from black liquor in the evaporation plant. Some of these nitrogen compounds have been formed in the causticising area from the nitrogen that has entered the dissolving tank with the recovery boiler smelt and then recirculated through the cooking process to the recovery boiler. Theoretically the contribution on NO_X is about 5 – 15 % of the total load, which is however difficult to verify with emission measurements.

Dilute malodorous gases contribute to less than 1 % of the NO_X emissions of the recovery boiler. Their effect on the TRS load of the recovery boiler is significant only when the boiler is outside the normal operation zone, i.e. running at low capacity. Then the highest air register of the recovery boiler can be too cold for TRS combustion.

Technical considerations relevant to applicability
The systems described can be installed in new and existing mills. In many older mills some of the washing equipment is of the open type. Collection of vent gases from these sources of dilute gases requires the handling of very high air volumes which may be both technically and economically difficult.

Economics
In some cases, a more complex mill layout can complicate the collection of all the dilute malodorous gases. The piping cost and blower requirements may rise significantly in these cases.

Driving force for implementation
Improved sulphur recovery, which has cost advantages (but may also cause imbalances with regard to the S/Na control). Advanced malodorous gas collection and treatment improves the

reputation of kraft pulp mills and the likelihood of general acceptance of their operation in the neighbourhood.

Example plants

Advanced modern mills with malodorous gas collection and treatment systems of a similar type to the one described above can be found in Botnia Joutseno and Rauma mills (FI), Heinzel Pöls (AU), or Mercer Stendal and Rosenthal mills (DE), etc.

Reference literature

[174, M.Ahlroth et al. 2009], [175, Recovery Boiler Committee 2006], [176, Hämäläinen 2009].

3.3.16 Control of strong and weak non-condensable gases in treatment systems with high availability

Introduction

Control of non-condensable gases (NCG) that cause emissions of reduced sulphur compounds and thus an unpleasant smell is divided into the treatment of concentrated non-condensable gases (CNCG) which contain about 2 – 5 kg TRS/ADt (measured as S), and the treatment of diluted non-condensable gases (DNCG) which contain about 0.5 kg TRS/ADt (measured as S). For more details on TRS emissions, see Section 3.2.2.6.4.

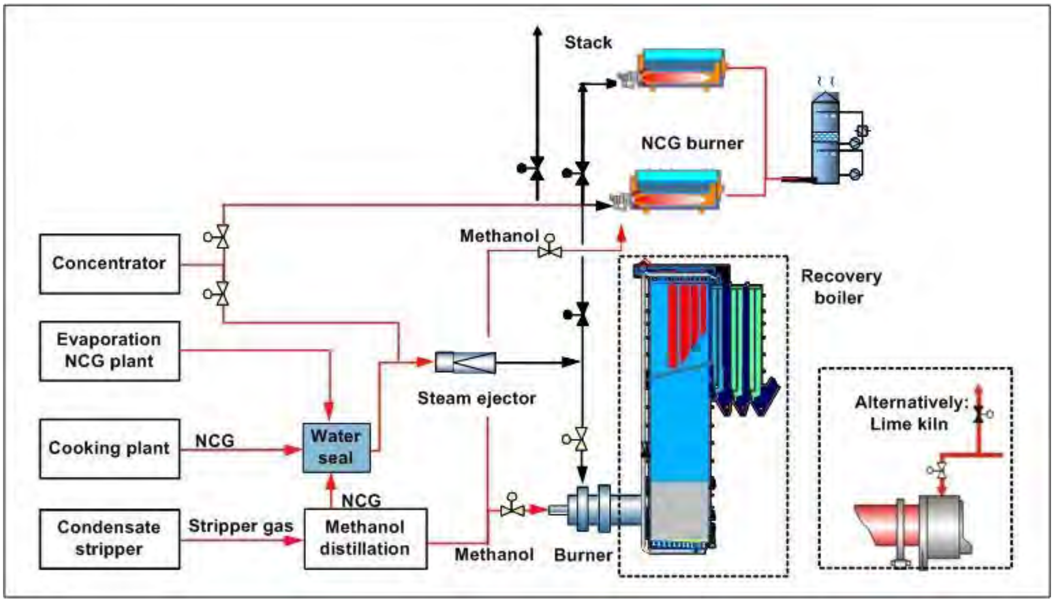
Highly concentrated and low volume gases (CNCG) from the cooking and evaporation stages are formed for example in turpentine recovery systems, continuous digester flash steam condensers, foul condensate storage tanks, evaporator non-condensable gas relief and hot wells, and in batch cooking blow heat recovery systems instead of continuous digester flash steam condensates.

High volume and low concentration gases (DNCG) are formed during black and white liquor handling, pulp washing and in floor channels with black or white liquor residues. The main sources of emissions are the washing and screening equipment of unbleached pulp, tanks of pulp and washing liquor in the washing and screening plant, black liquor storage tanks in the evaporation plant and white liquor storage tanks in the recausticising plant.

The collection of the NCG is carried out with gas pipelines, ejectors and blowers for gas transfer (see Section 3.3.15). Operational disturbances or system malfunctions should be prevented or reduced, and monitored and the number of failures and their duration recorded.

For odorous gas treatment, there are different technical options available: mainly incineration in the recovery boiler (see Section 3.3.16.1), the lime kiln (see Section 3.3.16.2) or in a dedicated NCG burner equipped with a SO_2 scrubber (see Section 3.3.16.3).

A schematic view of an example of a treatment system for CNCG is shown in Figure 3.44 and for DNCG in Figure 3.45. For strong gases, the gas destruction system always includes back-up systems. Figure 3.44 shows an example where the strong gases are primarily burnt in the recovery boiler with NCG burners as a back-up. Alternatively, the strong gases can be burnt in the lime kiln (also with a back-up) or in a dedicated NCG burner which in this case is also backed up (not shown in Figure 3.44).



Source: [32, Vakkilainen 2007]

Figure 3.44: Example of a CNCG treatment system

Figure 3.45 shows that diluted NCG collected from a large number of sources are preferably burnt in the recovery boiler, or in some cases also in power boilers (if operated), in NCG burners, or in the lime kiln (not shown in the figure). Often for DNCG incineration there are no back-up systems.

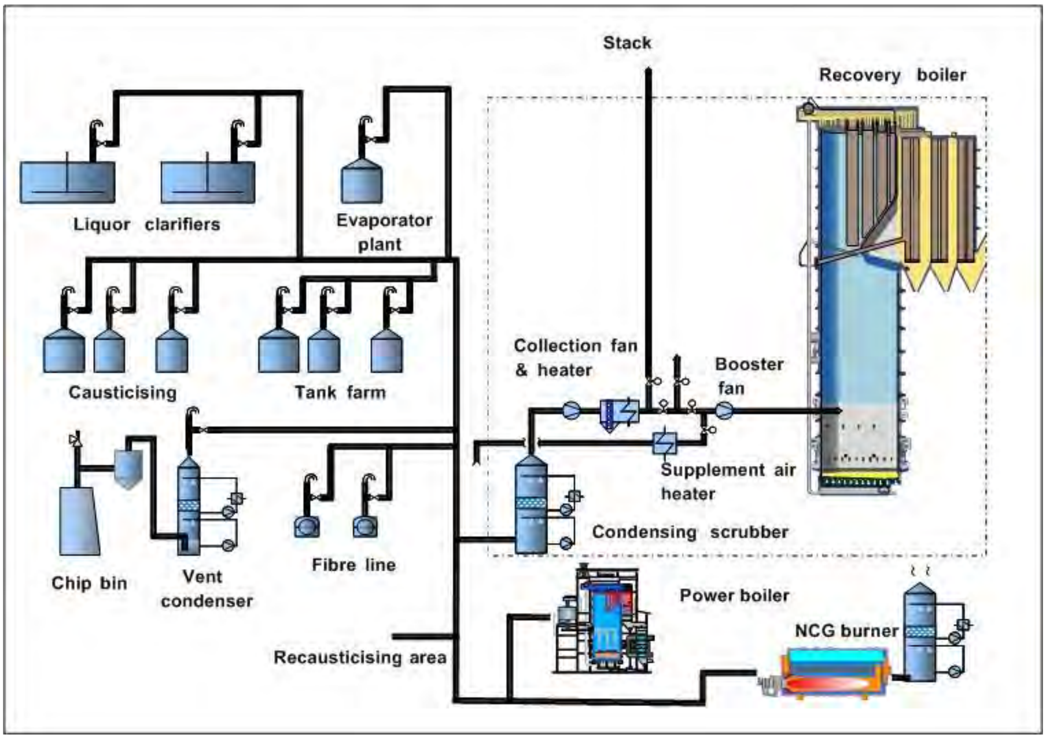


Figure 3.45: Example of a DNCG treatment system

The efficiency and availability of the gas treatment system depend on the type of system chosen (recovery boiler, lime kiln, dedicated NCG burner), the number and type of back-up devices which are activated in the case of operational disturbances, failures, maintenance, mill shutdown or other downtime of the normal system, and the monitoring and control of the entire system (with regard to availability, see also Figure 3.46). A high availability of the treatment system for strong gases can be achieved by the incineration of the strong and weak gases in the recovery boiler for example and by the use of the lime kiln as one back-up and a flare as a second back-up. For other options, the reader is referred to Sections 3.3.16.2 and 3.3.16.3.

Under normal operating conditions, the system ensures that there are always two units where CNCG can be destroyed. The design capacity for CNCG incineration should allow for treating more than 100 % of the gas generated during normal operating conditions. Also, during mill shutdown, at least one unit should be available to handle CNCG. If one of the options is a torch or NCG incineration boiler, keeping it burning requires incinerating a small part of the NCG continuously but not at maximum capacity. The different options are dealt with in the following sections.

3.3.16.1 Incineration of strong and/or weak malodorous gases in the recovery boiler

Description

The CNCG can be introduced into the secondary air level of the recovery boiler (see Figure 3.56) which uses their energy content and converts the reduced sulphur compounds into sulphur dioxide. When the dry solids content of the black liquor is high enough (see Section 3.3.17.1), the SO_2 emissions are practically unaffected when CNCG are burnt in the recovery boiler. No further abatement technique (e.g. a scrubber) is required for keeping sulphuric emissions very low (close to zero).

Collected diluted malodorous gases (DNCG) can be incinerated as secondary or tertiary air in the recovery boiler. Depending on the volume of DNCG and the layout of the pulp mill, some mills operate several TRS destruction systems for different departments.

For an example of the achieved emissions of a recovery boiler that burns the strong gases and is equipped with a scrubber, the reader is referred to Figure 3.55.

Achieved environmental benefits

Efficient odorous gas collection from all sources and effective treatment minimises sulphur emissions (TRS) and odour nuisances in the neighbourhood.

Environmental performance and operational data

The incineration of both strong and weak gases in the recovery boiler is used at many mills without problems. After burning NCG in the recovery boiler, they are almost completely destroyed and TRS emissions are mostly below 5 mg TRS/Nm^3 (6 % O_2), determined as an annual average value, see Figure 3.48 and Figure 3.49, and do not cause any more unpleasant smells in the neighbourhood.

The flow rate of the tertiary air level of the recovery boiler where the DNCG may be incinerated is limited and therefore other burning alternatives may be needed as well.

For achieved TRS and SO_2 emission data from recovery boilers, the reader is referred to Section 3.3.17.1.

Cross-media effects

Burning malodorous gases in a recovery boiler is a potential source of additional NO emissions because of the ammonia contained in odorous gases. The latest experiments, however, indicate that an increase in NO can mostly be avoided if the malodorous gases are injected in the correct way and in the right location in the furnace of the boiler [225, Hupa 2005] (e.g. the Södra: Värö and Mörrum mills).

Technical considerations relevant to applicability
The measure can be adopted in new and existing kraft mills.

Economics
No cost data were provided.

Driving force for implementation
Reduction of odour and sulphur emissions. Legal requirements.

Example plants
Korsnäs, Frövi; Södra: Värö and Mörrum, Skutskär; UPM Pietarsaari; Celbi, SE Oulu, UPM Kymi, UPM Fray Bentos, MB Joutseno, MB Kemi, Zellstoff Pöls AG; SE Veitsilouto, Zellstoff Stendal [33, COM 2011], [comment D1 Germany].

Reference literature
[33, COM 2011], [64, J.Malmström 2010], [65, N.DeMartini et al. 2010], [66, FRBC 2010], [225, Hupa 2005].

3.3.16.2 Incineration of collected malodorous gases (strong and weak gases) in the lime kiln

Description
The collected strong odorous gases can be incinerated as secondary air in the lime kiln (see Figure 3.44). Some mills also incinerate the weak odorous gases in the lime kiln, others use alternative methods (e.g. recovery boiler, scrubbers). Depending on the volume of DNCG and the layout of the pulp mill, some mills operate several gas treatment systems for different departments (see Figure 3.45). In the example mill described below under 'Environmental performance and operational data', all DNCG are treated in washers.

Achieved environmental benefits
Efficient odorous gas collection from all sources and effective treatment minimises sulphur emissions (TRS) and odour nuisances in the neighbourhood.

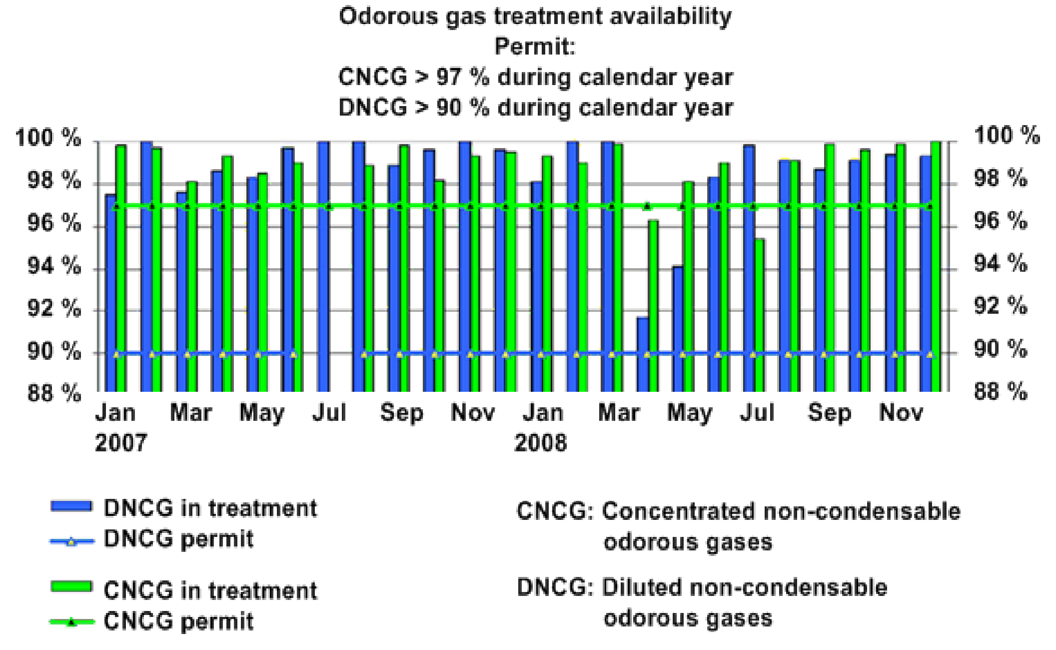
Environmental performance and operational data
Emission data for lime kilns that burn CNCG with and without a scrubber are given in Section 3.3.20.1.

An example of the availability of an odorous gas treatment system is shown in Figure 3.46.

In this case, the CNCG are burnt in the lime kiln and a dedicated boiler is used as a back-up. The back-up boiler is kept at 11 bar pressure with steam. From 'stop' to 'odorous gas burning' warming of the back-up boiler takes one hour. If burning of the strong odorous gases is not possible, they are vented via a 120 m high stack.

All DNCG are treated in washers (one in the fibre line, one in evaporation and two in the causticising area). If burning in the recovery boiler is not possible, then the gases are vented to atmosphere via a 120 m high stack.

The collection of CNCG is 100 %, and the collection degree for DNCG is almost 100 %. For three months in a two-year period, the CNCG treatment availability was below 97 % but it still reached this target value when considering the calendar year as a whole. The treatment availability for DNCG treatment was comparable or even higher than for CNCG during the reported period although the permit requires only > 90 % availability, i.e. <10 % of the DNCG can be vented to the stack and thus into the atmosphere. An availability of 100 % means that the odorous gas treatment systems are on all the time and no odorous gases are vented into the atmosphere. The reasons for decreased availability in this example mill were equipment failures (e.g. April – July 2008, evaporation unit failure), other process problems and start-up time intervals.



Source: [42, Botnia Rauma 2009]

Figure 3.46: Example of permit requirements and achieved availability of an odorous gas treatment system

The verification of the effectiveness of the treatment system and the operational time that weak gases are vented out via the stack can be calculated by the process automation of the mill. Figure 3.46 shows an example of such a monitoring system.

Cross-media effects

In most cases, burning malodorous gases in a lime kiln results in an increase in the NO level. Developing low-NO_X technology for lime kiln burning when both malodorous gases and the main fuel are present will require additional measures [225, Hupa 2005]. However, many lime kilns that are oil-fired and burn CNCG achieve a NO_X concentration below 300 mg/Nm^3 (at 6 % O_2) as an annual average value (see Section 3.3.21.1).

The advantage of burning the odorous gas in the lime kiln is that no extra furnace is needed. The drawback is that sulphur in the gas can only be partially absorbed in the lime. This is because the main sulphur-absorbing compound in the lime kiln is the calcium carbonate ($CaCO_3$) in the lime mud which has a weak absorption capacity. When this capacity is exhausted, SO_2 increases when strong non-condensable gases are incinerated in the kiln. SO_2 emissions correlate with the amount of odorous gas flow. To minimise the formation of SO_2, either the sulphur content in the fuel can be reduced or the sulphur compounds can be scrubbed out of these gases prior to burning in the lime kiln.

An average of 10 – 15 % of the fuel used in a lime kiln can be replaced by the heat value of the CNCG. However, the variation in the amount of energy of the gas may make it difficult to hold lime of a good and uniform quality. Condensation of methanol after the stripper column can minimise the problem of varying gas quality, but requires additional investment.

Technical considerations relevant to applicability

Generally applicable.

Economics
No information provided.

Driving force for implementation
The reduction of odour and sulphur emissions. Legal requirements.

Example plants
Most mills in Europe: 22 European mills reported that they use the lime kiln for the treatment of CNCG. Another four mills reported that the lime kiln is used as back-up for the treatment of these gases [33, COM 2011]. Example plants that burn CNCG in the lime kiln are shown in Figure 3.71 and Figure 3.72.

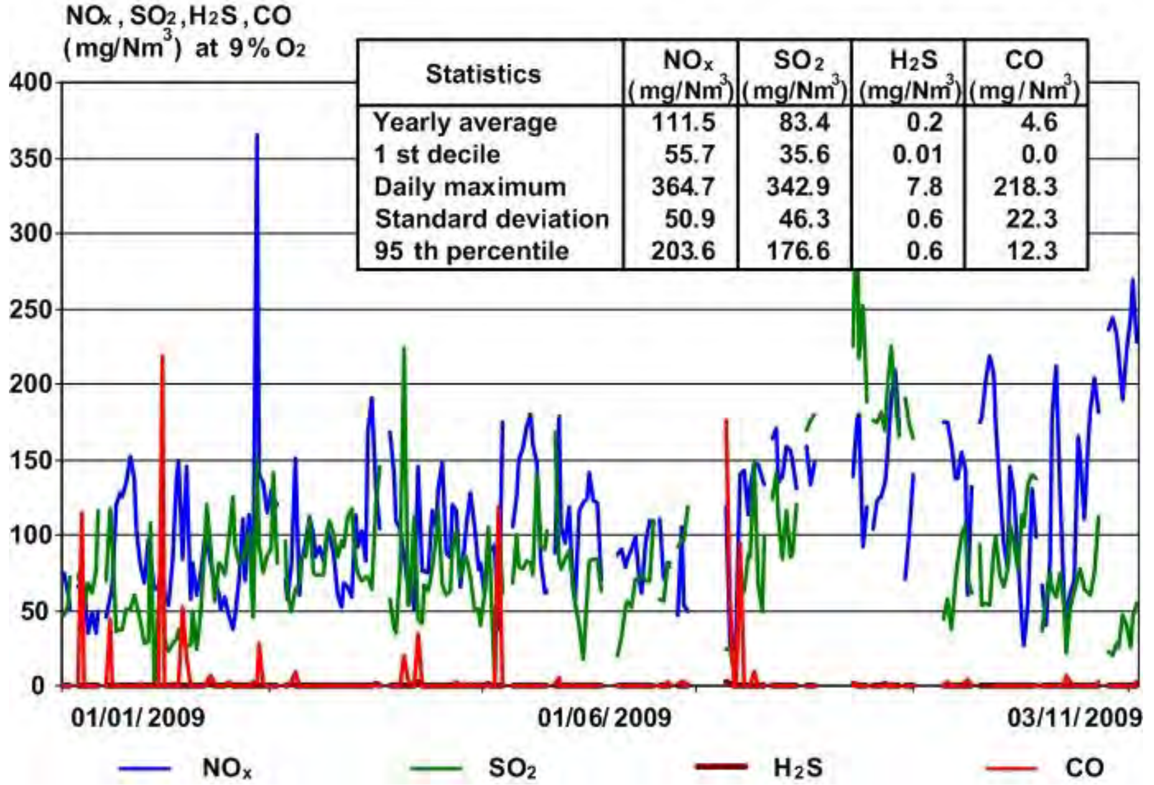
Reference literature
[33, COM 2011], [42, Botnia Rauma 2009], [64, J.Malmström 2010], [65, N.DeMartini et al. 2010], [66, FRBC 2010], [225, Hupa 2005].

3.3.16.3 Incineration of collected strong malodorous gases in a dedicated NCG burner equipped with scrubbers for SO_2 removal

Description and achieved environmental benefits
The incineration of non-condensable gases (see Sections 3.3.16.1 and 3.3.16.2) can also be carried out in a dedicated burner equipped with a SO_2 scrubber. The generated SO_2 can be scrubbed, e.g. by NaOH absorption, and the sodium bisulphite ($NaHSO_3$) generated can be used - instead of commercial SO_2 liquid - in the bleach plant for scrubbing bleach plant vent gases in order to remove residual chlorine compounds from the ClO_2 bleaching stages. Other mills use oxidised white liquor as washing liquid for the scrubber.

The dedicated NCG burner utilises the heat value of the CNCG to supply the boiler. The operation of a scrubber is described in Section 3.3.17.2.

Environmental performance and operational data
An example of achieved emissions to air from TRS burners for strong gases that are equipped with a steam boiler for heat recovery and scrubbers is given in Figure 3.47. The data are taken from the on-line transfer of emission data to the competent authority. Fuels for this boiler are light fuel oil, turpentine, methanol and the strong NCG. The weak gases are burnt in the recovery boiler in this case. The washing liquid for the scrubber is oxidised white liquor that is produced in the mill from white liquor (NaOH, N_2S) and oxygen (O_2). After being used in the scrubber, the white liquor and the absorbed sulphur compounds are sent back to the lime cycle. Dust emissions are below 5 mg/Nm^3 (at 9 % O_2).



Statistics	NO_x (mg/Nm³)	SO_2 (mg/Nm³)	H_2S (mg/Nm³)	CO (mg/Nm³)
Yearly average	111.5	83.4	0.2	4.6
1 st decile	55.7	35.6	0.01	0.0
Daily maximum	364.7	342.9	7.8	218.3
Standard deviation	50.9	46.3	0.6	22.3
95 th percentile	203.6	176.6	0.6	12.3

Source: Landesverwaltungsamt Halle, 2009, [173, J.Queiser 2009]

Figure 3.47: Emissions to air from a dedicated TRS burner equipped with a scrubber

In the example given, the pulp mill operates two independent, dedicated TRS burners for the incineration of the strong gases, thus guaranteeing process redundancy (reserve capacity in case of failures). The two burners use a joint steam boiler for heat recovery and a joint scrubber. Additionally, there is a torch in place in case of operational disturbances or system malfunctions. If there are still un-burnt strong gases in case of failures, they are released via the stack.

The weak gases are burnt completely in the recovery boiler. Because of the high volumetric rate of the weak gases, no back-up system is in place. Under normal operating conditions there are no odour problems recorded for the mill, the NCG burner of which is shown in Figure 3.47; for operational disturbances there are specific permit requirements to meet.

The emissions data collected from other NCG burners [33, COM 2011] show a similar performance, except some NCG burners that have significantly higher emissions.

Thirteen mills reported TRS (as S) emissions from the NCG burner equal to or below 5 mg/Nm^3 and SO_2 emissions below 100 mg/Nm^3 as annual average values. A few NCG burners have considerably higher emissions.

With regard to NO_X emissions, many mills have reported emissions from the NCG burner in the range of 100 – 300 mg/Nm^3 as an annual average (0.02 – 0.04 kg/ADt). However, other mills (6 mills in total) have reported considerably higher NO_X emissions from the NCG burner, between 1 400 mg/Nm^3 and 2 000 mg/Nm^3 as an annual average (or up to 0.2 kg/ADt). It is unclear why these emissions vary so significantly between different mills that fire very similar gas streams in the NCG burner. It is known that CNCG and condensate containing methanol contain a lot of ammonia and that the low-NO_X burner and proper air control have effects only on the thermal NO_X and not on the NO_X generated from nitrogen in fuel. These facts however apply just as much for the mills with the lower NO_X emissions as for the ones with higher NO_X emissions.

Cross-media effects
Incineration of odorous gases in a dedicated furnace may increase NO_X emissions if no countermeasure is taken (staged incineration, see Section 3.3.24.1).

Technical considerations relevant to applicability
The measure can be adopted in new and existing kraft mills.

Economics
No information provided.

Driving force for implementation
Reduction of odour and sulphur emissions. Legal requirements.

Example plants
SE Enocell, SE Imatra; SE Oulu, SE Sunila; UPM Kaukas; UPM Kymi Korsnäs AB, Frövi and many others; many mills also use a NCG burner as a back-up for the treatment of strong gases [33, COM 2011].

Reference literature
[33, COM 2011], [173, J.Queiser 2009].

3.3.17 Reduction of sulphur emissions (SO_2 and TRS) from the black liquor recovery boiler

3.3.17.1 Increasing the dry solids content of black liquor

Description
The most effective way to reduce both TRS and SO_2 emissions from kraft pulp mills is to run the recovery boiler with a high dry solids content. The sulphur content of CNCG and the fuel oil burnt in the recovery boiler are less significant for the reduction of SO_2 emissions.

a) SO_2 emissions
SO_2 emissions are formed mainly through the oxidation of H_2S and carbonyl sulphide (COS) in the lower furnace. The major source of gaseous sulphur emissions is the black liquor (see Table 3.12) and the sulphur content in additional fired streams such as CNCG. The emission levels are kept low by operating the boiler with a high black liquor dry solids content (higher temperature) and by optimising the combustion parameters such as air supply and mixing of air and fuel.

The emission of sulphur from the recovery boiler is influenced by the operating variables given below.

- Temperature in the different zones which is influenced by the dry solids content (heating value) of the strong black liquor and the amount of combustion air. With higher DS feedstock, the combustion temperature increases and causes more sodium (Na) to be vaporised which then takes up the SO_2 and forms Na_2SO_4, thus reducing SO_2 emissions from the recovery boiler. On the other hand, the fact that more sulphur is driven off in the evaporation when the dry solids content of the black liquor is raised could reduce the sulphur reaching the recovery boiler if the sulphur-containing odorous gases from evaporation are not burnt in the recovery boiler. A drawback to the higher temperature is that emissions of NO_X may increase.
- The sulphur to sodium ratio (S/Na_2) in the liquor (sulphidity). At higher sulphidity levels the release of sodium in the furnace in relation to the sulphur amount may not be sufficient to bind all the sulphur released and thus a share of the sulphur may leave the furnace as sulphur dioxide instead of sodium sulphate. The black liquor having a high dry solids contents may compensate this effect.

- Excess air supply, primary air temperature and distribution of combustion air.
- The load on the furnace. Operating a recovery boiler in an overloaded mode has an adverse effect on the SO_2 emissions characteristics. The load of the furnace is directly proportional to the temperature in the furnace, i.e. when the load of the furnace is changed, the temperature changes accordingly. In some boilers, the SO_2 emissions are sensitive to changes in load, i.e. SO_2 emissions may change due to the temperature changes in the furnace. SO_2 emissions may also increase when the boiler load is reduced. SO_2 emissions from other boilers (with very high DS) do not react to changes in the boiler load.

After conventional evaporation, the DS content in the strong black liquor is about 70 %. By installing a concentrator in the evaporation plant, a DS content of 80 % or above (85 %) can be achieved. The achievable DS content depends partly on the wood species (see Section 3.1.11).

b) TRS emissions

The emission of total reduced sulphur (TRS) from the recovery boiler is influenced by almost the same operating variables as the SO_2 emissions.

- Dry solids content. Due to firing black liquor with a high dry solids content there is enough sodium in the flue-gases to bind almost all the sulphur formed in black liquor combustion. Sulphur emissions are very low or even undetectable in fully loaded and stably operated boilers. And if there is enough sodium to bind all the sulphur virtually no SO_2 emissions are released.
- Load on the furnace. The load of the furnace is directly proportional to the temperature in the furnace. Operating a recovery boiler in an overloaded mode may have an adverse effect on the emissions characteristics, especially on the quantity of hydrogen sulphide produced. Rapid changes in the operation mode may generate some momentary TRS peaks. TRS emissions from boilers with a very high dry solids content do not react to changes in the boiler load.
- Air distribution. The main controlling factor for the TRS emissions from the recovery boiler furnace is the mixing of oxygen and sulphur-containing gases. If the gases are well mixed they are converted to SO_2. Modern air systems help to achieve sufficient mixing.

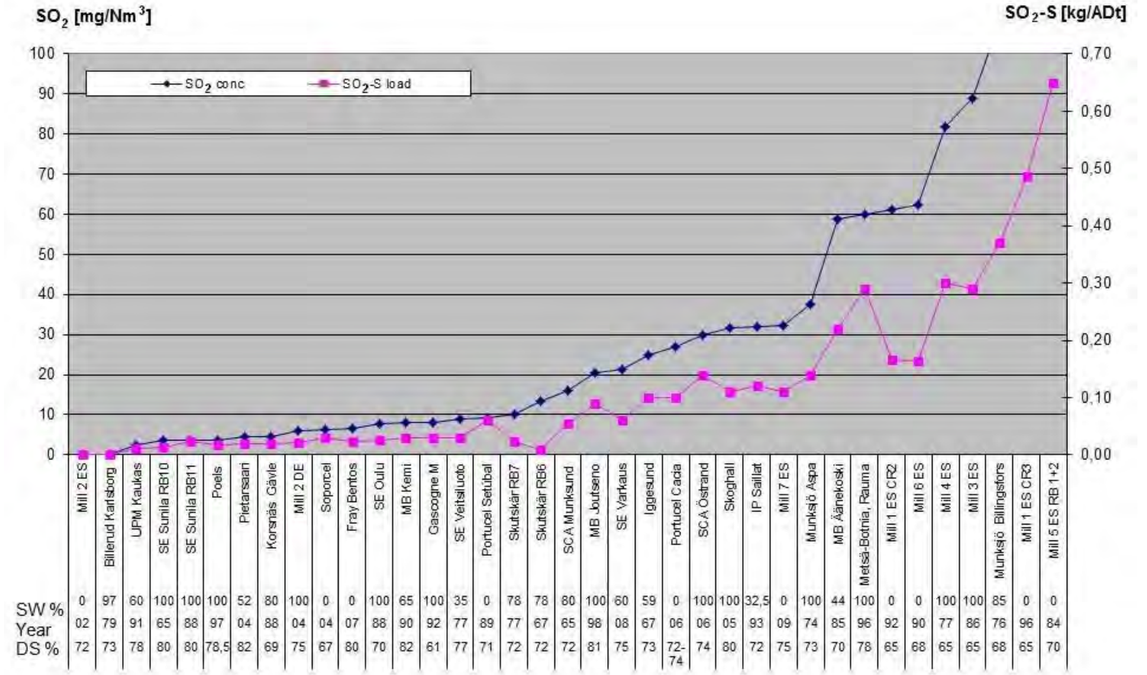
Achieved environmental benefits

Reduction of sulphur emissions and maximised electricity production.

Environmental performance and operational data

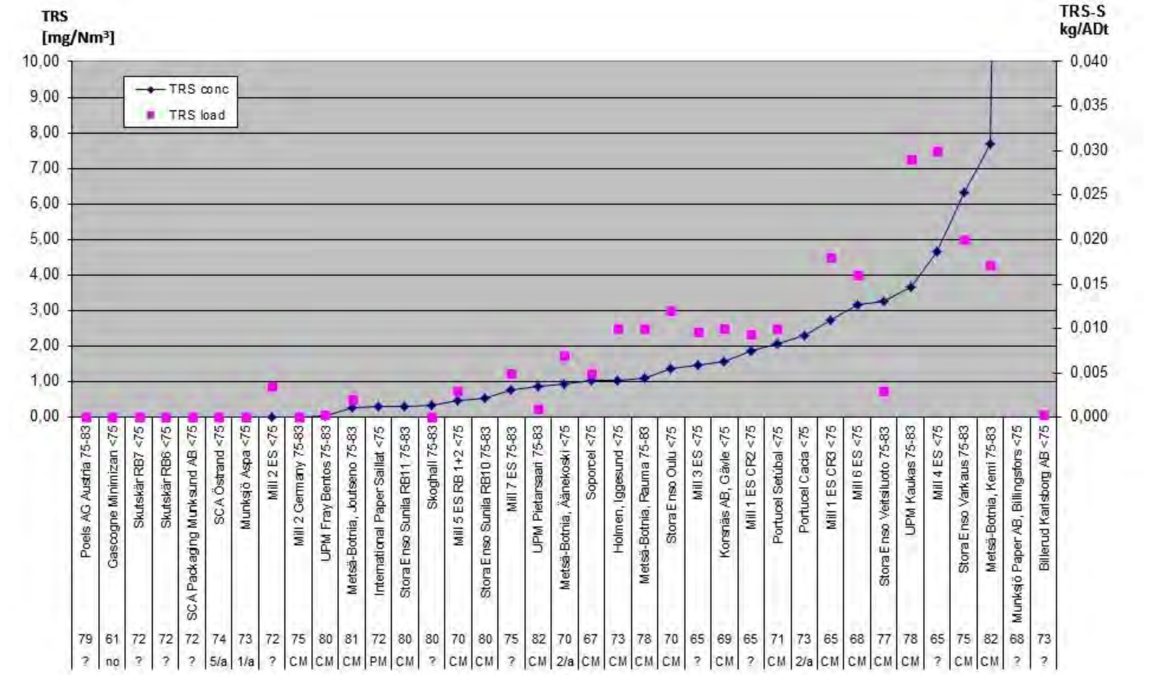
When boilers burn black liquors with a high DS content (about 80 %), SO_2 emissions are very low or even zero when the boiler is running in a steady state [207, T.Tamminen, et al. 2002]. The SO_2 produced in the furnace reacts with sodium compounds to produce sodium sulphate. With high solids firing, there is enough sodium to bind all sulphur dioxide. However, there are normally still some peak emissions due to unstable operational conditions (see also Section 3.2.2.6.1).

Figure 3.48 and Figure 3.49 show the annual average SO_2 and TRS (some mills reported H_2S only) emissions from recovery boilers fired with varying dry solids contents. For all mills that provided data, both the concentration values (mg/Nm^3, 6 % O_2) and emission loads (kg S/ADt) are plotted. Dry solids contents below 73 %, between 73 % and 80 %, and above 80 % are indicated.



Source: questionnaire launched by EIPPCB in February 2011 [33, COM 2011]

Figure 3.48: **SO_2 emission concentrations and loads from recovery boilers with different dry solids contents (%) of black liquor and different softwood/hardwood use**



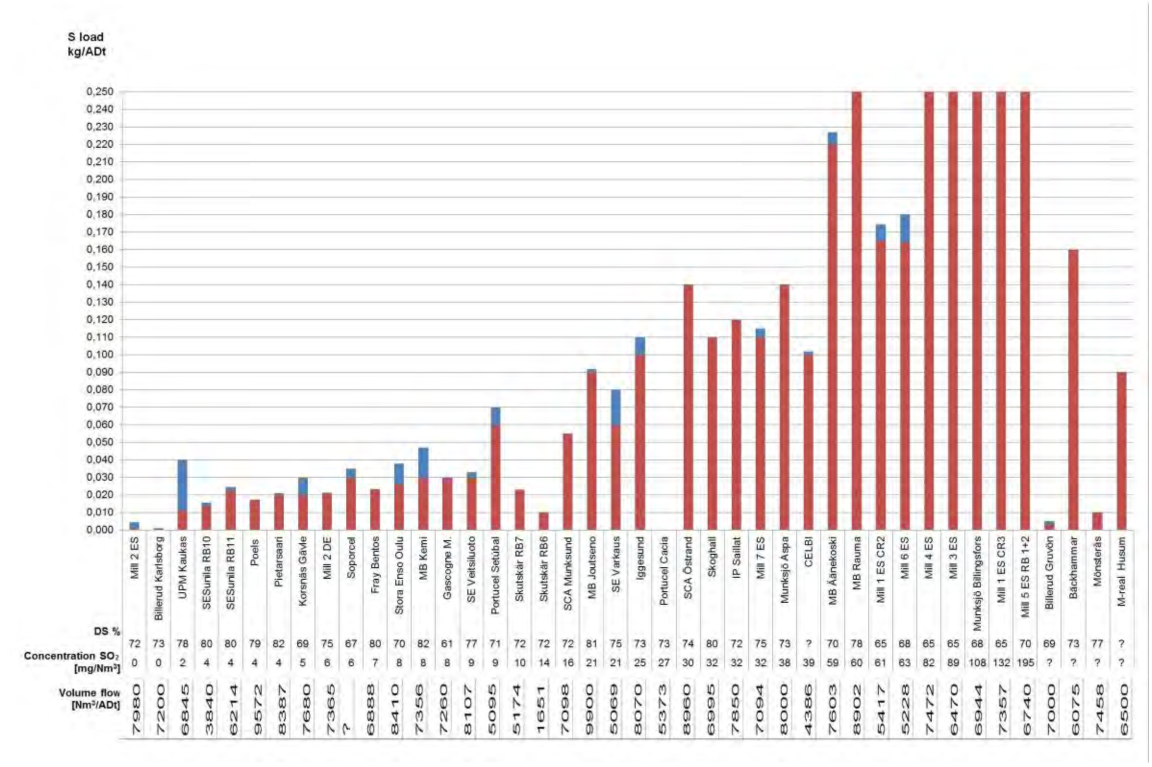
NB: CM = Continuous monitoring; PM = Periodic monitoring; ? = No information on type of monitoring

Source: questionnaire launched by EIPPCB in February 2011 [33, COM 2011]

Figure 3.49: **TRS-S emission concentrations and loads from recovery boilers with different dry solids contents (%) of black liquor and different softwood/hardwood use**

The data confirm that TRS emissions from the recovery boiler are very low or even zero when the boiler is running in a steady state. Normally, there are a number of peaks during the year. Most mills achieve emissions of <5 – 25 mg SO_2/Nm^3 or 0.01 – 0.10 kg SO_2-S/ADt of pulp. It can also be seen that firing high dry solids is an effective measure for low-sulphuric emissions from recovery boilers. Scrubbers are not needed to achieve these results. Normally some SO_2 peaks are measured during the year (see Figure 3.51).

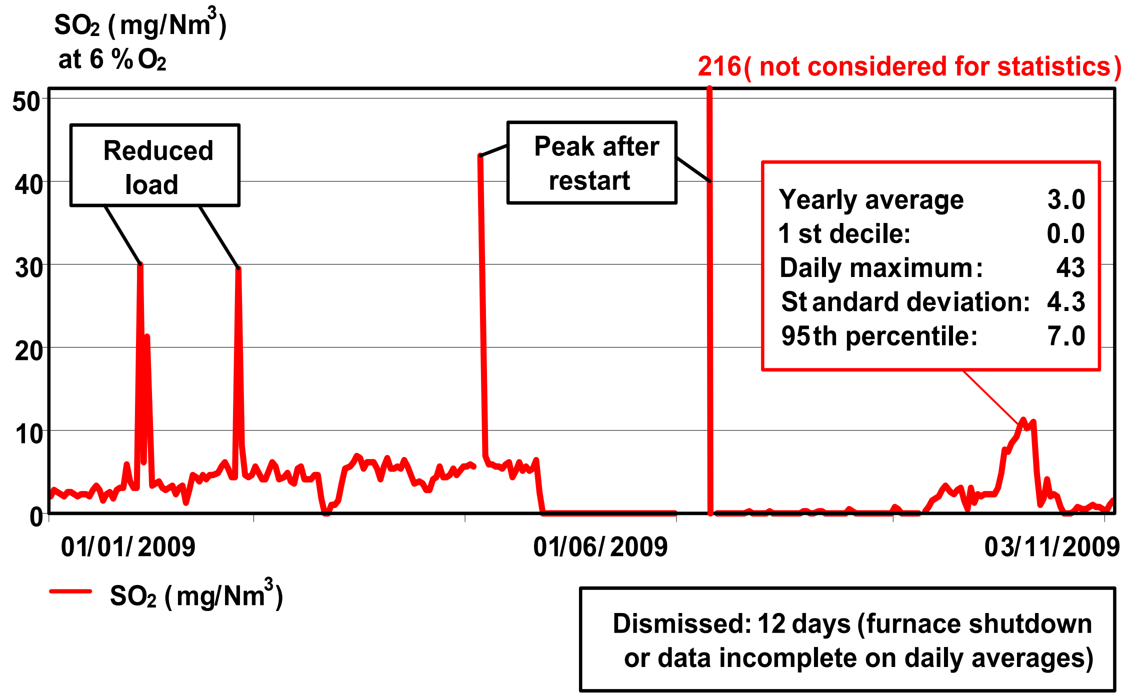
Reported total gaseous S emissions (TRS-S + SO_2-S) are shown in Figure 3.50.



Source: EIPPCB questionnaires from 2007/2009 and other TWG input

Figure 3.50: Gaseous S emissions from recovery boilers with the corresponding dry solids content (%) of black liquor, SO_2 concentration and waste gas flow

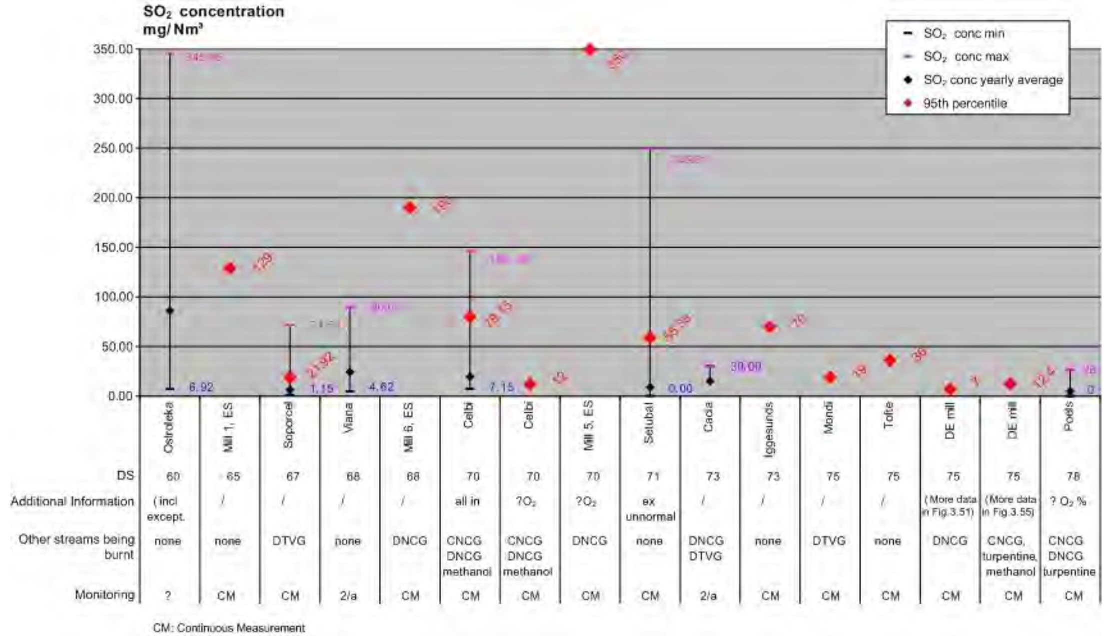
An example for the daily average SO_2 emissions data over a full year (dry gas, 273 K, 6 % O_2) of a mill that runs the recovery boiler with a DS content of 75 % is shown in Figure 3.51. The fuels are black liquor, and low-sulphur fuels (natural gas and light fuel oil) as a supporting fuel, and the weak malodorous gases. The data are taken from the on-line transfer of emission data to the competent authority (*Source*: Landesverwaltungsamt Halle, 2009, DE). SO_2 is measured continuously. H_2S emissions were below 1 mg/Nm^3 during the whole year. The yearly average value of 3 mg/Nm^3 in this existing example gives a yearly SO_2 load of 0.03 kg/ADt.



Source: [173, J.Queiser 2009]

Figure 3.51: **Continuously measured daily average data for SO_2 emissions from a kraft pulp recovery boiler**

The reported short-term SO_2 and TRS emissions are shown in Figure 3.52 and Figure 3.53.

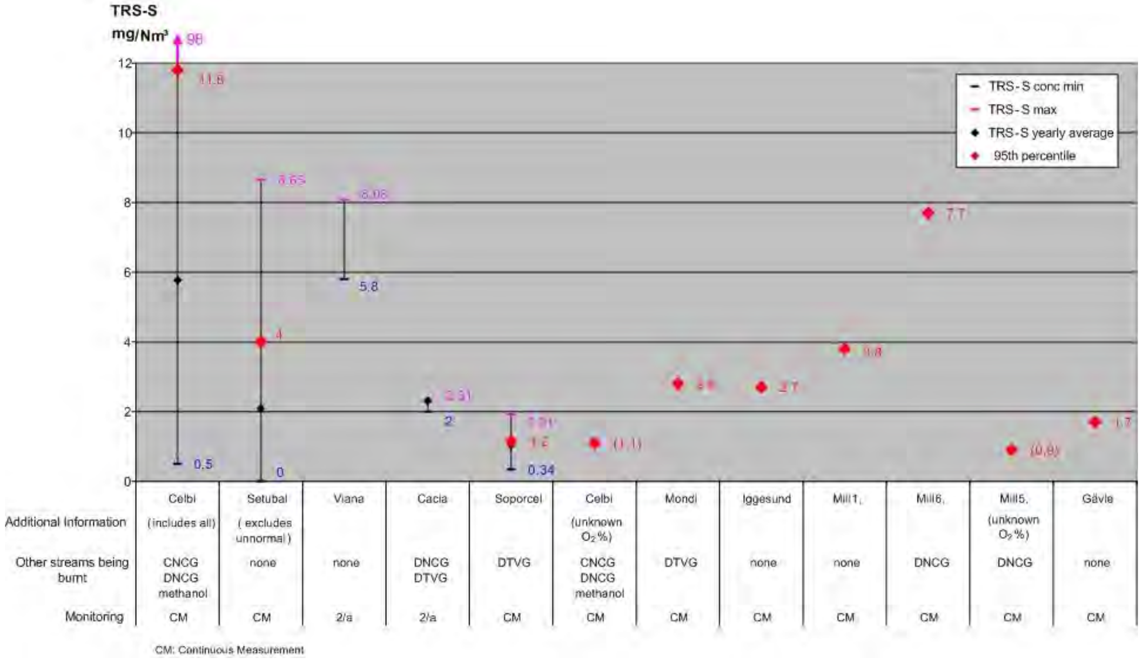


	Ostroleka	Mill 1, ES	Soporcel	Viana	Mill 6, ES	Celbi	Celbi	Mill 5, ES	Setubal	Cacia	Iggesunds	Mondi	Tofte	DE mill	DE mill	Poels
DS	60	65	67	68	68	70	70	70	71	73	73	75	75	75	75	78
Additional Information	(incl except.	/	/	/	/	all in	?O₂	?O₂	ex unnormal	/	/	/	/	(More data in Fig.3.51)	(More data in Fig.3.55)	? O₂ %
Other streams being burnt	none	none	DTVG	none	DNCG	CNCG DNCG methanol	CNCG DNCG methanol	DNCG	none	DNCG DTVG	none	DTVG	none	DNCG	CNCG, turpentine, methanol	CNCG DNCG turpentine
Monitoring	?	CM	CM	2/a	CM	CM	CM	CM	CM	2/a	CM	CM	CM	CM	CM	CM

NB: CM = Continuous monitoring; PM = Periodic monitoring; ? = No information on type of monitoring

Source: EIPPCB questionnaires from 2007/2009 and other TWG input

Figure 3.52: **SO_2 emissions from the recovery boiler as short-term average**



NB: CM = Continuous monitoring; PM = Periodic monitoring; ? = No information on type of monitoring

Source: EIPPCB questionnaires from 2007/2009 and other TWG input

Figure 3.53: **TRS emissions from the recovery boiler as short-term average**

Cross-media effects

Increasing dry solids increases furnace temperatures and decreases sulphur emissions, but increases NO_X emissions if no countermeasure is taken (see Section 3.3.17.2). Running recovery boilers with a high dry solids content and high furnace temperatures maximises the electricity production from the boilers (high pressures and temperatures).

The reduction of sulphur emissions by a high DS content increases the emissions of particulates prior to flue-gas cleaning. To compensate for this, a more efficient and expensive electrostatic precipitator has to be installed. At a very high DS content (>80 %) there is a considerable release of sulphur compounds from the last evaporator stage, which have to be collected and incinerated.

Technical considerations relevant to applicability

The process can be applied at both new and existing kraft mills. A superconcentrator can also be implemented as a separate phase to existing evaporation plants. Viscosity problems can be handled with pressurised storage or heat treatment before the last concentrator.

Economics

In existing mills the cost of improving the evaporation and concentration of strong black liquor is tied to the target concentration. At existing mills with 1 500 ADt/d kraft pulp production, the investment required for increased black liquor concentration from 63 % upward is as follows:

- concentration from 63 % to 70 %, EUR 1.7 – 2.0 million;
- concentration from 63 % to 75 %, EUR 3.5 – 4.0 million;
- concentration from 63 % to 80 %, EUR 8.0 – 9.0 million.

Increasing the dry solids content does not increase operating costs, and indeed significant savings are possible. The measure increases the energy economy of the mill and leads to gains in the recovery boiler capacity.

Driving force for implementation

Legal requirements and increased process efficiency.

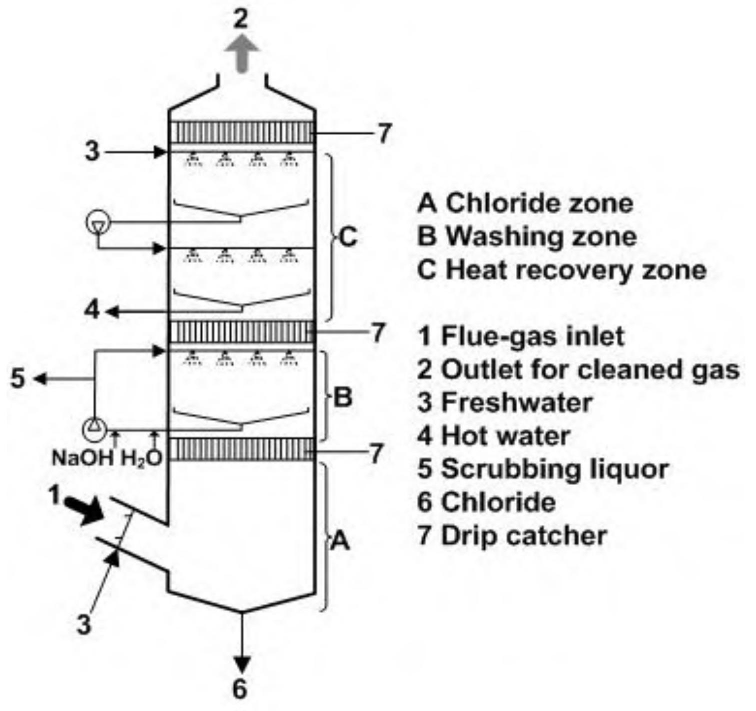
Example plants
The Finnish recovery boilers are, on average, firing close to 80 % dry solids; and Swedish recovery boilers are, on average, firing close to 70 % dry solids [66, FRBC 2010].

Reference literature
[1, Finnish BAT Report 1997], [33, COM 2011], [66, FRBC 2010], [173, J.Queiser 2009], [207, T.Tamminen, et al. 2002].

3.3.17.2 Installation of scrubbers on the recovery boiler

This measure can be applied as an alternative to the technique in Section 3.3.17.1. It is also a measure to further reduce the emission of particulate matter (see Section 3.3.19) or to recover heat.

Description
Wet scrubbing is a technology used to remove sulphur dioxide (SO_2) from the exhaust flue-gases of recovery boilers. A kraft recovery boiler scrubber of the wet type may include three process stages (see Figure 3.54 from the bottom upward).



Source: [127, SEPA report 1992]

Figure 3.54: Flue-gas scrubber for recovery boilers

Chloride is absorbed by cold water introduced in the flue-gas inlet. The chloride efficiency is normally 60 – 70 %. In the washing zone, SO_2 and particulates are removed. Scrubbing takes place at a pH of 6 – 7. The pH value is controlled with the addition of sodium hydroxide, weak liquor or oxidised white liquor. SO_2 reacts with the scrubbing liquor and Na_2SO_3 and also some Na_2SO_4 are formed. TRS in the form of H_2S can be removed together with SO_2. However, to remove hydrogen sulphide from the flue-gases, a scrubbing liquor with a high pH would be required. At such a high pH, carbon dioxide would also be absorbed, which is unrealistic due to the relatively large amounts of carbon dioxide being formed in the combustion.

Surplus liquor from the scrubber is recycled to the process, normally to the white liquor preparation.

Achieved environmental benefits
Reduction of sulphur emissions.

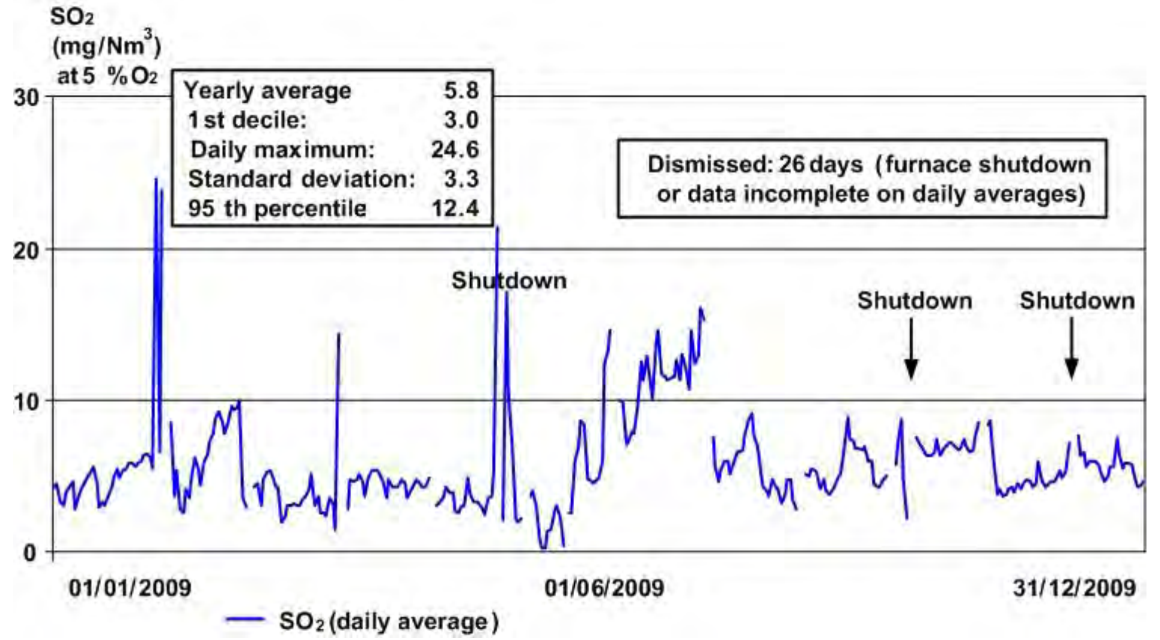
Environmental performance and operational data

Wet scrubbers are used at about one third of the recovery boilers.

However, if utilised, the reason is often also heat recovery. The removal efficiency of wet scrubbers for SO_2 is typically >90 %. According to the data gathered, the same performance for SO_2 reduction can be achieved by high dry solids content firing and by wet scrubbing the flue-gas.

For those mills that have higher SO_2 emissions even when running the recovery boiler at a high dry solids content (e.g. because of boiler overload), a scrubber can be a measure to reduce these emissions.

Figure 3.55 shows the variation of emissions over a complete year. The data are taken from company's internal on-line measurement data. The fuels used in the recovery boiler are black liquor (approximately 75 % DS), strong malodorous gases (approximately 3 kg S/ADt) and a mixture of turpentine and methanol. The washer in this example normally uses only water as the washing liquid; if the pH value in the water decreases to <7 (i.e. SO_2 emissions would increase in the stack), NaOH is added to the scrubbing liquid in order to control the sulphur emissions. The annual average emission load of this mill in 2008 was 0.014 kg SO_2/ADt (*Source*: questionnaire, 2008). Continuous SO_2 measurement prior to and after the scrubber is needed to control the operation of the scrubber.



Source: [172, A.Schweizer 2010]

Figure 3.55: **Continuously measured daily average data of SO_2 emissions of a kraft pulp recovery boiler equipped with an ESP and a scrubber**

Cross-media effects
By introduction of fresh water in the top of the scrubber, hot water can be produced (if there is a need). The water is normally clean enough to be used as wash water in the bleach plant. The scrubber needs alkali in the form of oxidised white liquor, weak liquor or sodium hydroxide, which can increase the capacity demands on the recovery department.

Technical considerations relevant to applicability
Installation of a scrubber is preferably done at the same time a new boiler is installed, although at a much higher cost existing boilers can also be equipped with scrubbers. Recovery boilers burning high DS black liquor normally have very low-sulphur emissions, which makes the installation of the scrubber less beneficial. It can also be used for the further decrease of emissions of particulate matter or to recover heat.

Economics
The equipment usually comes as a package from the supplier. The investment required for a bleached kraft mill with a production capacity of 250 000 and 500 000 t/yr amounts to EUR 7.2 million and EUR 10.4 million respectively. It includes the scrubber, scrubber liquor pumps, circulation pumps, electrification and instrumentation. The operating costs amount to EUR 580 000 EUR/year and EUR 920 000/year.

Driving force for implementation
Reduction of SO_2 emissions. Heat recovery. Dust removal in some cases. In pulp mills that run the recovery boiler with a high DS content the SO_2 emission can be substantially reduced and, for such mills, there is little need to install scrubbers. The internal energy situation of the mill might or might not require warm water production in the scrubber. In a modern kraft recovery boiler, especially if it operates on high DS, the H_2S is normally not a problem that needs scrubbing to resolve. Scrubbers can also be used as a second part of a two-stage dust removal facility (ESPs and wet scrubbers).

Example plants
Scrubbers have been installed in numerous recovery boilers in Europe.

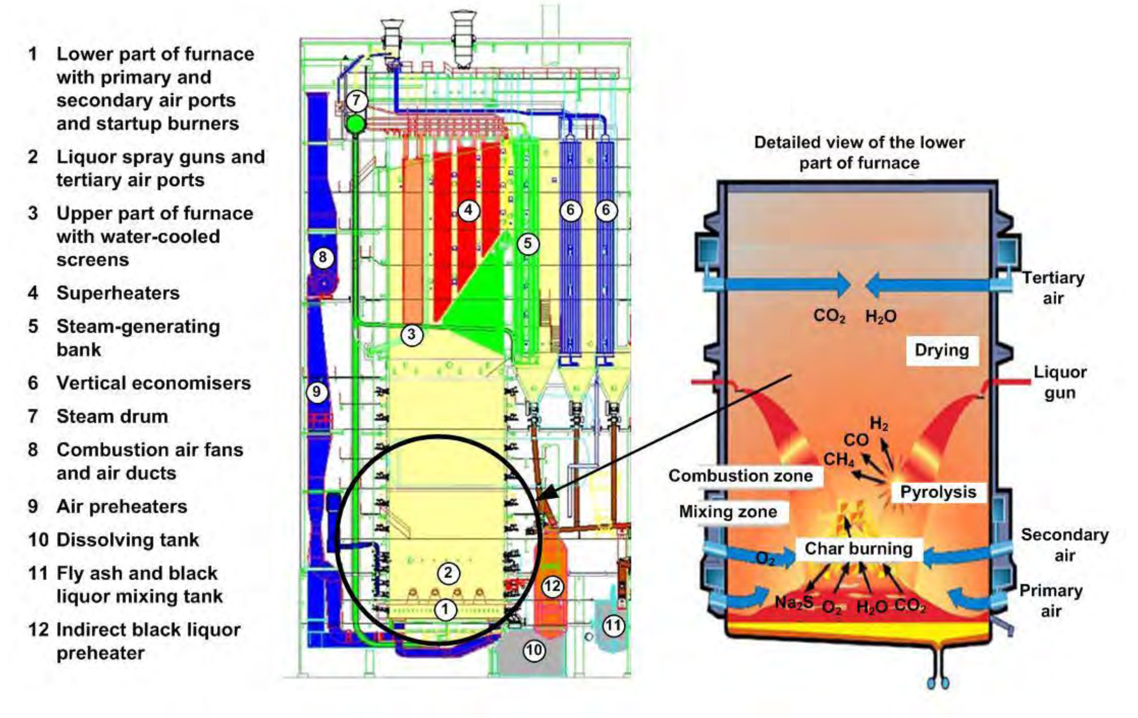
Reference literature
[127, SEPA report 1992], [131, SEPA report 1997], [172, A.Schweizer 2010].

3.3.18 Control of NOX emissions from black liquor recovery boilers

3.3.18.1 Optimised combustion control and control of the NO_X-influencing factors

Description
The complex nature of the combustion chemistry and the gas flows in a black liquor recovery boiler on the one hand limits the possibilities for reducing NO_X emissions, but on the other also offers some margin to reduce emissions. With proper combustion control and an improved air system (see Section 3.3.18.2), NO_X emissions can be reduced.

A typical modern recovery boiler from a kraft pulp mill is shown in Figure 3.56. The magnified picture on the right shows the basic principles of the combustion of black liquor in the lower furnace. Typically, combustion air is introduced through primary, secondary and tertiary air ports (and a quaternary air level in a few cases), but there are several different variations in the air systems. The number of secondary and tertiary levels may vary as well as the elevations or the respective location of the air ports. The black liquor is sprayed into the combustion zone by liquor guns. The start-up burners are located on the secondary air level and are fuelled by gas or fuel oil. In many recovery boilers the strong odorous gases (CNCG) are introduced into the furnace below the liquor guns. The diluted non-condensable gases (DNCG) are introduced either into the secondary or tertiary air level of the furnace. In the lower furnace a char bed is built. The smelt exits through the smelt spouts to the dissolving tank. The heat from combustion is recovered by the heat transfer surfaces before the gases enter the electrostatic precipitator (ESP).

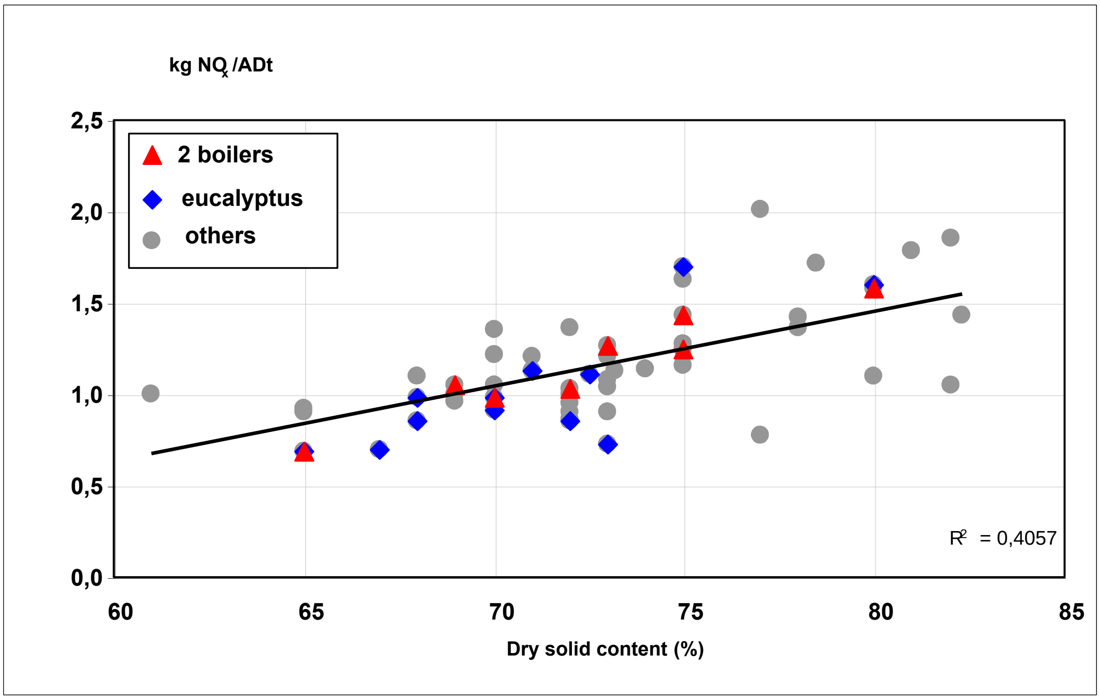


Source: Andritz, Metso

Figure 3.56: Complete view of a boiler and schematic view of the lower and middle part of the furnace of a recovery boiler of a kraft pulp mill

Factors that influence the emissions of nitrogen oxides (NO_X) from recovery boilers include the following [58, K.Grönblad et al. 2000], [61, Wallén et al. 2002], [64, J.Malmström 2010], [65, N.DeMartini et al. 2010], [66, FRBC 2010], [225, Hupa 2005], [226, Vakkilainen et al. 2005].

(a) **Dry solids content of the black liquor**. Increasing the black liquor dry solids (e.g. from 75 % to 85 %) increases the lower furnace temperature, reduces gas flow and may lead to increased NO_X emissions expressed both as concentrations and emission loads. Higher temperatures simultaneously minimise sulphuric emissions and maximise steam and electricity generation. A careful weighing of different emissions is needed. Figure 3.57 shows the regression line which shows the 'best fit' relationship between the dry solids content (%) and specific NO_X emission load from 30 different recovery boilers. Some of the mills run two recovery boilers (2 boilers in the graph).

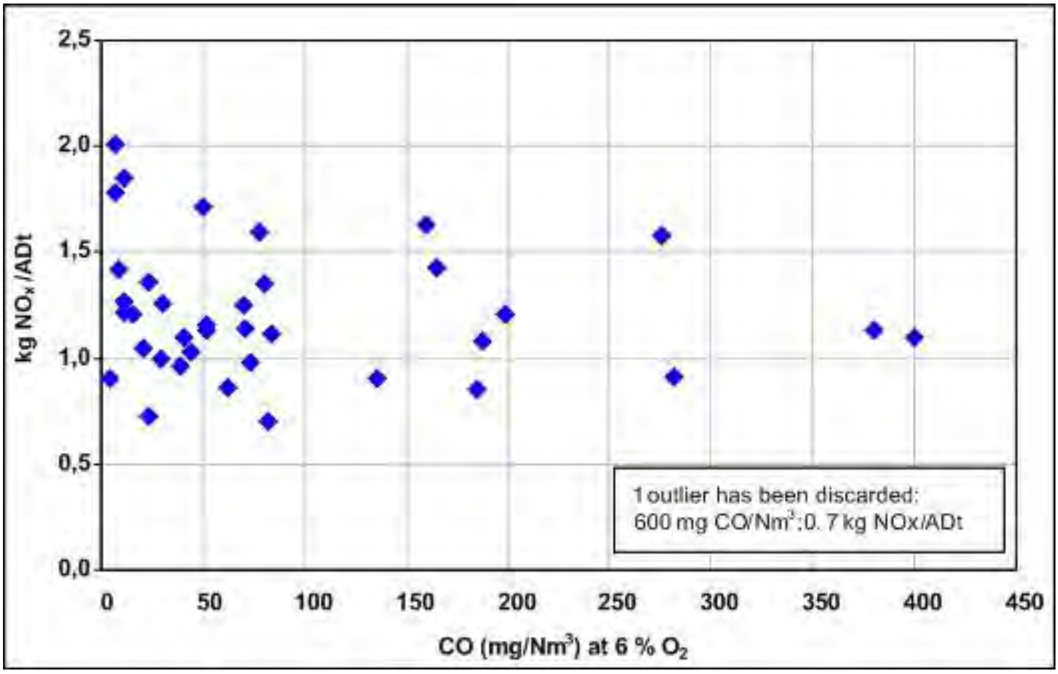


Source: results of a questionnaires launched by EIPPCB in February 2011 [33, COM 2011]

Figure 3.57: Specific NO_X emission load (kg NO_2/ADt) from recovery boilers as a function of black liquor dry solids content (%)

(b) **Excess O_2 and CO content during combustion.** There is a correlation between NO_X emissions and the concentration of O_2 and CO in the flue-gas of the recovery boiler. To minimise the NO_X emissions, it is important to optimise the input of air in the combustion chamber. The end burning should take place in the upper part of the combustion chamber, where the temperature is lower. Low excess air for combustion and moderately elevated CO levels tend to reduce NO_X emissions.

If the air ratio is decreased below about 2 % then NO_X decreases, but CO starts to increase dramatically. If O_2 is further decreased then TRS also is increased. A carbon monoxide concentration in the range of 250 – 500 ppm leads to significantly lower NO_X formation. Keeping the CO levels <50 – 100 mg CO/Nm^3 maintains emissions of VOC and polyaromatic hydrocarbon (PAH) low and simultaneously allows low NO_X emissions to be achieved, as confirmed by Figure 3.58.



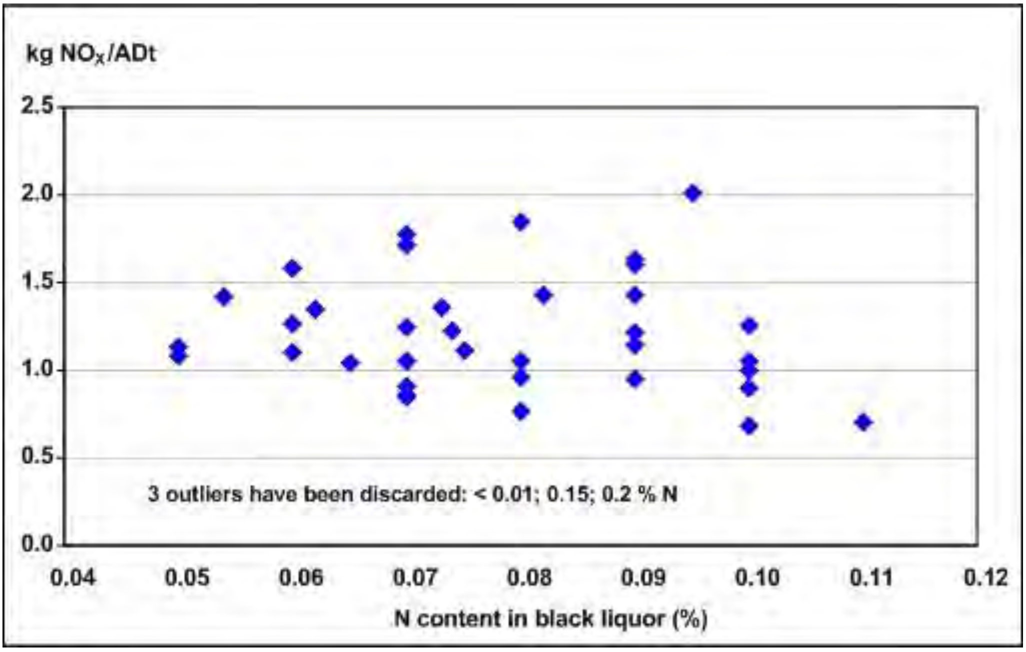
Source: results of the questionnaire launched by the EIPPCB in February 2011 [33, COM 2011]

Figure 3.58: Relationship between the CO concentration and the specific NO_X emission from black liquor recovery boilers

(c) **The air system design and design of the boiler (number and location of air ports and air levels).** Some of the recovery boilers have the possibility to install new air levels (see Section 3.3.18.2), but some do not when the recovery boiler is running at full capacity. All new boilers have an advanced air system to minimise the NO_X emissions. The mills with the newest recovery boilers have reduced their emissions from the recovery boilers by 20 – 30 %.

(d) **Nitrogen content in the DS black liquor.** The nitrogen content of the black liquor has a direct influence on the NO_X level of the black liquor recovery boiler. Around 30 % of the nitrogen in the black liquor is converted into NO_X. In normal operating conditions, it is difficult to achieve lower than 30 % conversion to NO_X. Hardwood generally contains more nitrogen than softwood. Therefore, softwood black liquor results in around 20 % lower NO_X emissions than hardwood.

A Swedish study [62, Hedenberg 1996] shows that hardwood contains ~370 g N/m^3 svb (solid volume excluding bark) and softwood contains ~225 g N/m^3 svb. For kraft pulp production the wood consumption is ~4 m^3 svb of hardwood and ~5 m^3 svb of softwood to produce one tonne of pulp. The input to the kraft pulp mill will be ~1 480 kg N/ADt for hardwood and ~1 120 kg N/ADt for softwood. About 90 – 95 % of this nitrogen is dissolved in the digester and follows the black liquor to the recovery boiler. In the recovery boiler, about 25 – 35 % of the nitrogen is transformed to NO_X and the rest to N_2. This would theoretically result in NO_X emissions that are approximately 30 % higher from hardwood production than from softwood production. Emissions from different real recovery boilers however do not confirm this, as shown in Figure 3.59. This is possibly because the N content of black liquor has often been reported giving relatively large ranges.



Source: [33, COM 2011]

Figure 3.59: Relationship between the N content in black liquor (%) and the NO_X emission load from recovery boilers

(e) **Combustion of CNCG in the recovery boiler** (alternatives are the lime kiln or a dedicated CNCG burner). Although NCG contain nitrogen, experience also shows that proper combustion of CNCG in the recovery boiler does not necessarily increase NO_X emissions. In most cases, burning CNCG in a lime kiln results in a significant increase in the NO emission from the mill.

(f) **Burning other N-containing fuels**. Fuels such as condensate containing methanol, dissolving tank vent gases (DTVG) or biosludge burnt in the recovery boiler may increase the NO_X emissions.

(g) **Black liquor recovery boiler furnace load.** The black liquor recovery boiler load has a considerable effect on NO_X emissions; a lower furnace load means reduced furnace temperature and enables better combustion control. A boiler that is operated above the design load normally produces higher emissions. Three major cases can be distinguished:

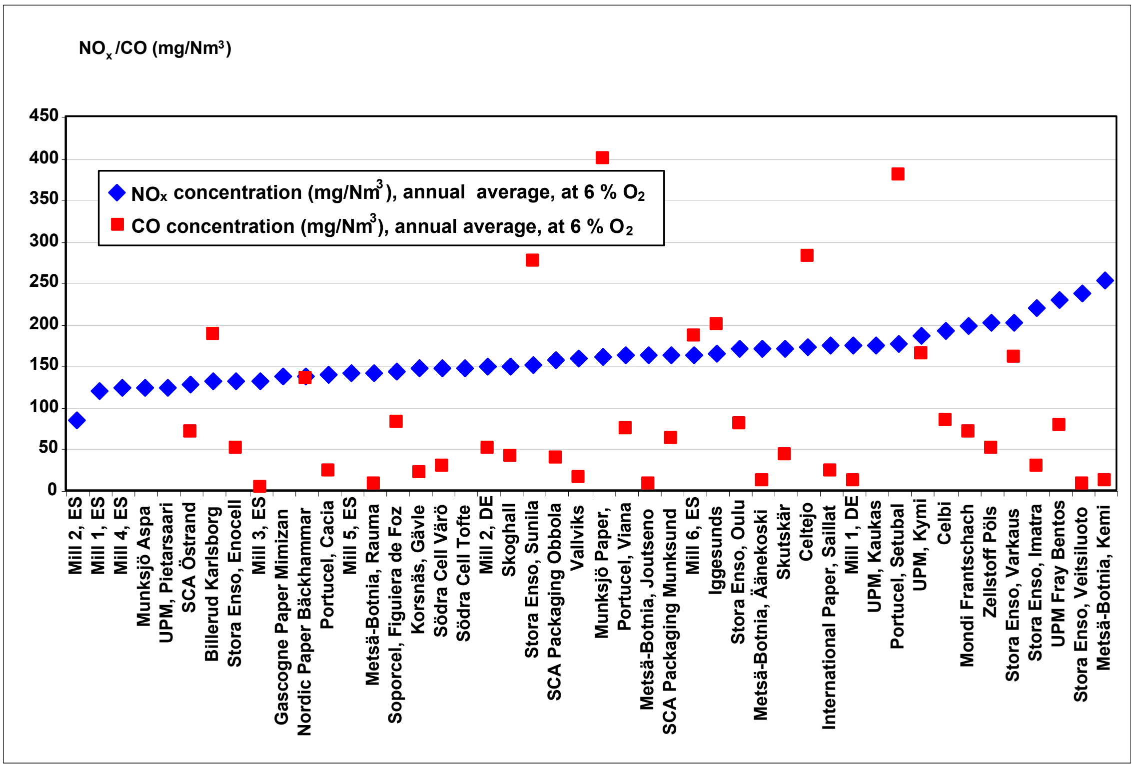
   i. High load where the air system is overloaded; there are minimum control possibilities; the retention times are too short, temperatures are high and a high conversion to NO_X is observed.
   ii. Normal load where the air system operation can be optimised and all air levels are used effectively; there are optimal retention times and optimal temperatures, and a minimum conversion to NO_X is observed.
   iii. Low load where the furnace has a low air demand; the upper air levels are not in use; there are long retention times and low temperatures. A moderate conversion to NO_X is observed.

(h) **Pulp yield.** A higher yield gives lower specific emission loads (kg NO_X/ADt): Unbleached pulp has a higher yield, i.e. generates less black liquor per manufactured tonne of pulp than bleached pulp, which gives lower specific emission loads - even if in both cases the black liquor recovery boiler has about the same NO_X concentration in the stack. The same effect applies for softwood and hardwood pulping, and especially for eucalyptus pulping (higher yield).

Depending on the boiler, NO_X emission can be controlled by optimising the above-mentioned factors. A prerequisite for low emissions is the continuous measurement and adjustment of the relevant combustion parameters (O_2, CO, temperature, gas flow, NO_X, SO_2, load of the boiler, fuels). The design of the recovery boiler and optimised air system can lower the CO and NO_X concentrations to a certain extent.

Achieved environmental benefits
The technique lowers NO_X emissions and attempts to control the CO emissions simultaneously.

Environmental performance and operational data
Figure 3.60 and Figure 3.61 summarise the NO_X emissions from the black liquor recovery boilers of European kraft pulp mills that filled in the questionnaire on air emissions from kraft pulp mills launched by the EIPPCB in February 2011. Some mills only reported specific NO_X loads. Because of the differences regarding the flue-gas flow, the NO_X concentration does not always correlate with the corresponding specific NO_X emission. In Figure 3.60, the annual average NO_X concentration values are plotted with the corresponding annual average CO emissions (at 6 % O_2).



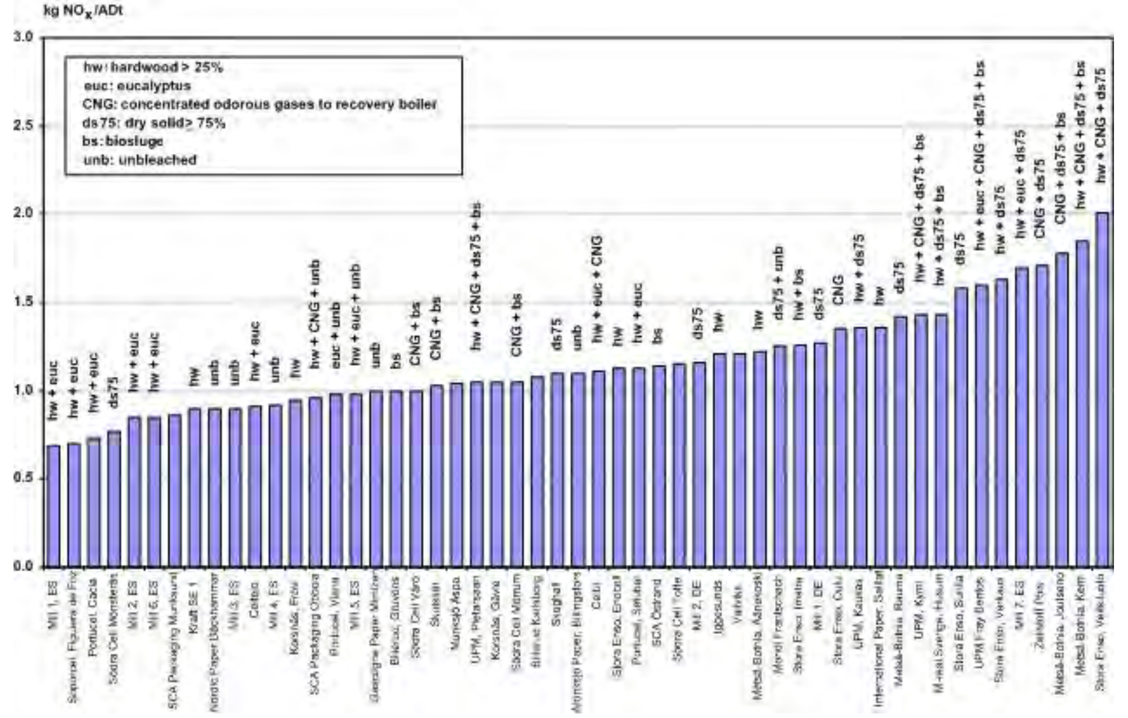
Source: [33, COM 2011]

Figure 3.60: NO_X concentration (as NO_2), at 6 % O_2 from black liquor recovery boilers

Depending on the determining factors discussed above, NO_X emissions between <140 mg/Nm^3 and 230 mg/Nm^3 (6 % O_2 content) as yearly average values were reported. In most cases, these levels were achieved with CO concentrations between <25 mg/Nm^3 and 200 mg/Nm^3 as a yearly average at 6 % O_2 content. There is relatively little variation for NO_X values and only a few strong peak values occur (see Figure 3.62, Figure 3.65 and Figure 3.66).

Figure 3.61 shows the specific NO_X emission from the pulp mills that provided data. Relevant NO_X -influencing factors are also given (dry solids content higher than 75 %, higher share of hardwood, incineration of CNCG and of biosludge in the black liquor recovery boiler). As illustrated, all recovery boilers that have higher specific emissions than 1.5 kg NO_X (as

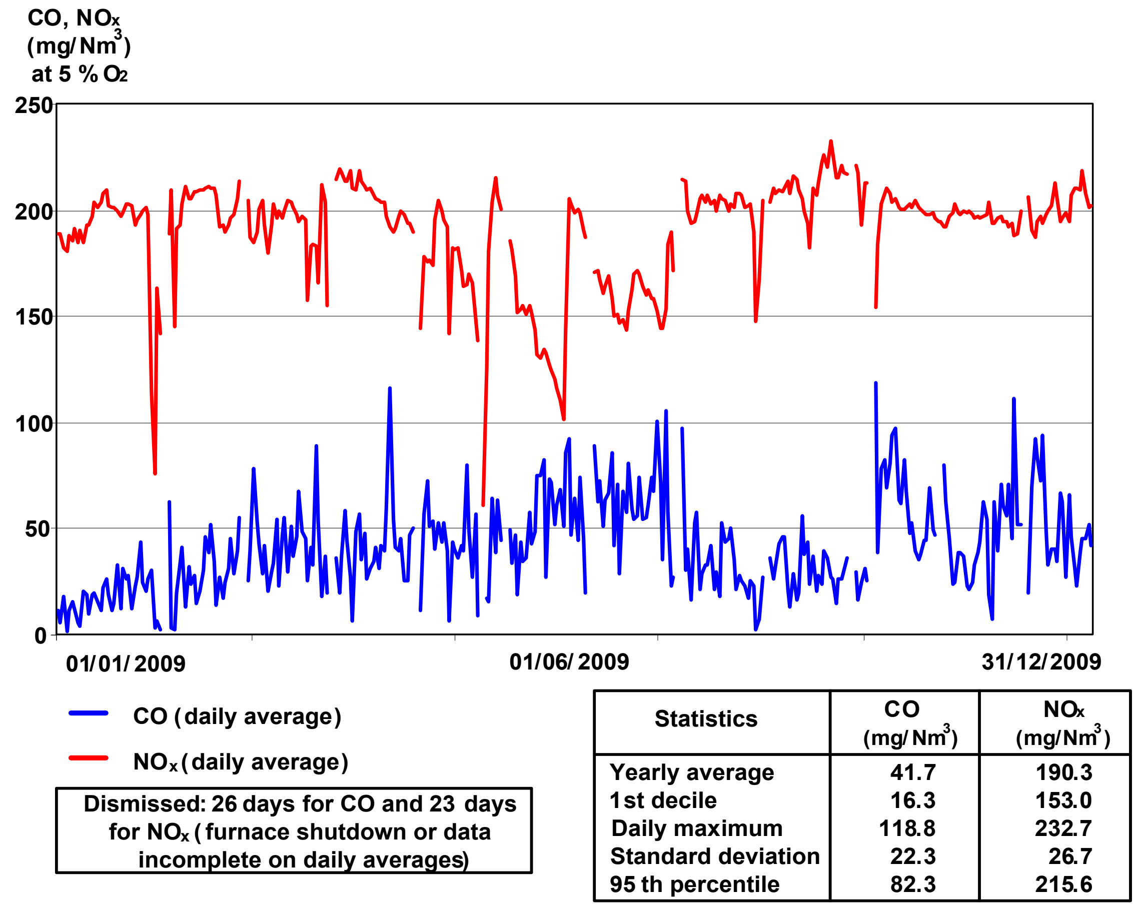
NO_2)/ADt combine two or more of these adverse factors. On the other hand, counterexamples are also shown that are more difficult to explain.



Source: [33, COM 2011]

Figure 3.61: Specific NO_X emissions from black liquor recovery boilers

An example of the emission profile of a recovery boiler with three air levels that burns black liquor (approximately 75 % DS), CNCG and a mixture of methanol and turpentine is shown in Figure 3.62. The specific NO_X emission is 1.5 kg/ADt. The nitrogen content in the dry substance (softwood) was 0.08 % on average (in 2008). The boiler runs slightly above the design capacity. No influence of the incineration of methanol in the recovery boiler was confirmed in this boiler. Around 33 % of the calculated N input is converted into NO_X emissions. The yearly average concentration is 190.3 mg NO_X/Nm^3 (at 5 % O_2). NO_X and CO are measured continuously.



Statistics	CO (mg/Nm^3)	NOx (mg/Nm^3)
Yearly average	41.7	190.3
1st decile	16.3	153.0
Daily maximum	118.8	232.7
Standard deviation	22.3	26.7
95 th percentile	82.3	215.6

Source: [172, A.Schweizer 2010]

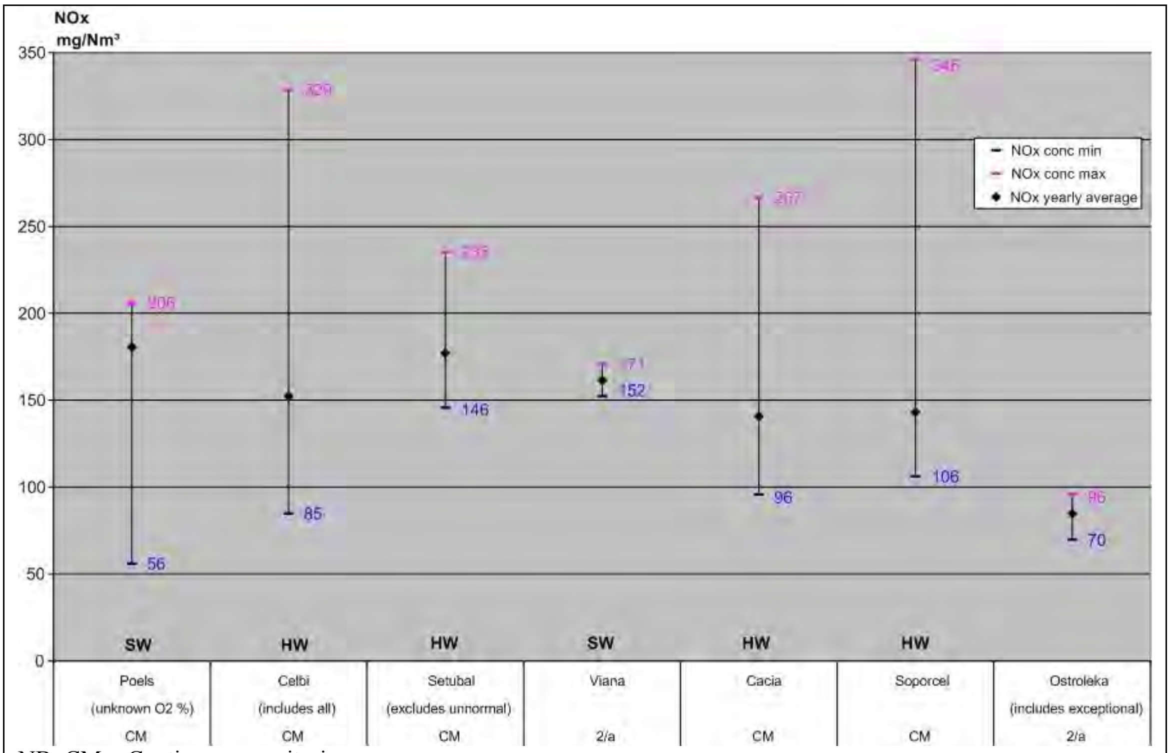
Figure 3.62: Daily average NO_X and CO values over a full year from a kraft pulp black liquor recovery boiler

The average specific NO_X emission from 22 Swedish black liquor recovery boilers that were operating in 2008 was 1.04 kg NO_X /ADt; seven mills reported NO_X emissions below 1 kg/ADt (*Source*: Swedish statistical data 2007). The highest NO_X emission from a black liquor recovery boiler in Sweden was 1.28 kg/ADt.

The six operational Portuguese pulp mills that pulp mainly eucalyptus wood reported NO_X emissions between 121 mg/Nm^3 (8 % O_2) or 0.73 kg/ADt) and 153 mg/Nm^3 (8 % O_2) or 1.13 kg/ADt (*Source*: Questionnaire 2009). All these recovery boilers run with three air levels.

For the specific NO_X values, it should be taken into account that eucalyptus pulping gives a somewhat higher yield (51 – 54 %) than Nordic softwood (44 – 46 %) and hardwood (47 – 49 %) and thus lower specific NO_X emissions.

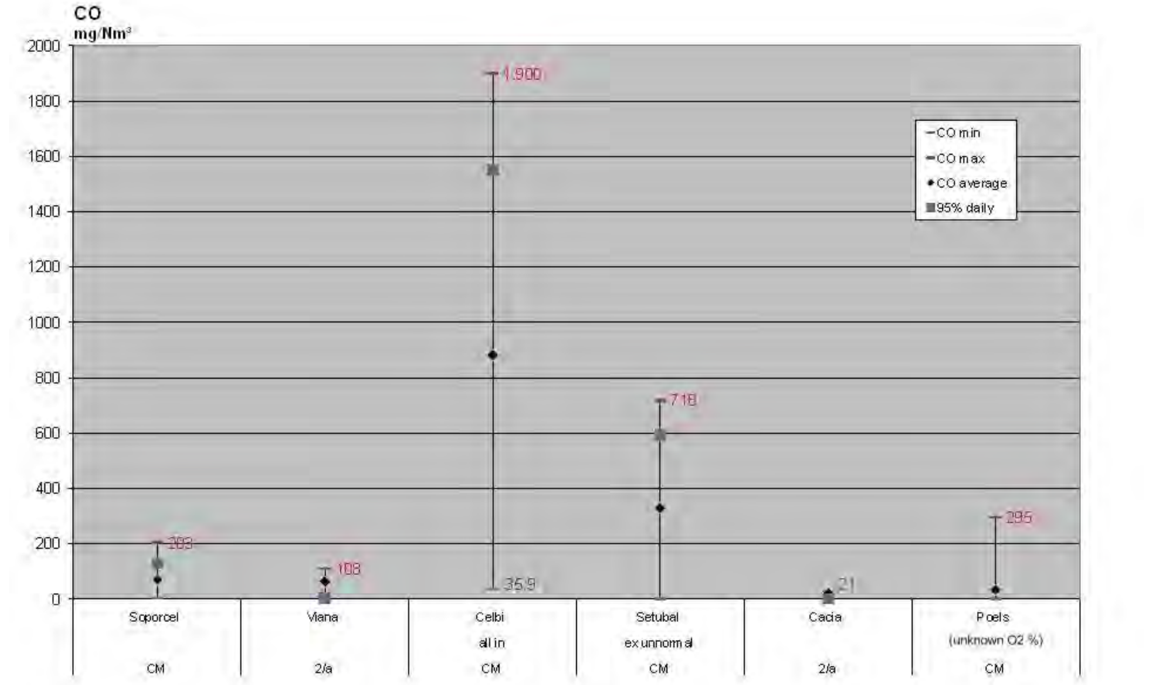
The reported short-term NO_X and CO emissions are shown in Figure 3.63 and Figure 3.64.



NB: CM = Continuous monitoring

Source: EIPPCB questionnaires from 2007/2009 and other TWG input

Figure 3.63: NO$_X$ emissions from the recovery boiler as short-term average



NB: CM = Continuous monitoring

Source: EIPPCB questionnaires from 2007/2009 and other TWG input

Figure 3.64: CO emissions from the recovery boiler as short-term average

Further NO$_X$ emission data for the whole mill are compiled in Section 3.2.2.6.7.2.

Cross-media effects
No environmental side effects or disadvantages to other media are caused by using this technique.

Technical considerations relevant to applicability
Measures are applicable to both new and existing mills.

Economics
The black liquor recovery boiler is the most expensive piece of equipment in a pulp mill. Therefore, the capacity of the boiler should be optimised. At some point, the mills have to invest in a new and larger boiler. But NO_X emissions are normally not the driving force.

Driving force for implementation
Environmental regulations and the aim of operators to run the recovery boilers efficiently are the driving forces for the implementation of this technique. As NO_X emissions from the black liquor recovery boiler correspond to approximately 65 – 85 % of the total emissions from the mill (see Figure 3.30), efforts are made to reduce NO_X emissions from these plants.

Some Member States (e.g. SE) have focused environmental programmes on the reduction of acidification and eutrophication. As a response, available measures have also been taken within the pulp and paper industry to reduce both emissions of sulphur oxides and nitrogen oxides.

Example plants
Many kraft pulp mills in Europe have implemented and are running recovery boilers as discussed above.

Reference literature
[33, COM 2011], [58, K.Grönblad et al. 2000], [61, Wallén et al. 2002], [64, J.Malmström 2010], [65, N.DeMartini et al. 2010], [66, FRBC 2010], [225, Hupa 2005], [226, Vakkilainen et al. 2005].

3.3.18.2 Optimised black liquor recovery boiler air systems

Description
The black liquor recovery boilers operate with a reducing atmosphere in the lower furnace. Accordingly, the NO_X formation in the black liquor recovery boiler is lower than from other furnaces. Modifications to the air systems have proved successful with respect to NO_X reductions.

On top of the conventional air feeding levels (commonly three), an additional air feeding level (fourth air level) positioned at a higher elevation from the boiler floor is incorporated in the boiler. Many black liquor recovery boilers have four air feeding levels, some even have five. Modifying the air feed system by introducing additional air inlets in the upper part of the boiler reduces NO_X formation.

The reduction of NO_X emissions with air staging depends on the black liquor recovery boiler design and load, and the NO emission level and will normally be 10 – 25 %.

Additional air levels above the conventional ones provide more freedom for managing NO emissions with combustion technology.

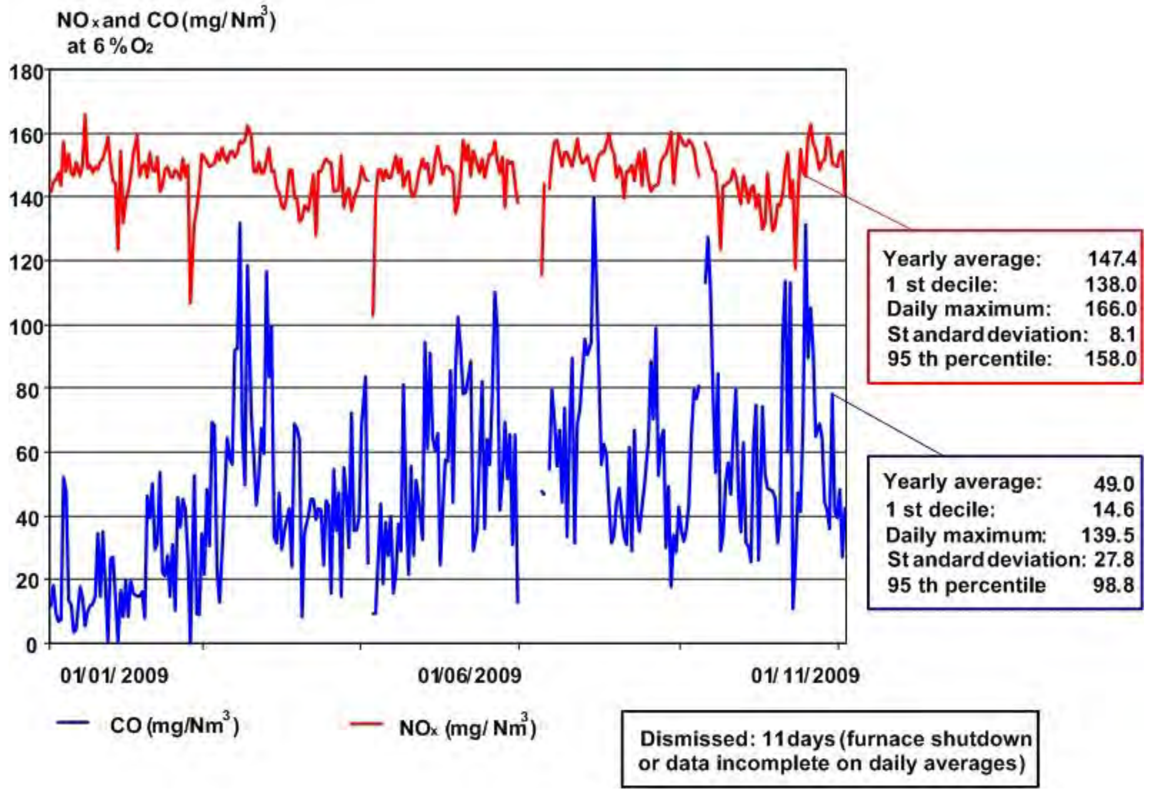
It has become apparent that NO reduction techniques based on optimising air distribution are not efficient if the boiler load is very high, as is the case at several pulp mills [225, Hupa 2005]. On the other hand, all retrofitted or more recently built black liquor recovery boilers for which low NO_X emissions were reported have several air levels. No more specific data about the success of specific air distribution systems have been provided.

Achieved environmental benefits
Lower NO_X emissions.

Environmental performance and operational data
The reduction of NO_X emissions attributable to the use of this technique is variable and depends on several factors. In many cases, about 10 – 25 % lower NO_X emissions have been reached [63, Salmenoja 2009], [64, J.Malmström 2010]. In contrast, for example, the IP kraft pulp mill in Saillat, France, reported that the introduction of a fourth air level did not result in any significant NO_X reductions (no data about boiler load or further details were provided). The technique has to be adapted to the specific conditions of black liquor recovery boilers.

The achievements of two kraft pulp mills that have implemented advanced air systems and are running a fourth air level are shown in Figure 3.65 and Figure 3.66 as examples.

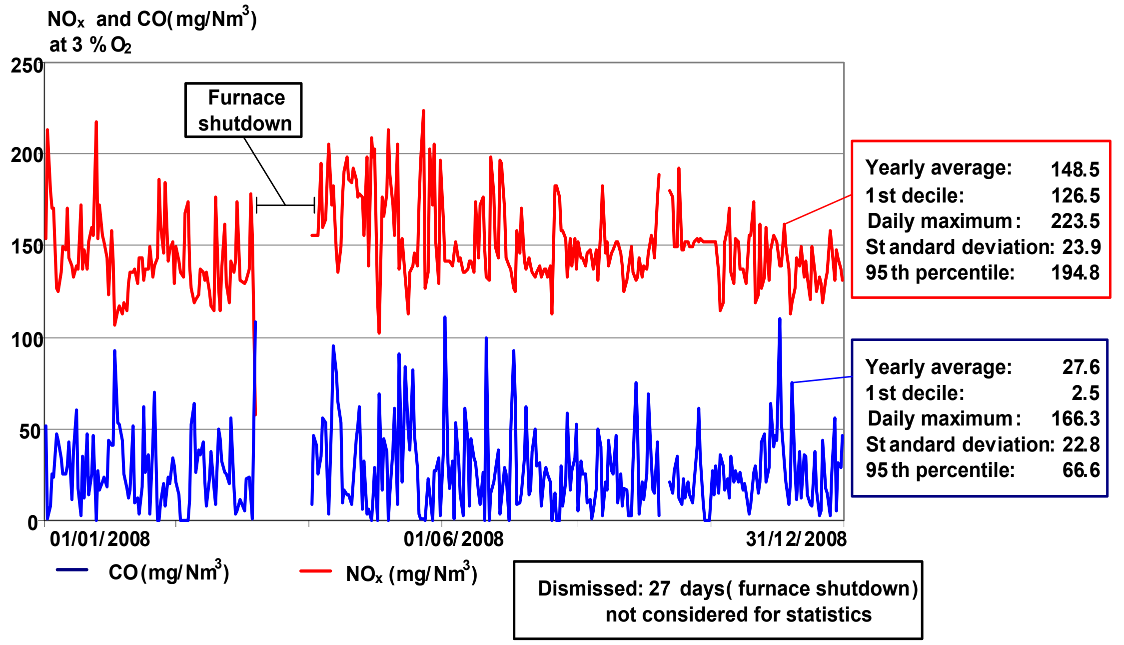
The first example is a European kraft pulp mill that uses softwood (pine and spruce) as pulpwood. The black liquor recovery boiler runs slightly below the design capacity and has a fourth air level. In the black liquor recovery boiler, black liquor (approximately 75 % DS), natural gas and light fuel oil as supporting fuel and DNCG are burnt. The emission concentrations for NO_X and CO are shown in Figure 3.65. In the filled-in questionnaires, the mill reported an emission level of 1.25 kg NO_X/ADt on an annual basis for the recovery boiler.



Source: [173, J.Queiser 2009]

Figure 3.65: Continuously measured daily average data for the NO_X and CO emissions of a black liquor recovery boiler

The second example is the Södra Värö kraft pulp mill in Sweden that uses softwood (spruce and pine) as pulpwood. The recovery boiler has a fourth air level. In the black liquor recovery boiler, black liquor (approximately 75 % DS), some fossil fuel and DNCG are burnt. The achieved emission levels for NO_X and CO are shown in Figure 3.66. The yearly average emission concentration corresponds to a specific NO_X emission from the black liquor recovery boiler of 1.02 kg/ADt on an annual basis.



Source: [171, R.Morin 2009]

Figure 3.66: Continuously measured daily average data for the NO_X and CO emissions of the recovery boiler of the Södra Värö kraft pulp mill

Newer recovery boilers where the combustion air is distributed through four or more air registers can achieve levels down to below 150 mg NO_X/Nm^3 (at 3 % O_2) or under 1 kg NO_X/t in some cases (see Figure 3.30).

A very exact process control is required to prevent an increase of CO formation during lean-oxygen combustion. In order to reduce NO_X emissions, black liquor recovery boilers are operated at low oxygen levels. Oxygen levels of 2.5 – 3 % in the exhaust gas are typical. An increase in excess O_2 may increase NO_X.

Cross-media effects

No cross-media effects occur.

Technical considerations relevant to applicability

Applicable to both new and existing mills. This technique will require considerable changes to the air feed systems of the furnace and in certain cases the special furnace wall tubes that can withstand corrosion in a reducing atmosphere would have to be extended from the lower part of the boiler to the highest air level, which would be a significant alteration in a boiler. The size and dimensions of the boiler may restrict the applicability of this measure in some cases.

Economics

The investment required for modifying the air introduction to the recovery boiler of a bleached kraft mill with a production capacity between 250 000 and 500 000 tonnes/year amounts to EUR 1.7 million and EUR 2.3 million respectively. The investment includes new air inlets to the recovery boiler, instrumentation, pipes and fans. There is a small change in operating costs (installing an additional fan slightly increases the electricity consumption).

Driving force for implementation

NO_X has an acidifying potential and may increase eutrophication. In some sensitive lake areas in Europe a further reduction of NO_X emissions by primary measures is therefore regarded as necessary.

Example plants
Many black liquor recovery boilers have four air levels, several secondary and tertiary elevations or vertical air systems on new and existing boilers.

Reference literature
[63, Salmenoja 2009], [64, J.Malmström 2010], [171, R.Morin 2009], [173, J.Queiser 2009], [225, Hupa 2005].

3.3.19 Reduction of dust emissions from the black liquor recovery boiler

3.3.19.1 Electrostatic precipitators

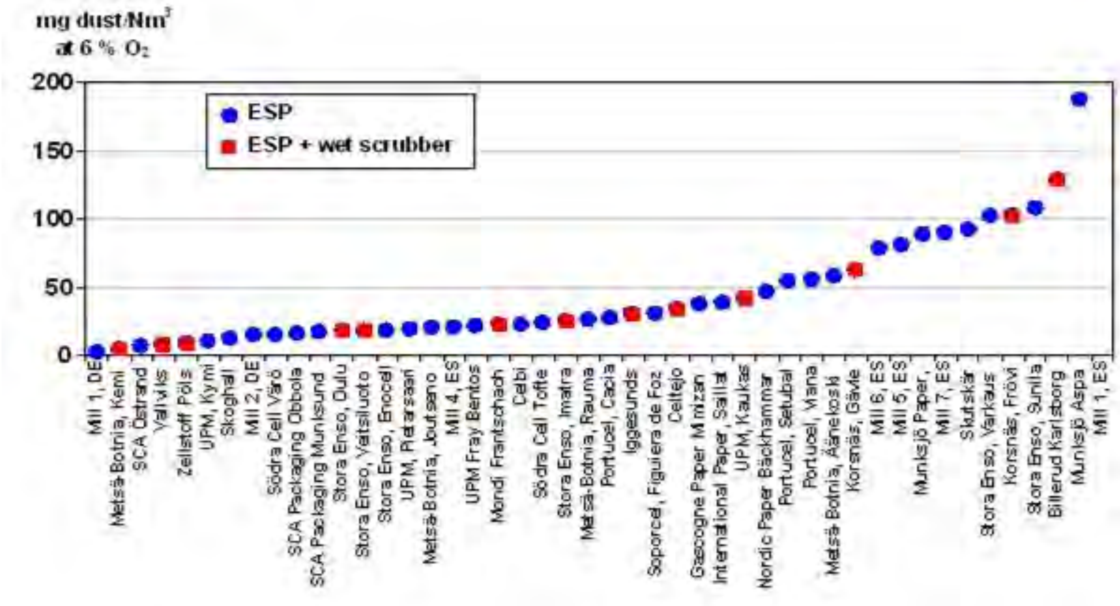
Description
ESPs generate an electrostatic field across the path of particulate matter in the air stream. The particles become negatively charged and migrate towards positively charged collection plates. The collection plates are rapped or vibrated periodically, dislodging the material so that it falls into collection hoppers below.

It is important that ESP rapping cycles are optimised to minimise particulate re-entrainment. Differences in the performance of ESPs depend on the design and dimensioning of the electrostatic filters and on a number of operational parameters, such as the flue-gas flow rate, the gas temperature, the start and stop operation, the number of fields, the strength of the electric field, the area and the shape of the electrodes, the SO_2 concentration and the maintenance work carried out. In particular, performance can be impaired by the build-up of material forming an insulating layer on the electrodes and so reducing the electric field. This effect needs to be controlled.

After leaving the recovery boiler, the exhaust gases are normally divided into two streams and led in parallel through electrostatic precipitators (ESPs). The two streams allow one ESP to be shut down for cleaning or maintenance work when it is needed. The ESPs in the two streams are typically sized to handle 65 % or more of the total gas flow from the boiler to allow service and maintenance without shutting down the boiler. Cleaning is needed regularly in order to remove the incrustation of Na_2SO_4 that is built up during normal operation.

Achieved environmental benefits
Removal of dust (particulate matter). Dust emissions from recovery boilers mainly consist of fine dust (<2 µm), see Figure 3.28.

Environmental performance and operational data
Figure 3.67 and Figure 3.70 summarise the reported dust emissions from recovery boilers of European kraft pulp mills. In Figure 3.67, the dust emissions are plotted as annual average concentration values (Nm^3, dry, at 6 % O_2) for those mills that reported concentration values. Mills that use ESPs only or ESPs together with wet scrubbers are shown.

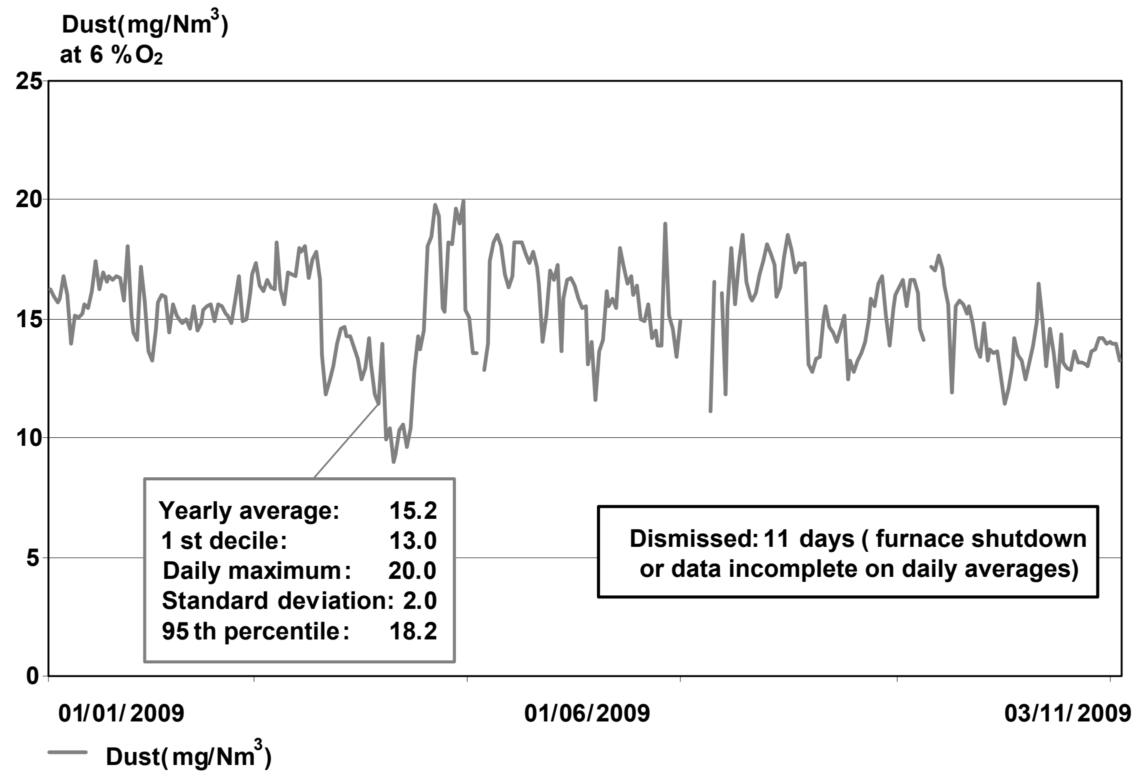


Source: [33, COM 2011]

Figure 3.67: Yearly average concentration of dust emissions from recovery boilers after the ESP or the ESP and wet scrubbers

ESPs with emissions of <10 – 30 mg dust/Nm^3 as an annual average (or 10 – 40 mg/Nm^3 (6 % O_2) determined as a daily average value) are achieved. Design criteria, process control and maintenance of the ESPs, optimal high voltage supplies, proper sizing and an appropriate number of electrical fields are important factors for a good ESP performance. The achieved levels depend not only on technical aspects but also on the targets set by the competent authorities or by the operator itself.

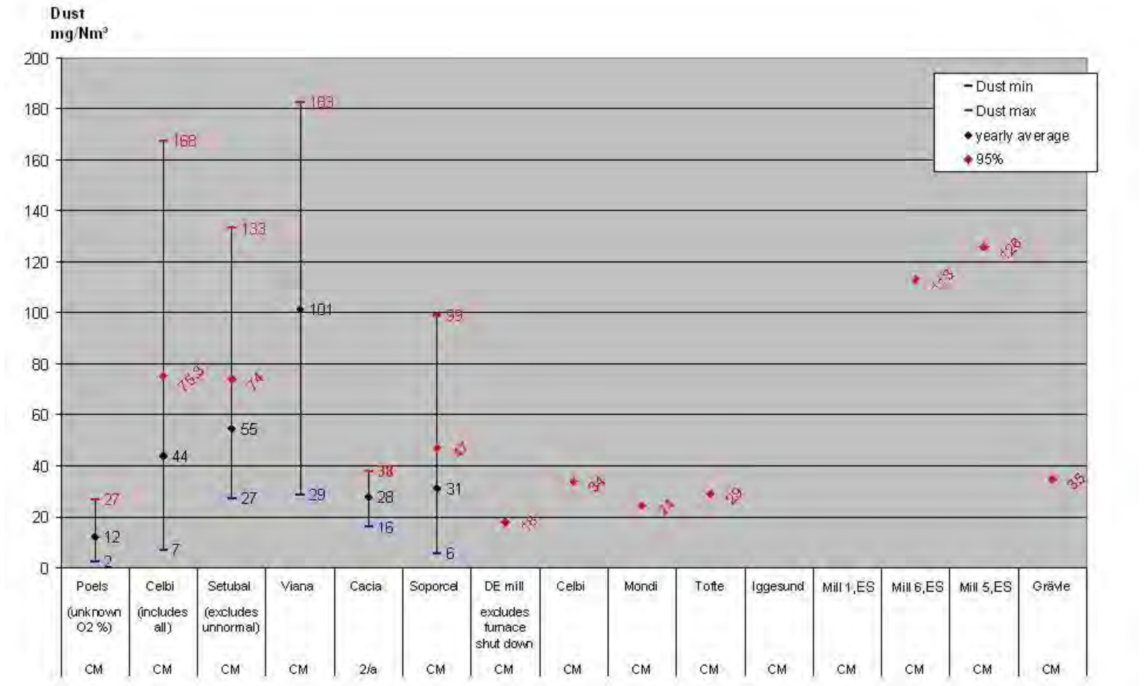
Figure 3.68 shows an example of a well-dimensioned ESP together with good gas flow distribution into the ESP and an optimised ESP cleaning regime. The daily average data over a complete year are shown. The data are taken from the on-line transfer of emission data to the competent authority. Dust is measured continuously. Dust emissions are reduced down to 15 – 20 mg/Nm^3 based on daily average values (dry gas, 273 K, 6 % O_2).



Source: Landesverwaltungsamt Halle, 2009, DE

Figure 3.68: **Continuously measured daily average dust emissions downstream of the ESP of a kraft pulp recovery boiler**

The reported short-term dust emissions are shown in Figure 3.69.

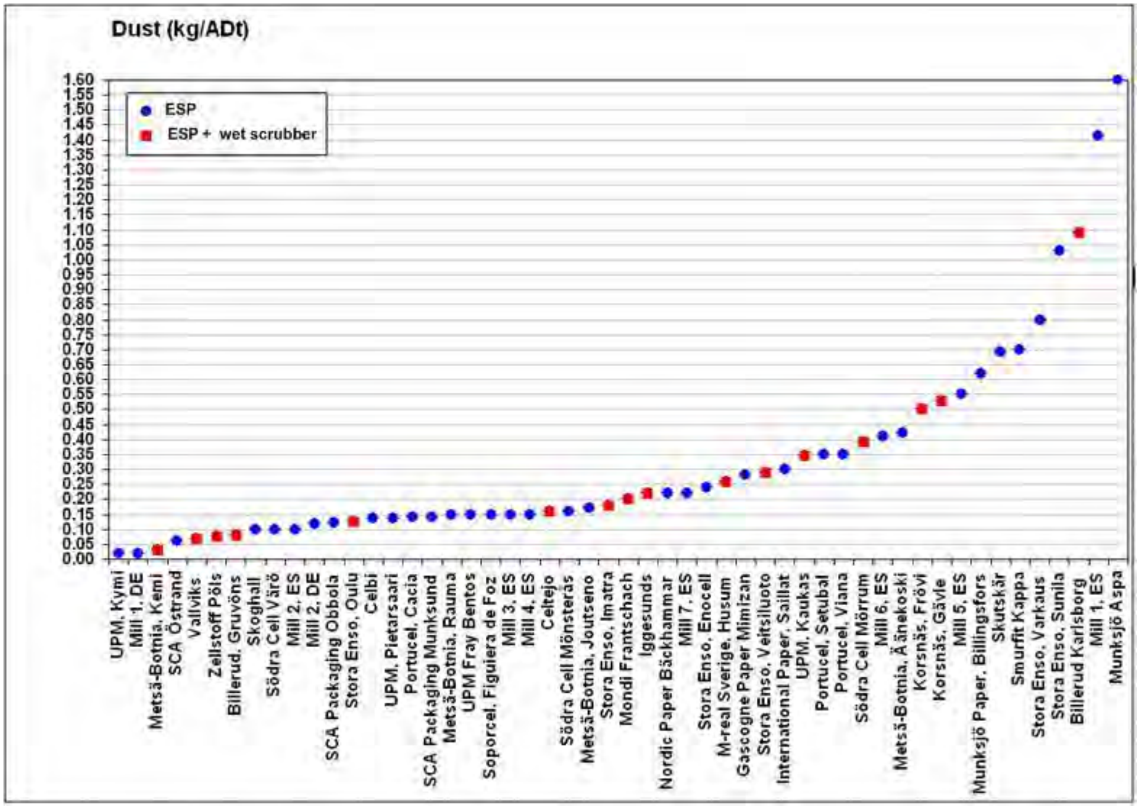


NB: CM = Continuous monitoring

Source: EIPPCB questionnaires from 2007/2009 and other TWG input

Figure 3.69: **Dust emissions from recovery boilers as short-term average**

Figure 3.70 shows the reported dust emissions from recovery boilers of European kraft pulp mills. The mills are those shown in Figure 3.67 and additionally those that reported dust emission loads only (no concentration values). Dust is expressed in annual average emission loads (kg dust/ADt). Mills that use ESPs only or ESPs together with wet scrubbers are distinguished.



Source: [33, COM 2011]

Figure 3.70: Yearly average dust emission loads from recovery boilers after the ESP or the ESP and wet scrubbers

Changes in fuel and dry solids content and the recovery boiler load may create disturbances for the ESP performance. However, there are ways to determine what fuel variations and changes in boiler output levels can be accepted by the operating ESPs. Monitoring the ESP input power (kV, mA, spark rate), along with monitoring the dust removal system operation, can be helpful in keeping the system operating at optimum levels. For example, if the output of a recovery boiler is increased there will be a larger amount of gas flow and dust to be collected in the ESP. By monitoring the T/R input power levels compared to the minimal values established by plant operations to meet the allowable emissions from the plant, the operators can determine the maximum load that the boiler can operate while staying in compliance. All of the systems associated with the ESP including the capacity of the dust removal system need to be monitored so that the system can meet the operating requirements for the plant and so that the emission peaks and disturbances of the ESP performance can be reduced.

ESPs are very efficient devices for collecting ultrafine particles (<0.5 µm), providing the particles have the ability to agglomerate, e.g. as recovery boiler dust. In kraft pulp recovery boilers, the particle size allows a good separation efficiency of the ESP. No aerosols are formed during combustion.

There are a number of special considerations to be addressed when designing and operating an ESP for use after the recovery boilers. Some of the key recommendations are:

- avoid flat surfaces in the gas path from the boiler to the ESP to prevent dust build-up;
- each gas path should be designed to allow a portion of the gas cleaning system to be taken out of service for maintenance while the boiler is operating at a reduced load (i.e. design for 70 % of total flow through one ESP system);
- with an increase in DS in the liquor, there is often an increase in the dust load to the ESP;
- the pH of the dust must be kept above 8.5 to avoid sticky dust that will be difficult to remove from surfaces;
- the gas flow distribution into each ESP must be kept as stable as possible (standard deviation of the gas flow after the first collection field should be 20 % or less);
- due to the difficulties in removing collected dust from the collecting electrodes, the electrode height, length and total area of collecting surface per rapper must be sized appropriately;
- the system for removing dust from the bottom of the ESP must be very robust, reliable, efficient and must not contribute to dust re-entrainment.

The performance of existing ESP installations can often be improved without the need for total replacement thereby limiting costs. Improvements to ESPs can be done by fitting more modern electrodes, installing automatic voltage controllers or upgrading the rapping systems. In addition, it may be possible to improve the gas passage through the ESP (improved gas flow distribution) or add supplementary stages. The performance of an existing ESP can be enhanced by improving the alignment of emitting electrodes with the collecting electrodes, eliminating gas sneakage around the electrodes, improving the collecting plate cleaning and ensuring that the electrical power supply is optimised. The latter may need to have the T/R set and controls changed. However, there are times when the increase in gas and dust load to the ESP or reduced allowable emissions from the plant are such that making changes to power supplies and controls will not be sufficient. In these cases, the existing ESP size would need to be increased. Only after a thorough evaluation of the existing ESP size, past performance and new performance requirements can the correct approach to upgrade the existing plant be determined.

The black liquor composition may change the ESP performance. The dust may adhere more strongly to the collecting plate. Cleaning the electrodes may need adjustment of the rapping. Modern control systems can detect this and alter the rapping for optimal performance. Also, the electrical power input will adapt to such a changing situation.

The size and electrical power consumption of ESPs increase exponentially with decreasing clean gas dust content. An ESP depends on defined raw gas conditions, such as temperature and humidity, for optimum operation. The lifetime of an ESP can be several decades, providing all recommended maintenance is properly carried out. Some parts, such as hammers and bearings, need regular replacement after a few years of operation as part of routine maintenance.

The ESP performance is often impacted by dust composition, gas flow distribution and gas volume, sneakage around the charging/collection systems, improper rapping system design, lack of advanced power supplies and controls, and general and poor maintenance of the ESP over time. Keeping the inside of the ESP clean, properly aligned and powered with the latest type of control system is needed to achieve the best possible performance. Routine inspections and scheduled maintenance of the inside of the ESP will result in reliable operation.

Monitoring the power input to each section of the ESP and reacting to large variations will help to keep the unit performing well: the dust collection efficiency of the ESP is maximised when the charging of the dust particles is optimised and the T/Rs used to convert the plant alternating current to high voltage direct current are operating at peak levels. Closely monitoring the secondary voltage (kV), current (mA) and the sparks per minute (spark rate) from each T/R and addressing variations by boiler operation are needed to achieve the best possible collection of the dust. Higher levels of secondary current and lower amounts of sparking are key factors in maximising the ESP collection efficiency. For the overall performance of ESPs, it is important to avoid CO trips.

Because of their high efficiency, low pressure loss, high availability and energy efficiency, electrostatic precipitators became successfully established for dust collection from recovery boiler exhaust gas. The major disadvantages of ESPs are their decreased efficiency with an insulating layer and the possible build-up of material on the collection plates.

No bag filter applications for recovery boilers were reported. The nature of the dust and flue-gas composition from recovery boilers is not well-suited to the bag materials used in fabric filters. The gas temperature and moisture content are higher than most filter bags can accept. The dust is small in size and is often very sticky. This type of dust composition would be difficult to clean from the bags, resulting in a very high pressure drop across the filter. Boiler upset conditions could also result in bag damage that would require an outage to repair.

Cross-media effects
Electricity consumption increases with increased removal efficiency. ESPs are designed based on the gas flow and level of removal efficiency required. The use of high frequency power supplies and advanced controllers for conventional transformer rectifiers (T/Rs) helps to keep the energy consumption to a minimum. The T/R power is the largest energy element of the ESP. However there are other items such as the rapping system, the dust removal system, the support insulator heaters/blowers, etc. that also consume energy. The higher the required removal efficiency per unit volume of gas flow, the higher the power consumption will be in the ESP. The removed dust is completely reused in the process.

Technical considerations relevant to applicability
Generally applicable, provided that there is sufficient space.

Economics
The cost for the various changes is determined by the size and complexity of the existing systems.

Driving force for implementation
Legal requirements, health and safety requirements for the workplace, local conditions.

Example plants
See Figure 3.67 and Figure 3.70.

Reference literature
[33, COM 2011], [229, Stubenvoll et al. 2007], [198, Porle 2005], [199, Herrlander 2010].

3.3.19.2 Electrostatic precipitators followed by wet scrubbers

The technique is described in Section 3.3.17.2 and simultaneously reduces the particulate matter and the sulphur emissions (SO_2, TRS).

Description
After dedusting the flue-gas by means of ESPs (see Section 3.3.19.1), the exhaust gas is either transported via an induced draught ventilator directly to the stack or is further cleaned with a single- or two-stage wet scrubber. The gas downstream of the ESPs is combined and cooled by injecting fresh water in order to reach the dew point. As washing liquor, Na(OH) is usually used for the gas cleaning. The separation efficiency of the wet scrubber depends on the particle size and on the dimensions (and thus the pressure loss) and efficiency of the last drip catcher. The dimensions of fresh water admission and of the mist eliminator are purely economic factors in terms of the basic layout of the facility.

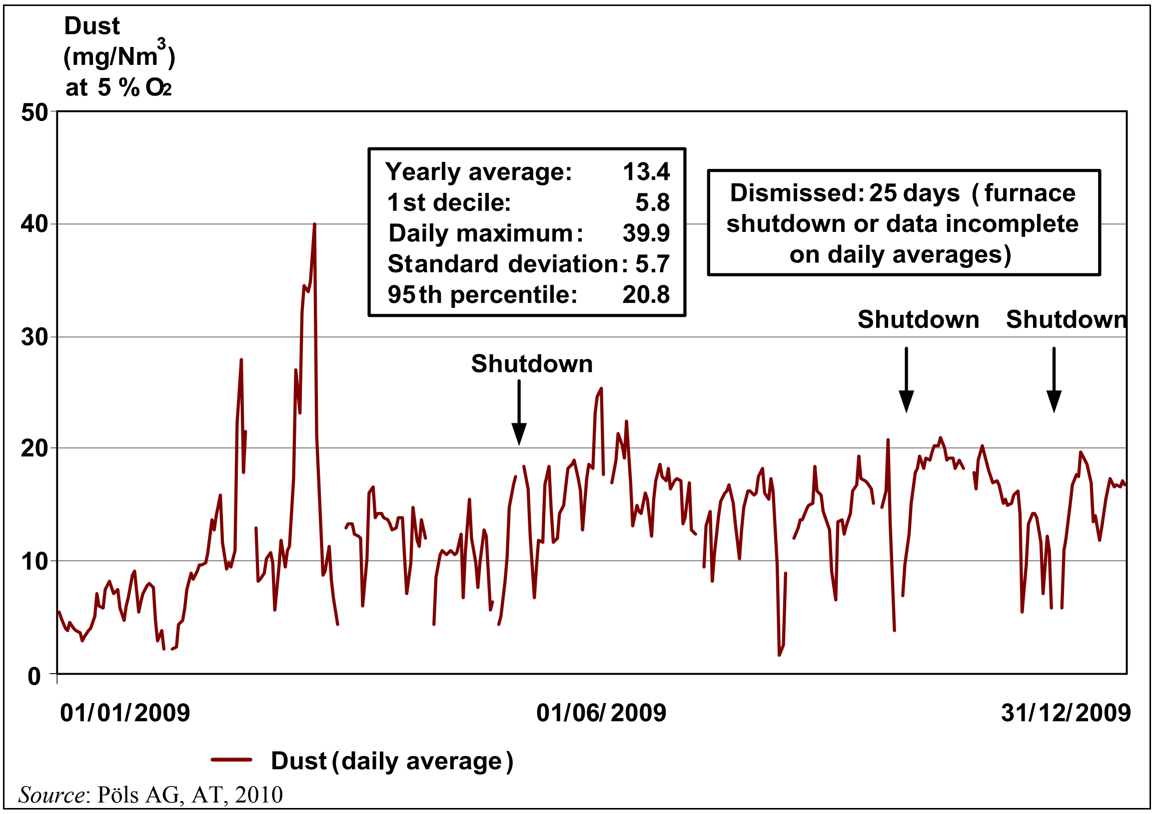
Achieved environmental benefits and cross-media effects
See Section 3.3.19.1.

Environmental performance and operational data

Efficient wet scrubbers remove up to 75 % of the dust after the ESPs. Performance data for ESPs and wet scrubbers for dust removal are shown in Figure 3.67 and Figure 3.70 above. As illustrated, low dust emissions are achieved with both systems, ESPs only and ESPs followed by wet scrubbers. Scrubbers are normally not used for dust removal but for reducing sulphuric emissions. Reduction of dust is merely a positive side effect.

Modern electrostatic precipitators (ESPs) alone achieve a high dedusting efficiency. Older systems often use two-stage dust removal facilities (ESPs and wet scrubbers). If the ESPs are not sufficiently dimensioned and well-maintained, dust emissions can still reach relatively high levels when running ESPs only. In these cases, a wet scrubber can keep the dust emission low. A few modern recovery boilers are also equipped with two-stage dust removal facilities (ESPs and wet scrubbers) mostly to ensure continuously very low-sulphuric emissions but also to recover heat (if there is a use for it).

An example of the achieved emissions of a two-stage dust removal facility (ESP and scrubber) is shown in Figure 3.71. Dust concentrations in the clean gas are between 10 mg/Nm^3 and 20 mg/Nm^3 as a daily average (dry gas, 273 K, 5 % O_2). The data shown in Figure 3.71 are taken from the company's internal on-line measurement data. The washer in this example normally only uses water as the washing liquid; only if the pH value in the water reaches <7 (i.e. SO_2 emissions would increase in the stack) is NaOH added to the scrubbing liquid. The recovery boiler of Figure 3.71 runs 13 % over capacity which results in a higher flue-gas flow. A higher flow rate leads to an increase in dust emissions after the ESP and the mist eliminator after the scrubber. At design capacity, the dust emissions of this mill were below 15 mg/Nm^3 as a daily average.



Source: Pöls AG, AT, 2010

Figure 3.71: Continuously measured daily average data for dust emissions downstream of the ESPs of a kraft pulp recovery boiler

Technical considerations relevant to applicability
The two-stage dust removal system (ESP and wet scrubber) can be applied to both new and existing plants.

Economics
No information provided.

Driving force for implementation
Legal requirements, health and safety requirements for the workplace, local conditions. The driving force for the use of a scrubber in the black liquor recovery boiler is not to reduce the particulate emissions from this source but to control the SO_2 emission (see Section 3.3.17.2) when internal measures like dry solids increase cannot be applied.

Example plants
See Figure 3.67 and Figure 3.70.

Reference literature
[172, A.Schweizer 2010], [229, Stubenvoll et al. 2007].

3.3.20 Reduction of sulphur emissions (SO_2 and TRS) from the lime kiln

3.3.20.1 Selection of fuels and control of the excess oxygen

Description
SO_2 emissions can be prevented or reduced by either using fuels with a low-sulphur content or, if odorous non-condensable gases (NCG) are burnt in the lime kiln, scrubbing out of sulphuric gases prior to burning in the lime kiln (see Section 3.3.22.2).

SO_2 is formed during combustion due to sulphur in the fuel and concentrated NCG if these are burnt. The role of the sulphur entering the lime kiln with the lime mud is marginal but may lead to increased TRS emissions in some cases (see Section 3.3.20.2). $CaCO_3$ from the lime mud may absorb some SO_2 but its absorption capacity is very limited. Additionally, a limited amount of sulphur can be absorbed in the lime kiln by gaseous sodium which is created by vaporising the remaining water-soluble alkali that the washed and dewatered lime mud fed to the kiln may still contain. These sulphur-absorbing alkali compounds in the lime mud are impurities of Na_2CO_3 that takes up some SO_2 and forms sodium sulphate (Na_2SO_4).

Almost all lime kilns use heavy fuel oil or natural gas. In a few cases, tall oil, dry pulverised bark, sawdust or gas from a bark gasifier are used (further details on the use of regenerative biofuels are given in Section 3.3.23). More typical alternative fuels that are used only as part of the main fuel are non-condensable gases (NCG), methanol and turpentine.

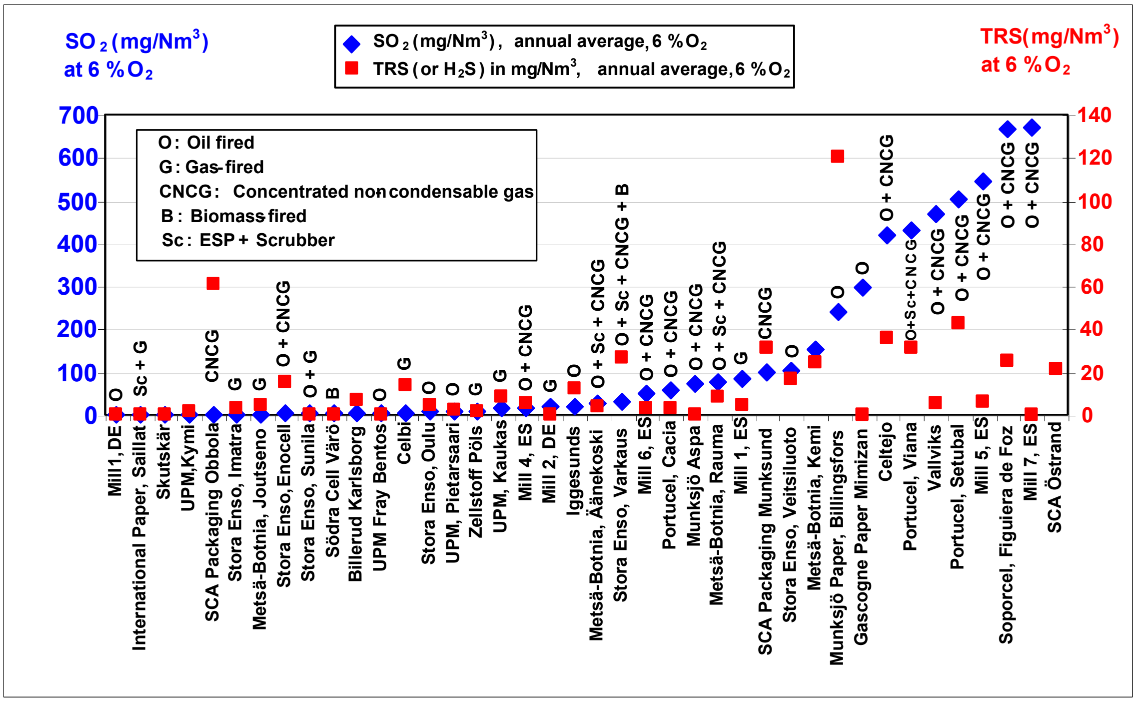
SO_2 emissions are significantly higher when strong non-condensable gases and/or condensate containing methanol are incinerated in the kiln and no scrubbers are used.

With properly dimensioned and operated lime mud washing and filtration, well-designed lime kiln burners and a sufficient air supply for complete combustion (the presence of sufficient excess air can be ensured by a residual oxygen control system), this does not increase the TRS emissions from the kiln.

Achieved environmental benefits
Reduced sulphur emissions.

Environmental performance and operational data

Figure 3.72 (expressed as concentrations) and Figure 3.73 (expressed as emission loads) summarise the achieved SO_2 and TRS emissions from lime kilns of European kraft pulp mills. Some mills have only reported emission loads and no concentration values, others measure H_2S and not TRS because TRS emissions from lime kilns consist mainly of hydrogen sulphide. Because of the differences regarding the flue-gas flow, the SO_2 concentration does not always correlate with the corresponding SO_2 emission load. In Figure 3.72, the SO_2 emissions (left y-axis) and TRS emissions (right y-axis) are plotted as annual average concentration values (at 6 % O_2). The fuels used are indicated (oil, gas, CNCG, biomass) as well as the use of scrubbers.



Source: [33, COM 2011]

Figure 3.72: TRS and SO_2 emission concentrations from lime kilns fired with different fuels

TRS (H_2S) emissions

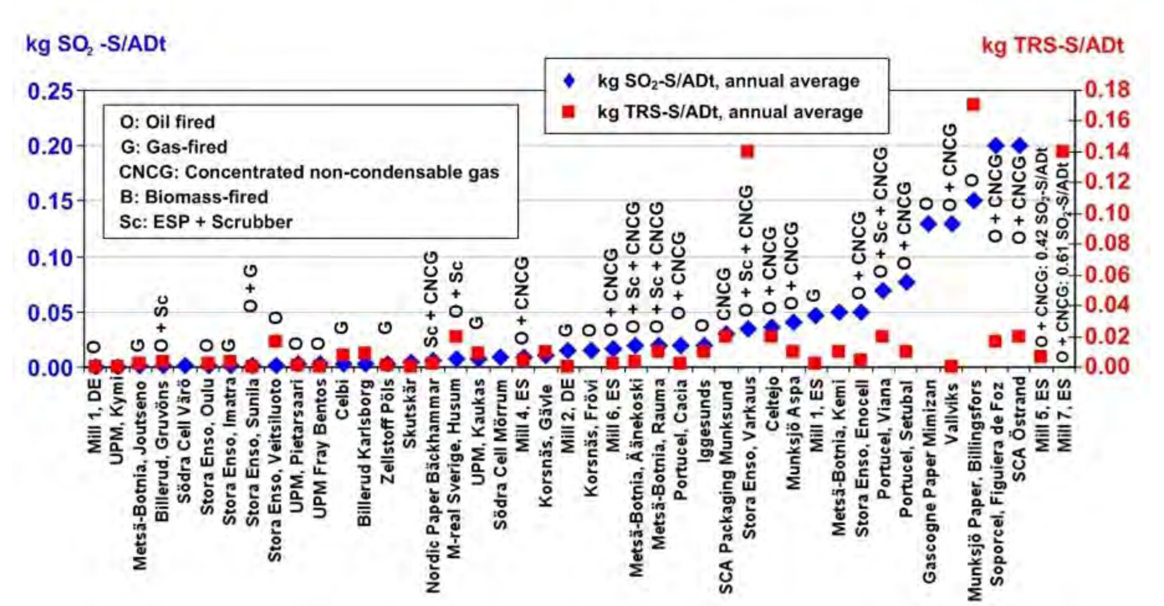
Flue-gases from the lime kiln may contain minor amounts of hydrogen sulphide due to incomplete washing of lime mud. Many mills also burn strong odorous gases in lime kilns which introduce total reduced sulphur compounds into the kiln. TRS emissions of lime kilns normally vary between close to zero and below 20 mg TRS (as S)/Nm^3 (at 6 % O_2). The corresponding emission load varies between almost zero and <0.02 kg TRS-S/ADt (see Figure 3.73).

SO_2 emissions

SO_2 emissions from the lime kiln depend on the selection of fuels, whether or not CNCG are burnt and if wet scrubbers are used (see Section 3.3.20.3). The data presented in Figure 3.72 and Figure 3.73 are summarised in Table 3.26 that shows the achieved SO_2 emissions from lime kilns for various fuels with and without the use of scrubbers.

Table 3.26: SO_2 emissions from lime kilns for various fuels with and without scrubbers

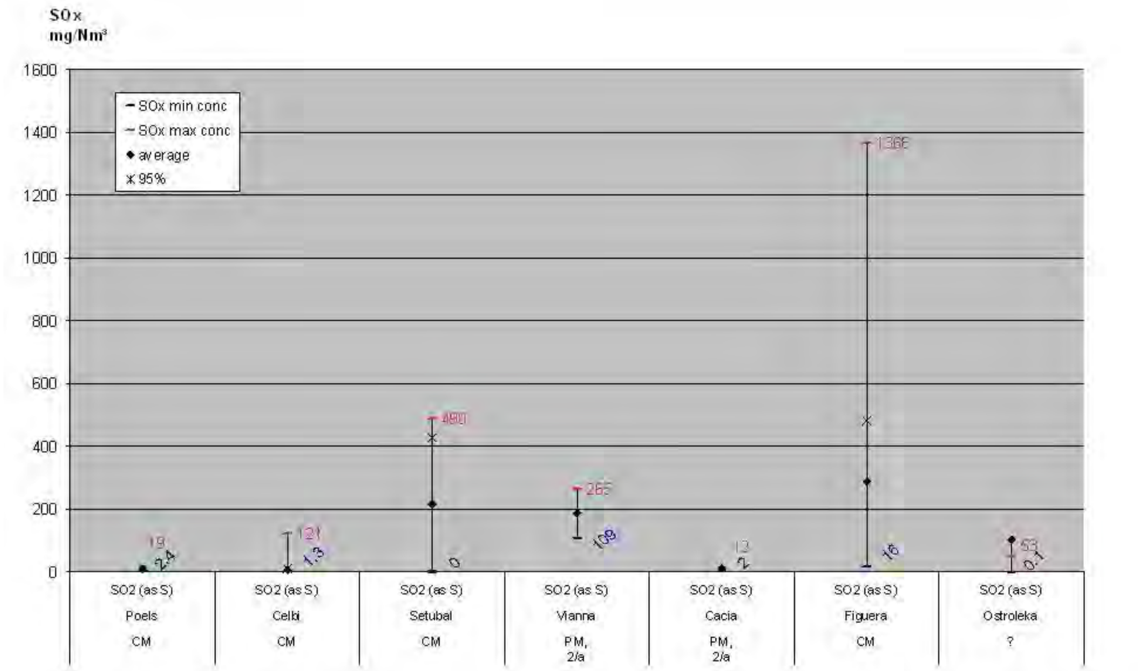
Main fuel used, burning of CNCG	Achieved SO_2 emissions, as annual average values	
Oil firing without non-condensable gases	5 – 50 <0.02	mg SO_2/Nm^3 (at 6 % O_2) kg SO_2-S/ADt
Oil firing with non-condensable gases (normally with use of alkaline scrubber)	100 0.05	mg SO_2/Nm^3 (at 6 % O_2) kg SO_2-S/ADt
Natural gas, wood gas or other biomass (gas firing in combination with CNCG not reported)	1 – 20	mg SO_2/Nm^3 (at 6 % O_2)



Source: [33, COM 2011]

Figure 3.73: SO_2 and TRS emission loads from lime kilns fired with different fuels

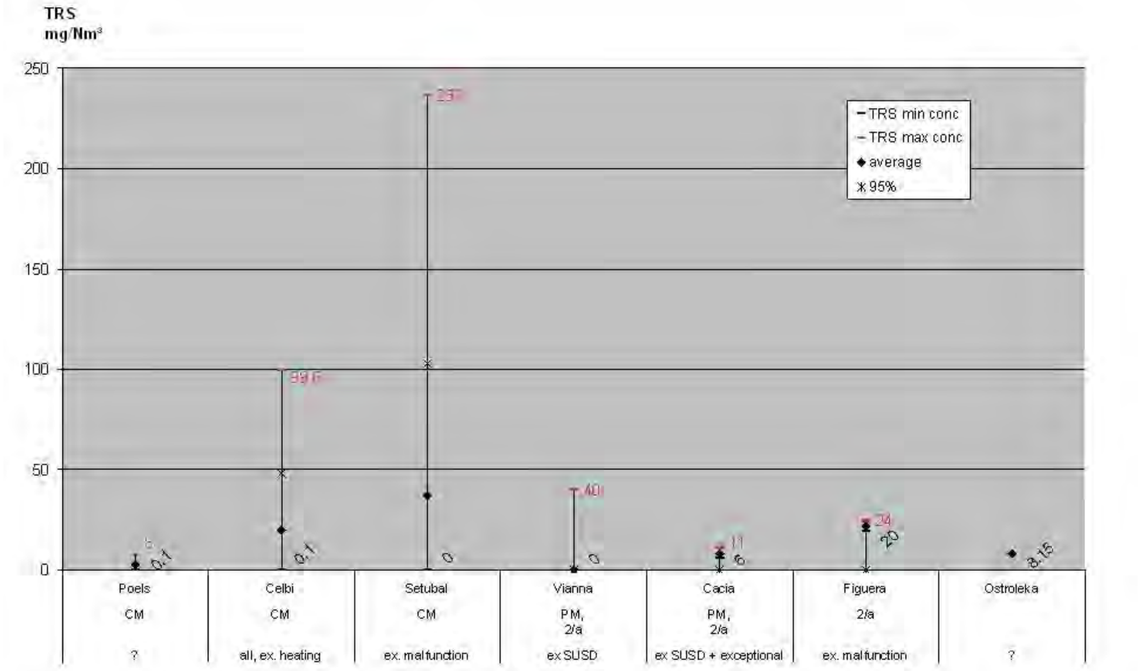
The reported short-term SO_2 and TRS emissions are shown in Figure 3.74 and Figure 3.75.



NB: CM = Continuous monitoring; PM = Periodic monitoring; ? = No information on type of monitoring

Source: EIPPCB questionnaires from 2007/2009 and other TWG input

Figure 3.74: **SO2 emissions from lime kilns as short-term averages**



NB: CM = Continuous monitoring; PM = Periodic monitoring; ? = No information on type of monitoring

Source: EIPPCB questionnaires from 2007/2009 and other TWG input

Figure 3.75: **TRS emissions from lime kilns as short-term averages**

Cross-media effects

The selection of fuels may have implications for NO_X emissions; gas- and biomass-fired lime kilns often have higher NO_X emissions.

Technical considerations relevant to applicability
Generally applicable.
Economics
No information provided.

Driving force for implementation
Legal requirements.

Example plants
See Figure 3.72 and Figure 3.73.

Reference literature
[33, COM 2011]

3.3.20.2 Installation of improved washing and filtration of lime mud in recausticising

Description
H_2S formation in the lime kiln can be controlled by the oxygen level and the amount of remaining sodium sulphide (Na_2S) in the lime mud fed into the cold drying and heating sections of the lime kiln.

Efficient washing and filtration of the lime mud reduces the concentration of Na_2S in the lime mud, thus reducing the formation of hydrogen sulphide entering the kiln during the reburning process. Insufficient lime mud dry solids content and purity may also cause H_2S formation. With modern LMD-Filters, a TRS content of 10 ppm can easily be achieved. Vacuum filters are mainly used for lime mud washing.

Lime (CaO) is used to causticise green liquor (Na_2S + Na_2CO_3) into white liquor (Na_2S + NaOH). After causticising, lime mud ($CaCO_3$) is formed. Normally lime mud is recycled in a lime kiln, where lime mud is reburnt and new lime is created. Before the lime is sent to the kiln, it must be washed in order to remove residual sodium hydroxide, sodium sulphide and other sodium salts.

The equipment used for lime mud washing is usually press filters. Single-stage lime mud washing in pressure filters is the dominant technique.

Improved lime mud washing and filtration (LMD-Filter) can reduce the residual white liquor content in the mud from 100 mg/l to 0 – 30 mg/l in modern filters. The lime mud dryness can be increased to 70 – 80 %. In addition to achieving energy savings, the operation of the kiln becomes more stable. The LMD-Filter keeps the remaining sodium content in the lime mud at a low level, which also prevents process disturbances like ring formation.

Achieved environmental benefits
Reduction of emissions of reduced sulphur.

Environmental performance and operational data
Improved washing of lime mud is common practice in pulp mills in Europe. Monitoring of residual sodium (NaOH) is required to avoid the damming of the lime kiln. No specific data concerning the effectiveness of this measure have been provided.

Cross-media effects
No significant effects.

Technical considerations relevant to applicability
Generally applicable.

Economics
The investment required is typically EUR 1 – 1.5 million.

Driving force for implementation
Reduction of H_2S (TRS) and odours from the flue-gases of the lime kiln.

Example plants
Many plants in Europe.

Reference literature
[131, SEPA report 1997].

3.3.20.3 Use of an alkaline flue-gas scrubber

Description
If strong non-condensable gases (CNCG) are burnt in the lime kiln, sulphur compounds can be reduced by the use of wet alkaline scrubbers prior to burning in the lime kiln. A small internal NaOH scrubber for the malodorous gas flow (i.e. not for the total flue-gas flow) will reduce H_2S almost completely, the methyl mercaptan by 70 – 90 % while the removal rate for methyl sulphides is lower. An alkali scrubber in one or two washing stages can remove SO_2 effectively from lime kiln flue-gas. The incoming level of SO_2 determines the number of spraying nozzles in the scrubber and the alkali charge. The SO_2 removal efficiency of alkaline wet scrubbers is >90 %.

Whether scrubbers are required or not depends on the sulphur content of the fuel and whether or not CNCG or condensate containing methanol are fed to the kiln.

Further information on the operating mode of scrubbers is given in Section 3.3.17.2.

Achieved environmental benefits
Reduced sulphur emissions.

Environmental performance and operational data
In order to decrease the TRS emissions from the lime kiln, some installations are equipped with a flue-gas scrubber (also for heat recovery). By using scrubbers, SO_2 emissions of 25 – 100 mg/Nm^3 (6 % O_2) determined as annual averages are achievable. Real data from five mills that use scrubbers for the lime kiln are given in Figure 3.72 and Figure 3.73 above. However, the use of wet scrubbers is not necessarily required to achieve the same level of TRS emissions as that achieved by the application of other techniques.

Cross-media effects
There are no significant negative cross-media effects. Wet scrubbers simultaneously reduce SO_2 and dust emissions (see Figure 3.84 in Section 3.3.22.2).

Technical considerations relevant to applicability
Generally applicable in lime kilns that burn CNCG or fuel oil with a very high sulphur content.

Economics
No information provided.

Driving force for implementation
Legal requirements.

Example plants
IP Saillat; MB Äänekoski; SE Varkaus; MB Rauma; Portucel, Viana.

Reference literature
[33, COM 2011]

3.3.21 Reduction of NOX emissions from the lime kiln

Most of the lime kilns in kraft pulp mills are preheater rotary lime kilns that are fed with a slurry of calcium carbonate with a water content of 30 %. The kilns in kraft pulp mills resemble a standard rotary lime kiln to regenerate lime. Therefore, it is worth referring to the Reference Document on the Best Available Techniques in the Cement, Lime and Magnesium Oxide Manufacturing Industries [272, COM 2013] where lime manufacturing and the environmental control measures for standard lime kilns are described in detail.

In this section the measures that are specific for reburning lime kilns that are used in kraft pulp mills are discussed.

3.3.21.1 Selection of fuels, optimised combustion and control of the kiln operation

Description
An integrated recausticising system includes the coordination of the lime mud washing and filtration (see Section 3.3.20.2), selection of fuels, choice of the location where non-condensable gases are burnt (see Section 3.3.16.2) and control of the kiln operation in order to stabilise the process, attain an even lime quality and also achieve low total emissions to air.

I. *Selection of fuels*
The selection of fuels has a significant effect on the emission from the lime kiln. Burning oil in a lime kiln produces lower NO_X emissions than natural gas, even though oil contains significant quantities of organic nitrogen that are not present in natural gas. This is because of the higher temperatures of the natural gas flame, which causes the formation of more thermal nitrogen oxide than the burning of oil. The firing of the lime kiln with sawdust, pulverised wood or gases obtained by gasification of biomass (bark) also increases NO_X emissions.

In most cases, burning malodorous gases in a lime kiln results in a significant increase in the NO level as the malodorous gases carry additional nitrogen to the kiln. Developing low-NO_X technology for lime kiln burning, when both malodorous gases and the main fuel are present, will require additional investment, and there is no reliable technical solution available at the time of writing (2013).

II. *Optimising lime burning and control of kiln operation*
Optimisation of the kiln operation and/or homogenisation of the fuel and raw material feedings may reduce NO_X emissions. Significant parameters for process control optimisation in a lime kiln which lead primarily to better and more stable lime quality and energy savings and can have a positive effect on NO_X emissions by being optimised are:

- good mixing of fuel and air;
- air staging (reduced oxygen supply in the primary reaction zone, then increase of oxygen supply);
- control of excess air;
- optimised secondary air temperature;
- flame shape and position and temperature profile;
- lime mud flow control;
- kiln speed, fuel rate and feed rate.

Achieved environmental benefits
Reduction of emissions and energy consumption.

Environmental performance and operational data

NO_X emission data specified according to the technologies used and the operation of the lime kilns for reducing NO_X emissions (as listed under II above) have not been provided. Therefore, in Figure 3.76 and Figure 3.77 the annual average NO_X emissions achieved from lime kilns are only presented considering the fuels used and whether or not the ammonia-containing CNCG are burnt in the kiln. Where the selected fuels are not indicated the data were not provided. The use of low-NO_X burners is also indicated in the figures (further information on this technology is given in Section 3.3.21.2).

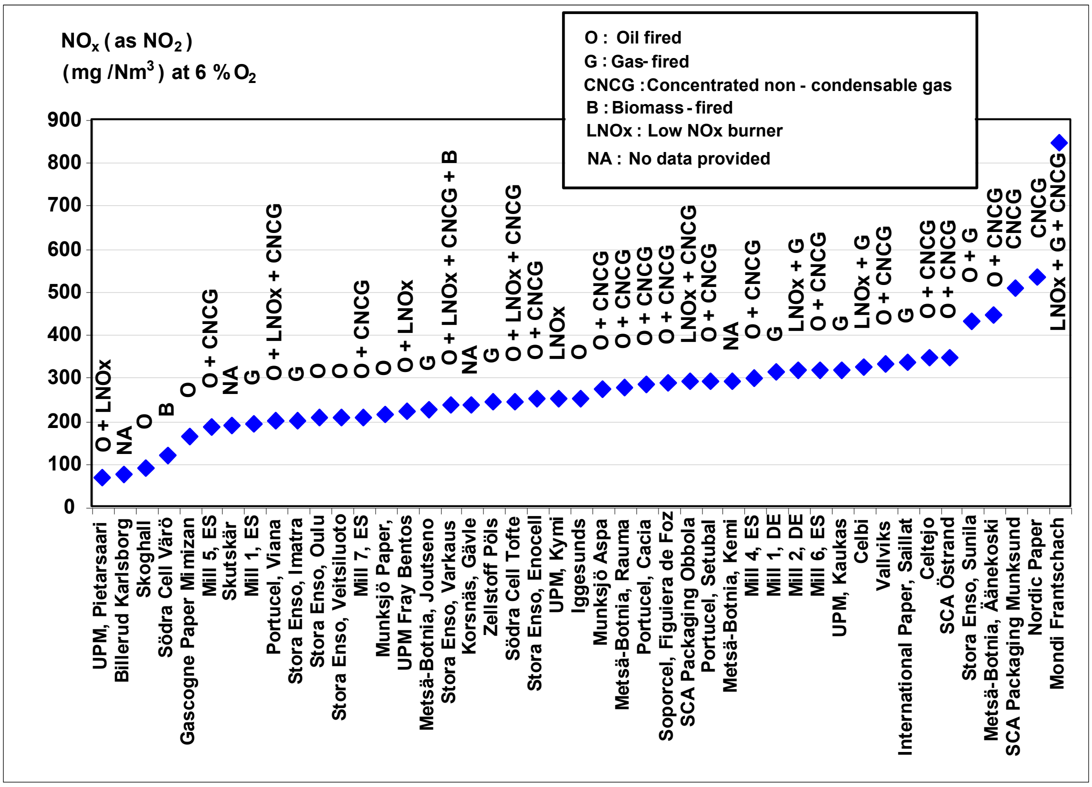


Figure 3.76: NO_X emission concentrations from lime kilns for various fuels

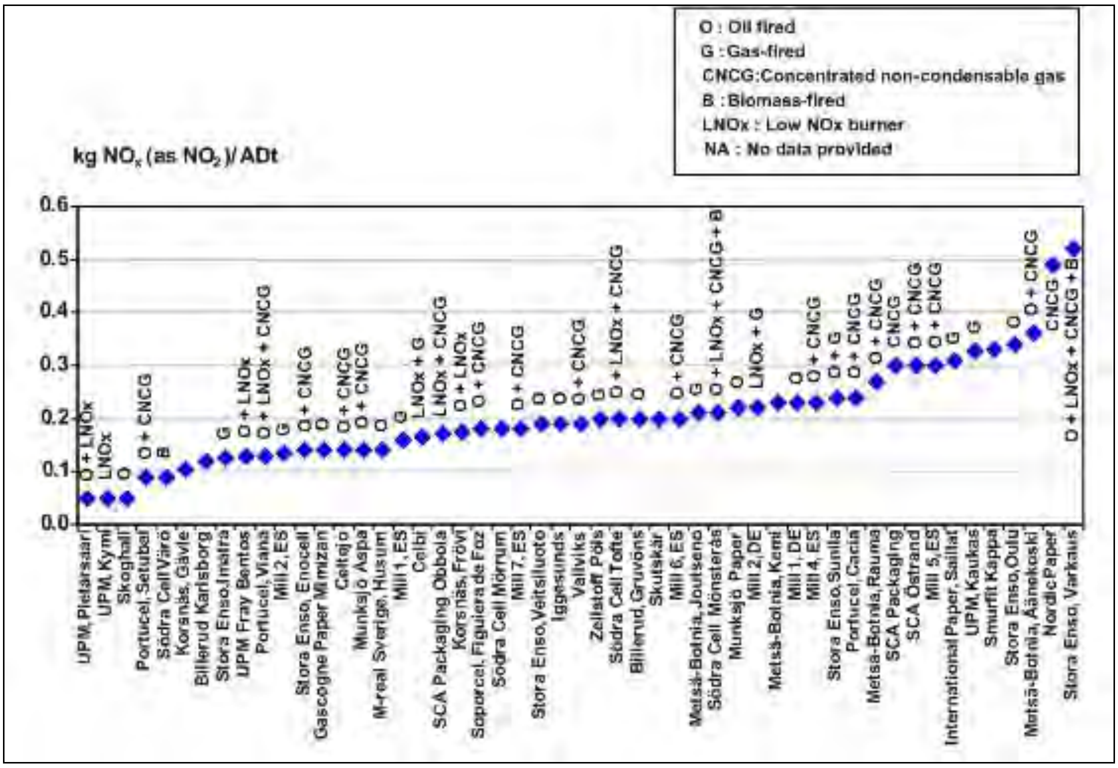


Figure 3.77: NO_X emission loads from lime kilns for various fuels

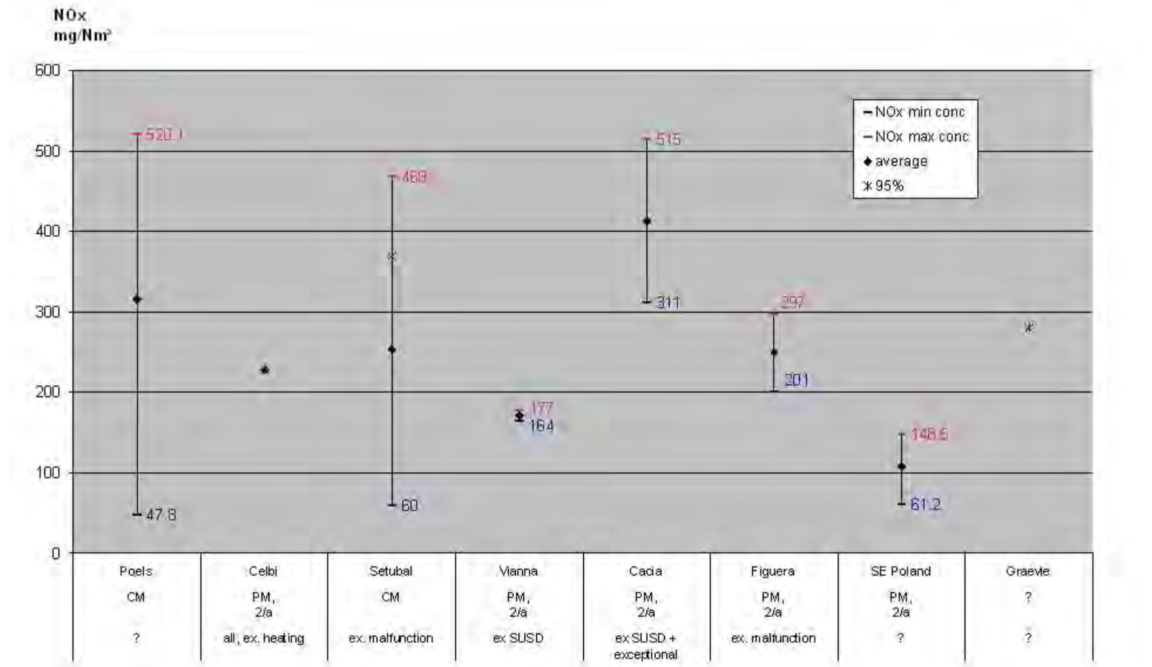
NO_X emissions achieved with primary measures in lime kilns with and without low-NO_X burners are summarised in Table 3.27. In the table, the achieved NO_X emissions are distinguished according to the main type of fuels used.

Table 3.27: NO_X emissions from reburning lime kilns

Main fuel used, burning of CNCG	**Nitrogen oxides** (as NO_2) as annual average
Oil firing (without CNCG or condensate containing methanol)	100 – 200 mg NO_X (as NO_2)/Nm^3 (at 6 % O_2) 0.05 – 0.2 kg/ADt
Oil firing (with CNCG or condensate containing methanol)	100 – 300 mg NO_X (as NO_2)/Nm^3 (at 6 % O_2) 0.1 – 0.3 kg/ADt
Gas firing (without NCG or condensate containing methanol)	200 – 350 mg NO_X (as NO_2)/Nm^3 (at 6 % O_2) 0.15 – 0.3 kg/ADt

For lime kilns that have significantly higher NO_X emissions, secondary measures such as SNCR may be considered. Experience with SNCR has been gained at single lime kilns in the lime manufacturing industry [272, COM 2013]. At reburning lime kilns that are operated in the pulp and paper industry, SNCR is not yet used however. According to an important supplier of lime kilns (confidential data), SNCR is also a reliable technical option for pulp mills.

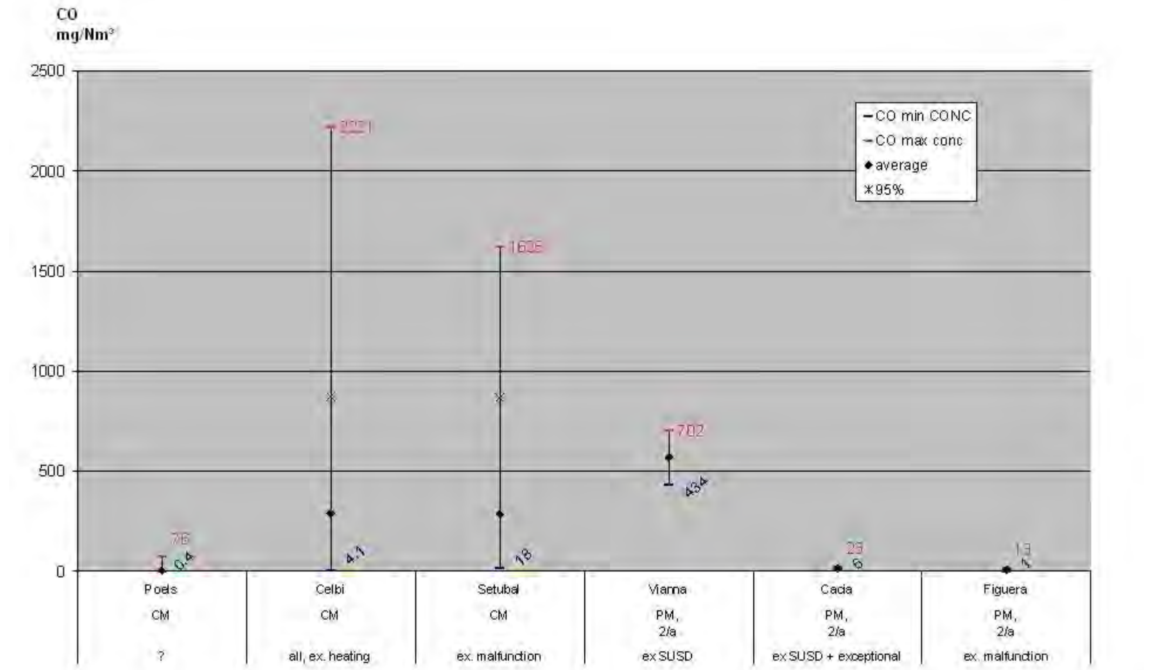
The reported short-term NO_X and CO emissions are shown in Figure 3.78 and Figure 3.79.



NB: CM = Continuous monitoring; PM = Periodic monitoring; ? = No information on type of monitoring

Source: EIPPCB questionnaires from 2007/2009 and other TWG input

Figure 3.78: **NO_X emissions from lime kilns as short-term averages**



NB: CM = Continuous monitoring; PM = Periodic monitoring; ? = No information on type of monitoring

Source: EIPPCB questionnaires from 2007/2009 and other TWG input

Figure 3.79: **CO emissions from lime kilns as short-term averages**

Cross-media effects

Lime kiln optimisation controls have been installed in a number of kraft pulp mills with success. These controls have achieved a stability of operation that has led to more stable and lower residual carbonate levels in the lime. Specific energy consumption has also been lowered, thereby saving on expensive fuels. As a side effect emissions are easier to control, more stable and generally reduced.

Technical considerations relevant to applicability
Optimising lime reburning and control of the kiln operation can be applied to new and existing kilns.

Economics
Optimisation of the firing process is associated with increased lime quality and energy savings.

Driving force for implementation
Stability of the lime quality and of the causticising process. The stability contributes to an increase in the causticising plant capacity.

Example plants
Stora Enso Veitsiluoto mill in Kemi, FI.

Reference literature
[225, Hupa 2005], [272, COM 2013].

3.3.21.2 Installation of low-NO_X burners in the lime kiln

Description
The low-NO_X burner technology used in steam boilers and power plants is also used in lime reburning. The low-NO_X burner technology allows for reducing the flame temperature and thus reducing thermal and (to some extent) fuel-derived NO_X. The NO_X reduction is achieved by an air supply in order to lower the flame temperature.

The combustion air entering the kiln via a burner, the ‘primary air’, is divided into two streams. Both air streams are necessary for the shape of the flame and to ensure its stability.

Low-NO_X burners are designed to reduce the primary air portion which leads to lower NO_X formation whereas common multi-channel burners are operated with a higher primary air portion of the total combustion air. The higher portion of the primary air leads to a shorter and more intense flame by the early mixing of hot secondary air and fuel. This results in higher flame temperatures along with the generation of higher amounts of NO_X, which can be reduced using low-NO_X burners.

Achieved environmental benefits
NO_X reduction.

Environmental performance and operational data
For achieved emissions, the reader is referred to Figure 3.76 and Figure 3.77.

Cross-media effects
No effects.

Technical considerations relevant to applicability
Low-NO_X burners can be used in both new and existing kilns.

Economics
The investment required is typically EUR 0.5 – 0.8 million. No major increase in the operating costs.

Driving force for implementation
Legal requirements.

Example plants
UPM Pietarsaari; Portucel Viana; UPM Fray Bentos; SE Varkaus; Södra Tofte; UPM Kymi; SCA Obbola; Celbi, Mondi Frontschach [33, COM 2011].

Reference literature
[33, COM 2011], [65, N.DeMartini et al. 2010], [66, FRBC 2010], [225, Hupa 2005].

3.3.22 Reduction of dust emissions from the lime kiln

3.3.22.1 Electrostatic precipitators

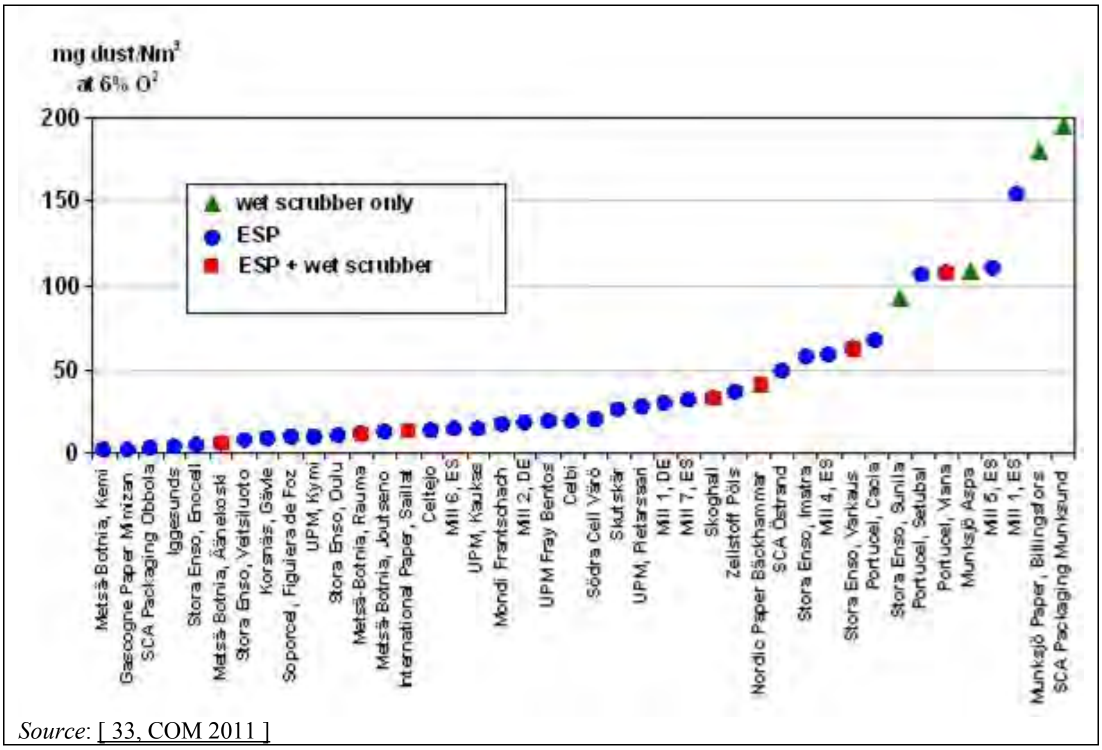
Description
Electrostatic precipitators generate an electric field across the path of particulate matter in the air stream. The particles become negatively charged and migrate towards positively charged collection plates thus removing the dust particles from the flue-gas stream. The collection plates are rapped or vibrated periodically, dislodging the material and allowing it to fall into collection hoppers below. Factors affecting ESP efficiency are flue-gas flow rate, strength of the electric field, conductivity of the dust, moisture content, and shape and area of the electrodes. In particular, the electric field can be unfavourably reduced by a build-up of material that forms an insulating layer on the collection plates.

In order to reduce the emission of CaO, Na_2SO_4 and Na_2CO_3 particulate matter, electrostatic precipitators (ESPs) are installed in nearly all pulp mills. ESPs have better dust removal efficiencies than a scrubber only. A few mills use ESPs and additionally wet scrubbers (see Section 3.3.22.2).

ESPs require regular maintenance and monitoring. Overloading or uneven loading may cause clogging of the chambers in the electrostatic precipitator.

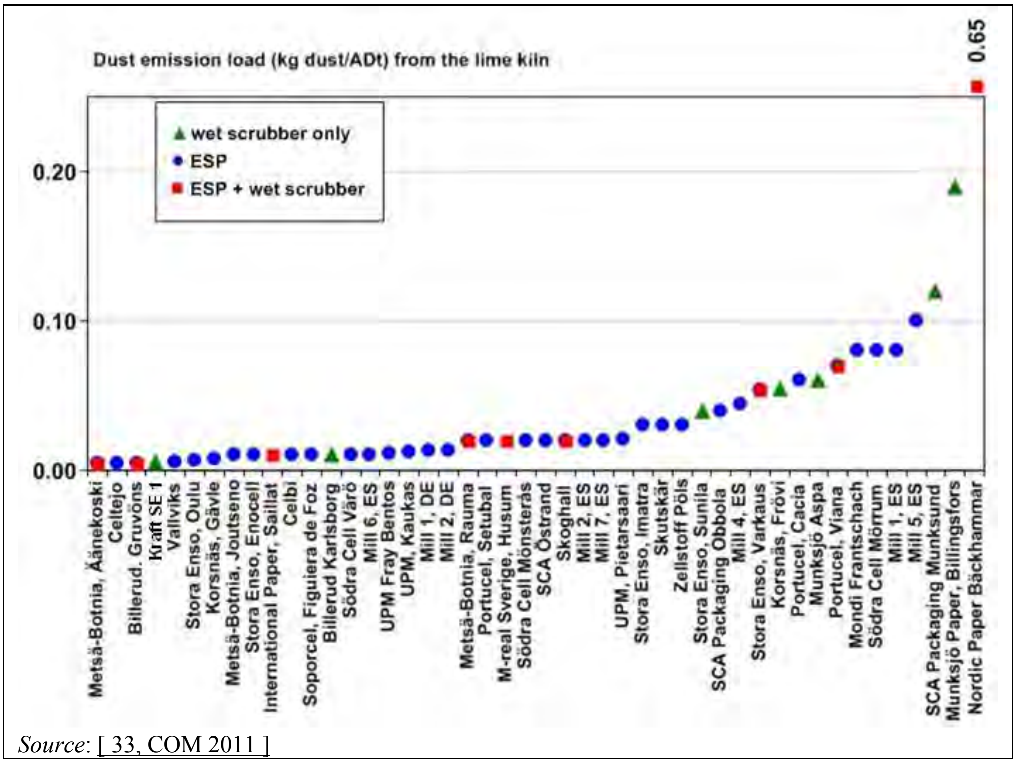
Achieved environmental benefits
Reduction of dust emissions.

Environmental performance and operational data
Figure 3.80 (expressed as annual average emission loads) shows achieved dust emissions from lime kilns of European kraft pulp mills. Some mills only reported emission loads and no concentration value. Because of the differences regarding the flue-gas flow, dust concentrations do not always correlate with the corresponding specific dust emission load (kg dust/ADt). It also indicates whether just ESPs or ESPs and scrubbers are used.



Source: [33, COM 2011]

Figure 3.80: Dust emission concentrations from lime kilns including applied dust abatement technique

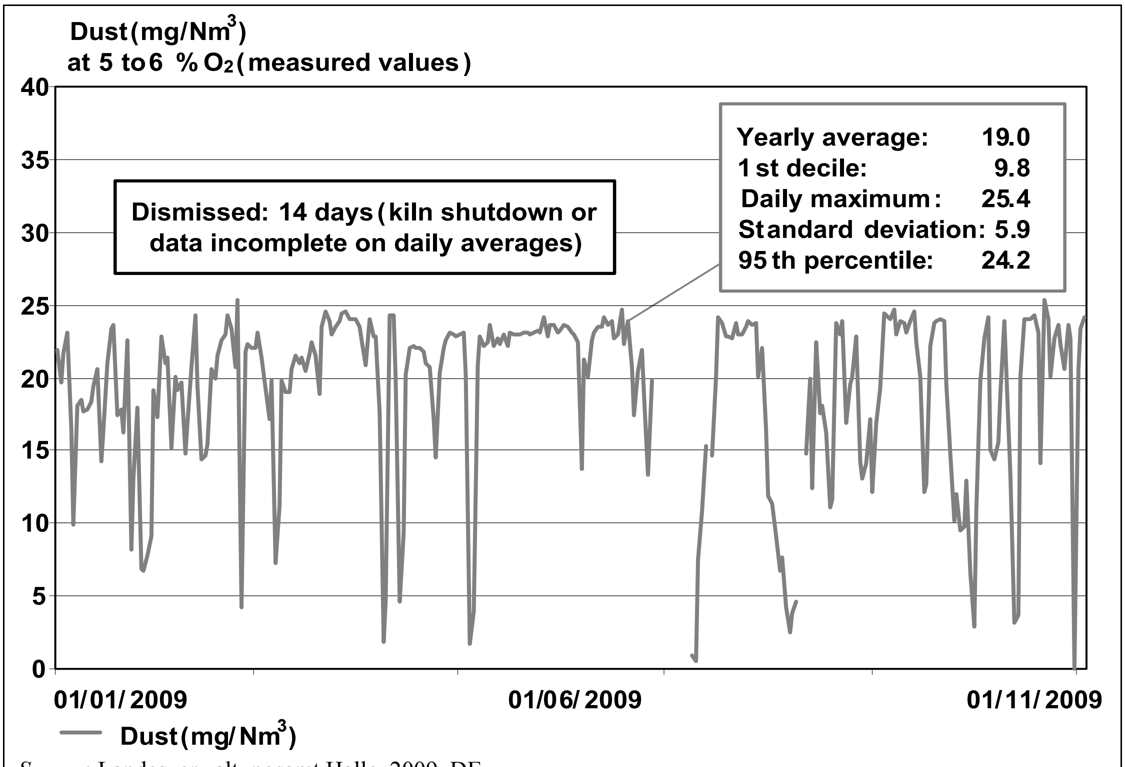


Source: [33, COM 2011]

Figure 3.81: Dust emission loads from lime kilns including applied dust abatement technique

The figures show that the electrostatic precipitators of many mills achieve dust emissions from reburning lime kilns of between 5 mg/Nm^3 and 25 mg/Nm^3 determined as annual average values (at 6 % O_2) or 0.02 kg dust/ADt.

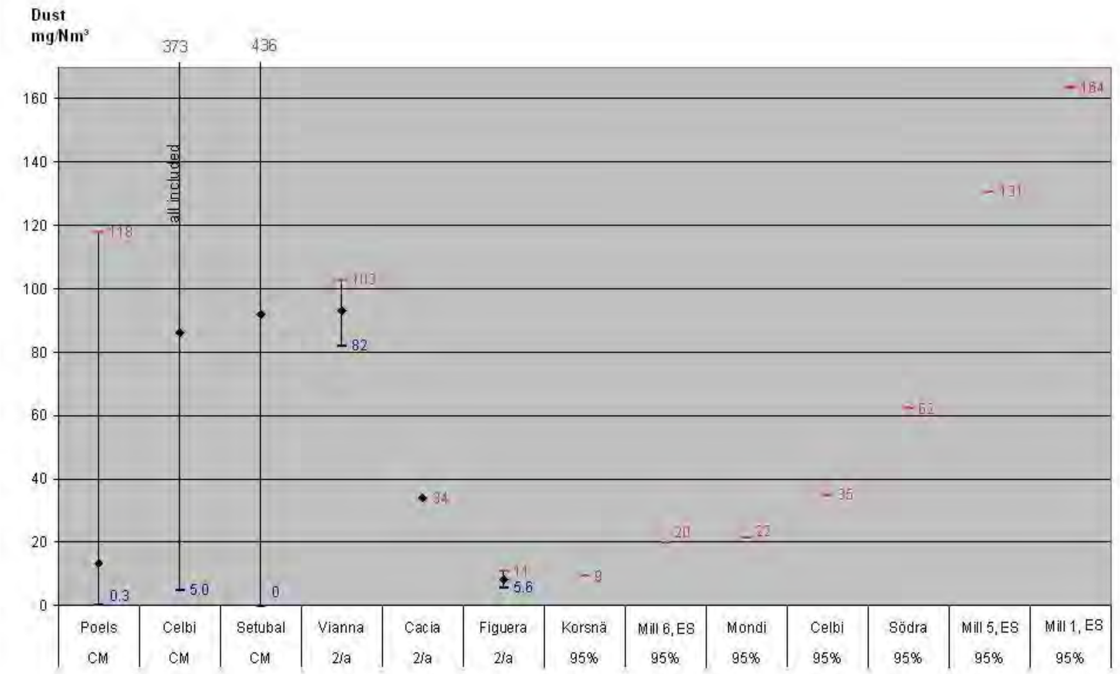
An example of achieved dust emissions over a complete year is given in Figure 3.82. Data show that in this case the dust emissions from the lime kiln are <25 mg/Nm^3 as a daily average (dry gas, 273 K, 5 – 6 % O_2), or less than 20 mg/Nm^3 as an annual average. The data are taken from the on-line transfer of emission data of the competent authority. Dust is measured continuously in this case.



Source: Landesverwaltungsamt Halle, 2009, DE

Figure 3.82: Continuously measured daily average data for dust emissions downstream of the ESPs of a kraft mill's lime kiln

The reported short-term dust emissions are shown in Figure 3.83.



NB: CM = Continuous monitoring

Source: EIPPCB questionnaires from 2007/2009 and other TWG input

Figure 3.83: Dust emissions from the lime kiln as short-term average

The majority of dust leaving the kiln with the flue-gas is CaO. It mostly escapes from the feed end of the kiln. The amount of dust coming from the hot end of the kiln is significantly lower. The main components of the dust emission of the stack are fine Na_2SO_4 and Na_2CO_3 particles, because CaO particles are more efficiently captured in flue-gas cleaning equipment.

The efficiency of an existing ESP can be improved by the addition of chambers (electrical fields) in line.

Cross-media effects

The energy consumption increases due to the operation of the ESPs.

Technical considerations relevant to applicability

The measure can be adopted in new and existing kraft mills provided that there is sufficient space.

Economics

In a 1 500 ADt/d kraft mill, the investment required for an electrostatic precipitator at the lime kiln is EUR 5 – 6 million. The operating costs are less than EUR 0.3 million/year.

Driving force for implementation

Legal requirements. The emission levels achieved depend mainly on the targets set by the competent authorities or by the operator itself.

Example plants

Numerous plants in Europe.

Reference literature

[33, COM 2011]

3.3.22.2 Electrostatic precipitators followed by wet scrubbers

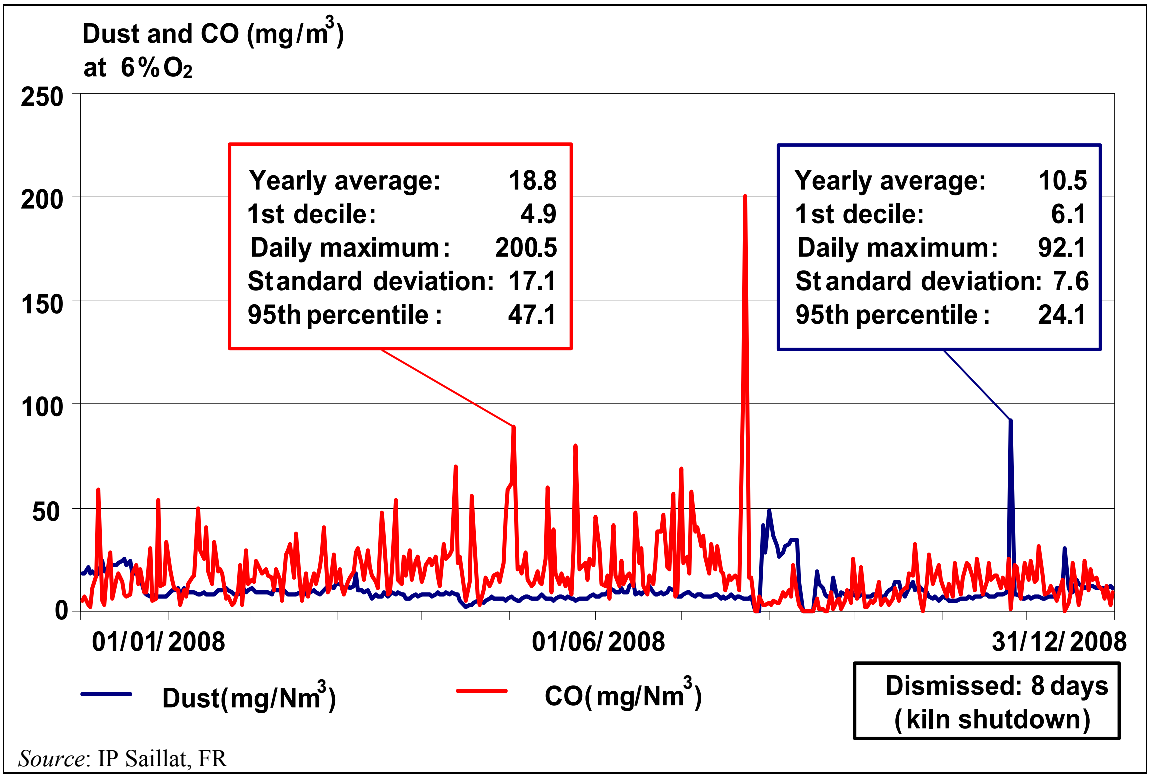
Description and achieved environmental benefits

Dedusting of the flue-gas is mostly carried out by means of ESPs (see Section 3.3.22.1) but in some mills it is further cleaned with wet scrubbers. As washing liquor, Na(OH) is usually used. The separation efficiency of the wet scrubber also depends on the particle size of the dust and on the dimension (and thus the pressure loss) and efficiency of the last drip catcher.

Environmental performance and operational data

Figure 3.80 and Figure 3.81 (expressed as annual averages) presented in Section 3.3.22.1 above show achieved dust emissions from lime kilns of European kraft pulp mills. As shown, lime kilns that are equipped with ESPs and additionally with scrubbers achieve very similar dust emissions to those that use ESPs only.

An example of achieved dust emissions over a complete year is given in Figure 3.84. Data show that in this case the dust emissions from the lime kiln are <25 mg/Nm^3 as a daily average (dry gas, 273 K, 5 – 6 % O_2), or around 10 mg/Nm^3 as an annual average. Dust is measured continuously in this case.



Source: IP Saillat, FR

Figure 3.84: **Daily average data over a full year for dust emissions from a lime kiln equipped with an ESP and a wet scrubber (CO emissions are also included)**

Cross-media effects

No significant effects.

Technical considerations relevant to applicability

Generally applicable. If ESPs are well designed, dimensioned, operated and maintained they achieve almost the same dust emissions as those mills that also apply wet scrubbers.

Economics

No information provided.

Driving force for implementation
Legal requirements, simultaneous removal of sulphuric emissions and odour.

Example plants
IP Saillat; Billerud Gruvöns; MB Äänekoski; SE Varkaus; MB Rauma; M-real Husum, Skoghall; SE Varkaus; Portucel, Viana; Nordic Paper Bäckhammar.

Reference literature
[33, COM 2011]

3.3.23 Substitution of fossil fuels used in the lime kiln

Description
The main consumer of fossil fuels in a kraft pulp mill is the lime kiln, representing approximately 1.1 – 1.4 GJ/ADt heat input. There are various technical alternatives to replace fossil fuels in the lime kiln with biofuels:

i) Use of bark powder in the lime kiln (e.g. KRAFT SE 1): The bark is dried, pulverised in a grinder and fired into a pulverised fuel burner.

ii) Gasification of bark and use of the generated gas in the lime kiln (e.g. Södra Värö, SE): The gasification system consists of a biofuel receiving station or fuel silo, a fuel screening and crushing section, a bark dryer, an air preheating section, a start-up burner and the gasifier itself. A gas line leads the pyrolysis gases from the gasified bark directly to the lime kiln. The bark to be gasified in the lime kiln gasifier should have a fuel moisture content of <15 % in order to avoid an extensive flue-gas flow that would limit the kiln capacity. A dryer is therefore needed in the system. The bark can be dried with excess secondary heat from the pulp mill.

The circulating fluidised bed gasifier is a refractory line reactor. The air required for gasification is introduced to the reactor through the bottom of the reactor. Due to the high velocity, the particles carry over into the cyclone where gas and the particles are separated. The gasifier operates at a temperature range of 600 – 700°C. Ash is removed from the bottom of the reactor.

In energy-efficient mills, bark is available to be used in the lime kiln, replacing fossil fuels because under normal operation bark is not needed for steam production. The steam generation from black liquor alone is higher than the process steam demand of the pulp mill. The bark surplus can be used either in the lime kiln or can be sold as dried biofuel or used for heat deliveries, e.g. to district heating networks.

iii) Some mills use tall-oil or tall-oil pitch in the lime kiln.

iv) Replacing fuel oil with lignin in the lime kiln has been investigated recently in the FRAM2 (Future Resource-Adapted Mill) research program [49, N.Berglin et al. 2010]. A full-scale trial to fire lignin powder in a lime kiln was carried out at the Södra Mönsterås mill. In total, 37 tonnes of lignin were co-fired with fuel oil. For part of the trial the kiln was operated on 100 % lignin. The experiences from the trial imply that it is possible to achieve stable and continuous operation of a lime kiln when lignin is used as the main fuel. The temperature levels in the kiln are of the same order of magnitude as when firing fuel oil or wood powder. Sulphur capture by the lime is very efficient, but there is a threshold above which SO_2 emissions increase rapidly. In the trial, this occurred when going from 90 % to 100 % lignin firing. White liquor can be produced from the lime with the same causticising efficiency and at the same rate as during normal operation. The mill operators also commented that it was easier to control the performance of the kiln when co-firing lignin and oil compared to the normal operation with co-firing of bark and oil.

Achieved environmental benefits

Minimisation of the need for fossil fuels. CO_2 neutral heat supply in the lime kiln.

Environmental performance and operational data

i) The KRAFT SE 1 mill, SE, for instance, has used pulverised bark in the lime kiln since the 1980s.

ii) Since 1985 the Södra Värö mill, SE, has run a bark gasifier producing pyrolysis gases with a capacity of 28 MW. Metsä Botnia has decided to invest in a gasification plant at the Joutseno pulp mill in Finland. The investment will replace fossil fuel used in the lime kiln with biofuel, which is manufactured of bark. The mill will become a carbon dioxide neutral plant during its standard production. The gasification plant will utilise the mill's excess heat during drying of the bark.

iii) Botnia's Rauma mill reduced the use of fossil fuels so that in normal operations the mill runs exclusively on biofuels. Earlier, fossil fuel use was confined to start-ups, process disturbances and the lime reburning process. The fossil fuels utilised in the lime reburning process have been replaced thanks to cooperation with the nearby tall oil refinery. Tall oil as a by-product of the softwood pulp production process is sold to the refinery and in return the pulp mill receives pitch, which is burnt in the lime kiln as a replacement for fossil fuel.

Cross-media effects

The heat for drying the bark to 85 % DS can be recovered from the flue-gases of the recovery boiler or the lime kiln itself. No significant negative environmental effects are reported. Firing biomass in the lime kiln increases the NO_X emissions compared to oil-fired kilns and results in similar NO_X levels as from gas-fired kilns.

Technical considerations relevant to applicability

The application will depend on the legal framework on green energy, the costs of fossil fuel and some local considerations. The gasifier technology for lime kilns has been around since the 1980s. However, for economic reasons it was not used on a larger scale. The replacement of fossil fuels in the lime kiln is today's available technology. Some mills use the by-product tall oil or tall oil pitch in the lime kiln too which is also a regenerative biofuel.

Economics

The economy and payback time of the use of biomass-based fuel in the lime kiln and some other situations (start-up, disturbances) depend on oil and gas prices, the necessary gasifier size and the costs of carbon dioxide emissions. The bark boiler can be entirely eliminated in energy-efficient kraft pulp mills.

Driving force for implementation

High prices for fossil fuels and the CO_2 emissions allowances. The dependency on fossil fuels can be reduced.

Example plants

Södra Värö mill, SE; KRAFT SE 1; Botnia Rauma mill, FI; Joutseno mill. FI.

Reference literature

[49, N.Berglin et al. 2010], [134, Södra Värö 2009], [135, KRAFT SE 1 mill 2010].

3.3.24 Reduction of NO_X emissions from dedicated TRS burners

3.3.24.1 Staged incineration

Description

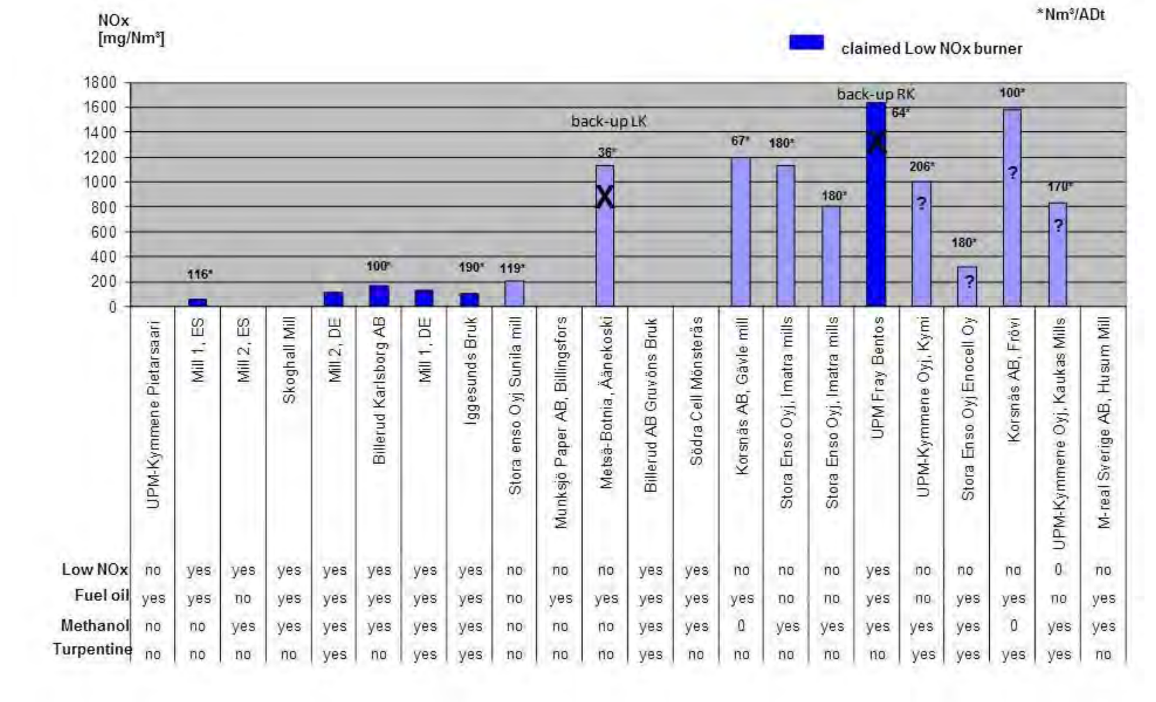
Staged incineration is based on the use of two burning zones, with controlled air ratios and temperatures in a first chamber. The first burning zone operates at substoichiometric conditions to convert ammonia compounds into elementary nitrogen at a high temperature. In the second zone, an additional air feed completes combustion at a lower temperature. After the two-stage incineration, the flue-gas flows to a second chamber to recover the heat from the gases, producing steam in the process.

Achieved environmental benefits

The reduction of NO_X emissions from the incineration of strong gases in dedicated TRS burners.

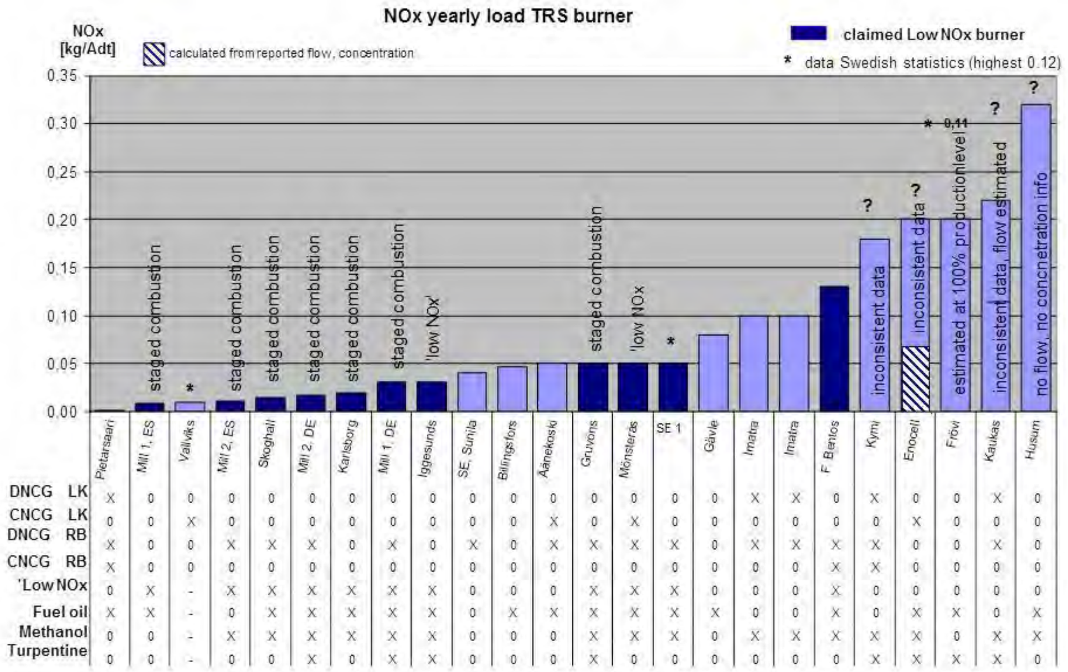
Environmental performance and operational data

Yearly average emissions reported, both in concentration and load terms, are shown in Figure 3.85 and Figure 3.86.



Source: EIPPCB questionnaires from 2007/2009

Figure 3.85: NO_X emission concentrations from dedicated TRS burners



	Pietarsaari	Mill 1, ES	Vallviks	Mill 2, ES	Skoghall	Mill 2, DE	Karlsborg	Mill 1, DE	Iggesunds	SE, Sunila	Billingsfors	Äänekoski	Gruvöns	Mönsterås	SE 1	Gävle	Imatra	Imatra	F Bentos	Kymi	Enocell	Frövi	Kaukas	Husum
DNCG LK	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	X	0	X	0	0	X	0
CNCG LK	0	0	X	0	0	0	0	0	0	0	0	X	0	X	0	0	0	0	0	0	X	0	0	0
DNCG RB	X	0	0	X	X	X	0	X	0	X	0	X	X	X	X	0	X	X	X	X	0	0	X	0
CNCG RB	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	X	0	0	0	0
'Low NOx	0	X	-	X	X	X	X	X	X	0	0	0	X	X	X	0	0	0	X	0	0	0	0	0
Fuel oil	X	X	-	0	X	X	X	X	X	0	X	X	X	X	X	X	0	0	X	0	X	X	0	X
Methanol	0	0	-	X	X	X	X	X	X	0	0	0	X	X	X	0	X	X	X	X	X	0	X	X
Turpentine	0	0	-	0	0	X	0	X	X	0	0	0	X	0	0	0	0	0	0	X	X	X	X	0

Source: EIPPCB questionnaires from 2007/2009

Figure 3.86: NO$_X$ emission loads from dedicated TRS burners

Cross-media effects
No information provided.

Technical considerations relevant to applicability
Generally applicable for new plants and for major refurbishments; for existing mills, if space allows for installation of equipment.

Driving force for implementation
Reduction of NO$_X$ emissions.

3.3.25 Reduction of emissions from bark or multi-fuel boilers

See Section 2.9.7.

3.3.26 Integrated waste management concept

Description
Integrated waste management systems start with the separation of waste fractions at the source and aim to reduce the amount of waste to be disposed of. They enable high rates of reuse, recycling and recovery of process residues (see Section 2.9.8). For any residue, the possibilities for prevention, reuse, recycling and recovery as a raw material or as a source of energy (see waste hierarchy of [205, WFD 98/EC 2008]) are assessed. As a last option, the remaining waste is safely disposed of.

Environmental performance and operational data
Table 3.28 compiles available data on major waste fractions that arise in market kraft pulp mills. The data provided show huge differences in how waste is being handled and recorded. Differentiation and grouping of waste types differ from mill to mill; some mills reported waste

fractions separately while others summed them up. Additionally, waste fractions that in one mill are considered for reuse or recycling are being landfilled in others. Some very low figures for waste to be disposed of correlate with higher recycling for the same waste fraction (e.g. lime mud). The comparability of data from different mills is therefore limited.

Table 3.28: Major waste fractions from market kraft pulp mills

Residues to be reused or recycled		
Waste fraction	**Source**	**kg DS/ADt of pulp**
Bark and wood residues, wood handling waste etc.	Wood yard	11.4 – 205
Primary sludge(1)	Primary waste water treatment	2.1 – 13
Secondary sludge(1)	Biological waste water treatment	1.6 – 9.7
Lime mud	Causticising	1 – 29
Others (paper, glass, scrap metals, plastic etc.)	Whole mill	1.5 – 2.5
Waste fraction	**Source**	**kg DS/ADt of pulp**
Dregs, grits, slaker grits	Recovery/causticising	2 – 22
Green liquor sludge	Causticising	6 – 10.9
Lime mud	Causticising	0.01 (2) – 51.3
Fluidised bed sand	Bark boiler	0.27 (3) – 28
Ashes	Bark boiler	3.5 – 11
General non-pulp-specific waste (glass, scrap metals, plastic, etc.)	Whole mill	0.4 – 2.4

(1) One plant reported a total (primary + secondary sludge) of 49 kg DS/ADt.
(2) 29 kg DS/ADt declared to be recycled.
(3) About 6 kg DS/ADt declared to be reused or recycled.
Source: [138, PP TWG 2009]

Large portions of the generated process residues can be reused, recycled or recovered. The amount of waste landfilled totalled between 15 and 38 kg DS/ADt, with some exceptions reaching 52 kg/ADt. A small amount of hazardous waste (between 0.14 and 1.2 (wet) kg DS/ADt of pulp) is collected separately at the mills and needs to be safely handled and disposed of.

Technical considerations relevant to applicability
Generally applicable.

Economics
Reducing the amount of waste to be landfilled in many cases also reduces costs.

Driving force for implementation
Legal requirements; increasing costs for landfilling.

Example plants
For the compilation of data given in Table 3.28, the following plant data were assessed: ZPR Blankenstein; Celbi; Celtejo; Portucel Setubal; Portucel Viana, Portucel Cacia; Södra Cell Värö; Soporcel Figueira da Foz; Stendal Arneburg; SE Poland SA.

Reference literature
[138, PP TWG 2009]

3.3.27 Measures for increased energy efficiency

With regard to energy efficiency, useful general information can be found in the Reference Document on Best Available Techniques for Energy Efficiency (ENE) [268, COM 2009].

Description

The measures for increasing energy efficiency ([34, Kankkonen et al. 2010], [35, Raukola et al. 2002]) can be distinguished into measures for reducing the consumption of heat or steam, for lower consumption of electrical energy and for higher power production especially by use of highly energy-efficient recovery boilers.

I. Measures for reducing heat losses and for low heat consumption:

- high DS content of bark by efficient pressing or drying;
- high efficiency steam boilers, e.g. low flue-gas temperatures, high amount of air preheating, high amount of feedwater preheating, high main steam temperature and pressure;
- effective secondary heating systems, for example the most effective mills possess three clean hot water levels, e.g. 80 – 90 °C, 60 – 70 °C and 40 – 50 °C, and several secondary condensate heat levels where the condensate temperature equals the usage temperature;
- well closed water system that leads to reduced water consumption;
- relatively well closed bleaching plant;
- high pulp concentration (middle or high consistency technique);
- highly effective evaporation plants with an increased number of effects (which may also save power depending on the type of evaporator); the evaporation plant has the highest development potential;
- recovery of heat from dissolving tanks, e.g. by vent scrubbers;
- management of secondary heat balance with optimised water and secondary condensate utilisation;
- recovery of waste heat from effluents and other sources;
- use of available low temperature waste heat sources (secondary heat) to heat buildings, boiler feedwater and process water;
- heat recovery from the flue-gas from the recovery boiler between the ESP and the fan;
- monitoring and control of processes by advanced control systems;
- optimise integrated heat exchanger network;
- energy management system.

II. Measures for low consumption of electrical power:

- as high a pulp consistency as possible in screening and cleaning;
- speed control of various large motors;
- efficient vacuum pumps;
- proper sizing of pipes, pumps and fans;
- optimised tank levels.

III. Measures for a high generation of electric power:

- high black liquor dry solids content (increases boiler efficiency, steam generation and thus electricity generation);
- high recovery boiler pressure and temperature;
- high biomass boiler main steam pressure and temperature (if operated on site);
- outlet steam pressure in the back-pressure turbine as low as is technically feasible;
- condensing turbine for power production from excess steam;
- high turbine efficiency;
- preheating of feedwater to a temperature close to the boiling temperature;

- ◦ preheating of combustion air and fuel charged to boilers.

Further improvements in energy efficiency can be achieved through process integration that makes it easier to utilise surplus heat from one process in another.

Achieved environmental benefits

The energy-saving techniques reduce the thermal and electrical energy consumption and the associated CO_2 emissions. Resources, indirect emissions and waste that are associated with energy generation are reduced. The less energy is used, the less fossil fuels or other fuels are used and the less emissions to air including carbon dioxide are generated.

Environmental performance and operational data

When applying the energy-saving measures mentioned before, the indicative electrical energy consumption levels that can be achieved for a market pulp mill are 660 – 750 kWh/ADt. The energy required for producing the bleaching chemicals is not included in this figure and adds 100 kWh/ADt to the indicative level if done on site. Due to the higher yield of eucalyptus wood compared to softwood, recently built eucalyptus market kraft pulp mills have a lower electrical energy demand. The indicative energy consumption levels for eucalyptus pulp are 550 – 700 kWh/ADt.

The following system boundaries were considered for the indicative energy consumption levels:

(1) The indicative energy consumption levels refer to entire mills' net production and include pumps, agitators and compressed air. Peripheral subsystems for raw and waste water, sludge and rejects such as dissolved air flotation, reject screw presses or sludge presses, and waste water treatment are also covered.
(2) The figures represent the gross energy consumption and do not take into consideration that most of the mills produce significant parts of the energy themselves by incinerating all of their black liquor. Several of the mills also produce steam from burning bark, sludge, etc. which is also not taken into account for gross energy.
(3) The ranges include all process units related to kraft pulping, starting with the wood yard and ending either at the storage tank where the pumpable pulp (ready for use) is stored (for integrated mills) or after the pulp dryer (for market pulp).
(4) The figures for power consumption do not consider the primary energy input of fuels for the generation of power but represent the process heat and power used.
(5) For heat, the consumption values refer to the thermal capacity of the used steam.

Some of the energy-saving techniques are implemented by replacing old equipment with new techniques. New equipment mostly has a lower energy consumption and is more energy-efficient (e.g. debarkers, screens, washers, pumps, evaporators). Other measures are related to best practice, good management, process control and stepwise optimisation of the processes. Higher energy efficiencies have been achieved through continuous trimming but primarily through major retrofit projects or entirely new production lines. A modern kraft pulp mill could be totally self-sufficient in terms of energy with respect to both electricity and steam.

The biomass fuel surplus could be used outside the pulp mill to replace fossil fuels used for heat and/or power production, e.g. for:

- electricity – particularly in connection with black liquor gasification (see Section 3.4.2);
- solid or liquid biomass fuel – dried bark, tall oil, lignin or methanol;
- heat – to a district heating network.

The achieved heat and power consumption is reported by using data from an existing mill [138, PP TWG 2009] and comparing them with the Ecocyclic Pulp Reference mill KAM2 [193, Axegård et al. 2003]. This reference mill is designed with all modern processes in operation in the reference year (2002), however not all at the same plant. This reference mill has an often considerably lower steam demand than the current average mill. Although the KAM reference mill is much more energy-efficient than typical (average) mills, it is possible to go even further and substantially decrease the heat demand.

In Table 3.29, the BAT reference mill according to the Swedish MISTRA Research Programme is compared with the achieved energy consumption in an energy-efficient example mill that has undertaken an energy management and improvement program, the Swedish Södra Värö mill.

Table 3.29: Comparison between the steam demand (GJ/ADt) of the BAT reference mill with ECF bleaching and an energy-efficient market kraft pulp mill

Heat-consuming process	**KAM2 (summer)**	**Södra Värö mill (projected)**
Wood yard	0	ND
Cooking	1.6	2.25
Hot water production	-	0.05
Oxygen delignification	0.14	0.08
Bleaching	1.37	1.33
Bleaching chemical preparation	0.10	0.14
Sum fibre line	***3.21***	***3.85***
Evaporation + stripper	4.01	3.78
Dryer	2.20	2.17
Soot blowing + blowdown	1.01	1.23
Sum dryer and recovery	***7.21***	***7.18***
Miscellaneous, losses	0.37	0.39
Sum entire mill	**10.8**	**11.4**
Purchased fuel	0	ND

NB:
ND = No data
Source: [134, Södra Värö 2009], [193, Axegård et al. 2003].

It appears that the Södra Värö mill has nearly the same steam requirements as the BAT reference mill. However, the Värö mill applies TCF bleaching which requires slightly more steam than ECF bleaching and includes steam consumption in summer and winter (during the winter the consumption may increase by roughly 0.8 GJ/ADt because of the thawing of frozen wood chips).

Most of the steam demand can be satisfied by low-pressure steam (approximately 145°C). Medium-pressure steam (180 – 190°C) represents roughly 40% of the steam consumption and is primarily used in cooking, oxygen delignification and the pressurised (PO) stages.

The simplified steam balance of the BAT reference mill is shown in Table 3.30 distinguishing market pulp production from integrated fine paper manufacturing.

Table 3.30: **Steam balance of Ecocyclic Pulp Reference mill KAM2 including turbines**

Energy production and consumption	**Bleached market softwood pulp**		**Integrated fine paper mill**	
	GJ/ADt	**Produced power (kWh/ADt)**	**GJ/ADt**	**Power produced and used (kWh/ADt)**
Production				
Black liquor	17.7		14.9	
Non-condensable gases	0.2		0.2	
Secondary heat	0.6		0.2	
Bark	0		1.8 + 0.2 bought bark	
Total	18.5		17.3	
Consumption				
Processes (incl. soot blowing)	10.8		13.6	
Back-pressure power	2.9	790	3.7	984
Condensing power	1.7	465	0	0
- Ditto, condenser	3.2			
Bought power		0		504
Total	**18.5**	**1 255**	**17.3**	**1 488**
Source: [193, Axegård et al. 2003]				

The market kraft pulp mill has a considerable steam surplus which is used for condensing power production. The mill itself consumes 712 kWh/ADt (see Table 3.32) resulting in an electric power surplus of about 540 kWh/ADt. The reference mill does not run a bark boiler. Bark is dried and gasified bark is used in the lime kiln. Surplus bark is sold instead of used for steam generation. Secondary heat is recovered heat that is used to preheat make-up water and condensate from the condensing turbine.

In the case of integrated fine paper mills, it is more difficult to derive representative consumption values for energy-efficient mills because of the complexity of the supply to the paper machine; in most cases two or more different fibre types are used (the reference mill uses 25 % softwood, 75 % hardwood, 20 % filler and some starch for surface sizing). The power demand of the chemical pulp reference mill department of the integrated fine paper mill is 588 kWh/ADt and hence lower than for the market kraft pulp mill. The reference paper mill requires 900 kWh/ADt which sums up to a power demand of 1 488 kWh/ADt for the integrated mill. The integrated reference mill has a bark boiler and is nearly self-sufficient with steam. As an average only 1 % is based on bought fuel. However, about 35 % of the electricity demand is purchased (504 kWh/ADt).

This example illustrates that integration of pulp and paper mills can take care of the steam surplus in an energy-efficient pulp mill but there is a deficit with regard to the power balance.
Generally achievable steam consumption levels (in GJ/ADt) as an annual average, if the processes are well designed and operated, can be found in Table 3.31. Steam for any production of electrical power is not included in these figures.

Table 3.31: **Steam consumption of energy-efficient market bleached kraft pulp mills expressed as an annual average**

Process	Cooking	O_2 delignification	Bleaching	Drying	Evaporation	Other	**Total**
Steam consumption (GJ/ADt)	1.6 – 2.0	0.2 – 0.4	1.5 – 2.0	2.2 – 2.6	4.0 – 4.5	1.5 – 2.0	**11 – 12**

The heat demand of the lime kiln (fuels used for the reburning of lime mud) is not included in the steam demand given in Table 3.31. About 1.1 – 1.4 GJ/ADt of primary thermal energy for lime reburning has to be added to the steam demand to get the total process heat demand.

It is currently not possible to present reliable and comparable figures on the total use of process heat per tonne of kraft pulp. Methods to monitor, calculate and report the heat energy used differ between mills. Heat consumption also depends to some degree on where the mill is geographically situated. Heat (and electricity) consumption data should be interpreted together with the simplified energy balances of the mill. Dumped steam is not part of the process heat used. However, it may occur that a new piece of process equipment consumes less steam but the surplus steam has no immediate alternative use. The mills should always strive towards finding such a use.

The power consumption of an energy-efficient market pulp mill is typically between 660 kWh/ADt and 800 kWh/ADt. The reference mill's consumption is 712 kWh/ADt (see Table 3.32). The energy required for producing the bleaching chemicals is not included in the figures and would add 100 kWh/ADt.

Table 3.32: Power consumption of the BAT reference mill with ECF bleaching (in 2002)

Processes	Power consumption [kWh/ADt]
Wood yard	45
Digester	44
Brown stock washing and screening	60
Oxygen delignification	60
Bleaching	80
Post-screening	45
Drying	120
Evaporation	30
Recovery boiler	60
Causticising and lime kiln (incl. gasification of bark)	57
Cooling tower, etc.	20
Raw water	20
Effluent treatment	30
Bleaching chemical preparation (incl. chemicals for oxygen delignification)	10
Miscellaneous consumers, losses	30
Total	**712**

Source: [193, Axegård et al. 2003]

Recently started eucalyptus greenfield mills achieve considerably lower electrical power consumption levels. The lower power consumption is partly due to new technology and partly due to the higher yield of eucalyptus wood compared to softwood. The higher yield gives lower specific energy consumption per tonne of pulp and lower specific electrical energy being generated because less organic material is converted during cooking into black liquor to be burnt later in the recovery boiler.

a) The Veracel ECF eucalyptus greenfield kraft pulp mill, Brazil, started production in 2005 and manufactured 1.1 million tonnes of bleached kraft pulp in 2008. In its latest sustainability report, the mill reported the electrical power-related values shown in Table 3.33. In most modern mills, bark is not burnt in the mill but forest debarking is utilised.

Table 3.33: **Power balance of the Veracel kraft pulp mill**

	Electrical energy (kWh/ADt)		
	2006	**2007**	**2008 (1)**
Total electrical energy generated in the facilities	810	826	750
Electrical energy used in pulp production	607	553	520
Acquired electrical energy	0	0	110
Sold energy	203	213	230

NB:
(1) In 2008, Veracel spent 78 days without generating energy due to technical problems in the turbo-generator. During that period the company had to acquire energy to produce pulp. Values for 2007 do not match up 100 %.
Source: [122, Veracel 2009]

b) The greenfield Fray Bentos ECF eucalyptus kraft pulp mill, Uruguay, started production in 2007 and in 2009 manufactured 1.1 million tonnes of bleached kraft pulp. The Botnia Annual Report 2009 reported electrical power production of 826 kWh/ADt and only 500 kWh/ADt of power consumption [119, Botnia 2010]. The power used for the production of chemicals is not included in the energy values for the Veracel and Fray Bentos mills.

For market bleached kraft pulp mills, the recovery boiler may produce all the steam needed in the mill (except start-up fuel). There is no need for a bark boiler for steam production although most mills still run a bark boiler. All the generated steam can be used in a back-pressure turbine. A market kraft pulp mill is also self-sufficient in electricity.

Steam not needed in the processes can be used for power production in a condensing turbine which also takes care of the variations in the steam system. Deducing the own power consumption, excess electricity of about 400 – 500 kWh/ADt can be generated and sold.

Power generation varies between hardwood and softwood mills. For example, eucalyptus pulping generates less black liquor and therefore also less excess electrical power.

Comparison of achieved power surpluses should consider whether bark is used for steam generation or used in the lime kiln, is sold, or used for heat deliveries. The pulp yield (kappa number after cooking) and prices for power sold from biomass are also essential when comparing performance figures.

Cross-media effects

No negative cross-media effects have been observed.

Technical considerations relevant to applicability

The measures are applicable, in principle, to all kraft pulp mills. There is a large technical potential to achieve a more energy-efficient kraft mill, even within the established technology, if there are sufficient economic incentives.

Economics

No information provided.

Driving force for implementation

Energy use is one of the key cost factors of pulp and paper mills. On the other hand, there has been little incentive for market kraft pulp mills to keep the steam consumption below present levels as the steam generation from black liquor alone in in today's average mill is around 16 GJ/ADt. Without condensing turbines, but with maximum back-pressure power generation, the lowest reasonable steam consumption would be about 13 GJ/ADt with a back-pressure electricity generation of about 800 kWh/ADt. A lower process steam demand will lead to a steam surplus even without using bark to generate steam that can be used for condensing power production (up to 465 kWh/ADt) or other uses (e.g. district heating or other users). Because of the lower steam requirements in the mill there is no need to burn bark. The excess bark can be dried with excess steam from 40 % to 60 % dryness and sold as biofuel to the external market. The reduced consumption of electrical energy reduces production costs and improves the profitability of the mills.

Example plants

Many kraft pulp mills in Europe have implemented some of the above-mentioned measures. For example, in the context of an energy management programme, the Södra Värö kraft mill (SE) has implemented most of the measures listed above. SCA Östrand, SE, started a highly efficient recovery boiler in 2007. Recent greenfield eucalyptus pulp mills built in South America (Veracel, Fray Bentos) are examples of the lowest power consumption.

Reference literature

[34, Kankkonen et al. 2010], [35, Raukola et al. 2002], [119, Botnia 2010], [122, Veracel 2009], [134, Södra Värö 2009], [137, K.Touminen 2010], [138, PP TWG 2009], [193, Axegård et al. 2003], [268, COM 2009].

3.3.28 Techniques for noise reduction

See Section 2.9.13.

3.4 Emerging techniques

A number of promising new techniques are presently being developed that result in a reduction of emissions or energy savings. Improvements in environmental performance may not always be the main driving force but they do play an important role in the development. Some of these techniques are described below. This chapter includes environmental issues that have only recently gained interest and research programmes related to the development of environmentally improved solutions for the production of high-quality pulp and paper products.

3.4.1 Enhanced generation of electricity, biomass-based products and the utilisation of excess heat

Description

Energy-efficient pulp mills have a biomass fuel surplus that can be used inside and outside the mill to produce biofuels out of renewable sources or other biochemical products. In order to improve the production economics of pulp mills, especially in the northern hemisphere, the concept of 'biorefinery' has been introduced. Companies have been looking at converting the wood raw material and the wood-based residuals (e.g. bark, fibre rejects) into new types of energy products from biomass such as bioethanol, diesel, oils and others. A number of demonstration-scale plants have been constructed based on extensive research to develop these technologies further. In addition, the increased or more efficient use of some existing technologies could increase biomass-based energy products.

Some of the energy products of future mills will be rather similar to those of today. These include dried bark and screening rejects sold as biofuel, methanol, turpentine, soap and tall oil. These primary products can be processed further for various purposes including liquid biofuels, heat for district heating and power from renewable sources. Separated parts of the side-streams like lignin, hemicellulose, etc. may be refined further to other energy products.

The major differences in terms of energy and other biomass-derived products of future kraft pulp mills are possibly:

i. increased power sales;
ii. replacement of fossil fuels used in pulp production, mainly in the lime kiln (see Section 3.3.23);
iii. increased utilisation of excess heat for district heating in colder areas;
iv. integration of pulp production with other manufacturing processes utilising biomass as a raw material.

Status of development

The status of development of the different options (i. to iv.) can be described as follows:

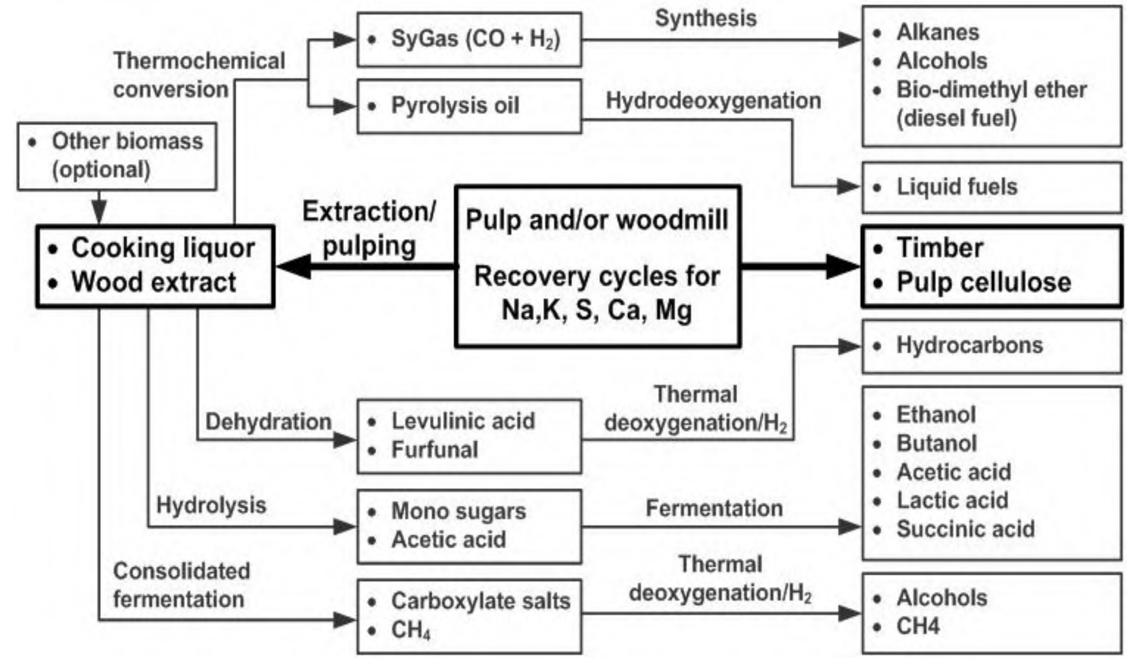
i. Generation of surplus energy/electricity. The main possibilities for increasing the generation of surplus energy are the reduction of own heat and power consumption (see Section 3.3.27) and the implementation of high efficiency recovery boilers firing black liquor with a high dry solids content. More energy-efficient black liquor recovery boilers have an increased power-to-heat ratio by utilising feedwater heating, combustion air preheating, flue-gas heat recovery and especially higher steam temperatures and pressures.
In the Swedish SCA Östrand pulp mill in 2007 a new efficient boiler was installed. Before the installation, the mill had an electricity deficit of 114 GWh/year; after the installation of the new boiler the mill could produce 90 GWh/year of excess power [137, K.Toumінen 2010]. Energy-efficient recovery boilers are an available technology.
Modern recently started-up boilers achieve 515 °C and 110 bar and the total power generation can increase up to 16 % compared to the baseline case, if all features for the increase of power generation are incorporated into the design of the boiler

[124, Mäntyniemi 2010]. The power generation efficiency of the system can be further increased when a clean fuel gas, rather than black liquor, is used as the fuel for the final superheating of steam. The gas combustion chamber can be closely integrated into the recovery boiler. As a result of this arrangement, much higher steam temperatures of up to 560 – 600 °C can be applied [137, K.Touminen 2010]. A possible future solution to further increase electricity generation (by the conversion of black liquor energy potential) is the black liquor gasification technique (see Section 3.4.2).

ii. Replacement of fossil fuels used in pulp production, mainly in the lime kiln (see Section 3.3.23). This technology has been available since the 1980s, but was implemented only in a few mills. Because of increased prices for oil and gas and costs for CO_2 allowances, this technology will possibly be more profitable in the future.

iii. Increased utilisation of excess heat for district heating is a proven technology in many pulp mills especially in the Nordic countries (e.g. Södra Värö and Mönsterås mill) and will probably continue to increase.

iv. Integration of pulp production with other manufacturing processes utilising biomass as raw material (biorefinery concepts). Future pulp mills may gradually convert into platforms for integrated production facilities for other energy and biorefinery products. There are synergies from common feedstock logistics and handling, common service facilities, effluent treatment and especially heat and power systems that can be integrated into the new technologies and processes. Different general pathways have been identified which integrate biomass conversion to commodity products within existing pulp and paper mills. Figure 3.87 shows these pathways from biomass to fuels and chemical products. Possible fuels and chemicals are listed on the right.



Source: [133, A.v.Heiningen 2010]

Figure 3.87: Forest biorefinery pathways

On the left of the diagram the different feedstocks are listed including wood extract and spent black liquors created during the cooking of wood chips. Other possible feedstocks are forest biomass, agro-lignocellulosics (straw, corn stover, etc.) and sludges. Some of the technologies have been constructed on a demonstration scale; extensive research is being carried out. All pathways still have challenges to overcome, but it is likely that some will be implemented in the very near future on a full commercial scale [133, A.v.Heiningen 2010]. The integration of pulp mills with other facilities is expected to increase.

Environmental implications
All these techniques improve the CO_2 balance of kraft pulping, result in greenhouse gas savings and enhance the use of renewable energy sources instead of fossil fuels for different purposes. There was no information available about the emissions and other environmental concerns associated with production facilities for other energy and biorefinery products such as biofuels, syngas, ethanol and others.

Economics
The pulp and paper industry faces increasing competition from new producers in tropical and subtropical regions. These new competitors have significantly lower manufacturing costs due to the availability of fast-growing and high-quality plantation wood which allows for increased scale production. In order to remain economically viable, the producers of traditional pulp and paper products in temperate regions must change and consider the integration of wood products and pulp mills with biorefineries which produce pulp, bioenergy and biochemical products. An important opportunity for pulp and paper mills is that renewable and carbon-neutral bioenergy and biochemical product pathways (biofuels, biomaterials, chemicals) are generally more economically attractive when integrated into existing pulp and paper operations. This transformation towards an integrated forest biorefinery will allow the industry to improve its own energy sustainability and economic viability by using existing infrastructure and know-how.

Reference literature
[34, Kankkonen et al. 2010], [124, Mäntyniemi 2010], [128, P.McKeough et al. 2010], [133, A.v.Heiningen 2010], [137, K.Touminen 2010].

3.4.2 Gasification of black liquor

Description
Black liquor gasification (BLG) is a promising technique for pulp mills for the generation of a surplus of electrical energy or the production of biofuel. The principle of BLG is the process of converting concentrated black liquor into inorganic compounds (mainly sodium and sulphur) appropriate for the recovery of cooking chemicals and combustible fuel gas comprising mainly hydrogen and carbon monoxide.

BLG is used to produce syngas for combustion in a gas turbine. One of the most interesting opportunities with the BLG processes is to run a gas turbine in combination with a steam turbine in a combined cycle. The evaporated black liquor is gasified in a pressurised reactor under reducing conditions. The generated raw syngas is separated from the inorganic smelt, dust and hydrogen sulphide. The resulting clean gas is fired in a gas turbine for power generation. The hot flue-gases are used to generate steam in a waste-heat boiler and the resulting high-pressure steam generates additional power in a steam turbine [13, Landälv et al. 2010], [193, Axegård et al. 2003, p. 58, p. 165].

Gas turbine technology exists, but is not tunable to mill fluctuations (thus support fuel such as natural gas is needed) and applicable gas turbines have not been optimised for low heating value fuels so work is needed in turbine development as well as the gasifier to realise the full potential of a BLG combined cycle.

BLG can also be used to produce synthesis gas as a raw material for making higher value chemicals for sale (see Section 3.4.1 above). This is sometimes referred to as the biorefinery concept [55, M.Naqvi et al. 2011].

Status of development
At the time of writing (2013), BLG technology at high pressure and temperature, developed by Chemrec, is the most promising and closest technology to implementation on an industrial scale. Compared to an advanced recovery boiler system, the Chemrec combined cycle, consisting of a

gas and steam turbine, is able to produce 400 kWh of power more per tonne of pulp, 80 kWh/ADt of which is extra electric energy for sale. However the mill's performance must be higher than 450 000 ADt/yr in order to achieve such power efficiency from the gasified black liquor [57, O.Grigoray 2009].

Despite the fact that the gasification of black liquor seems to be a promising technology for the pulp and paper industry, there are obstacles hindering its commercialisation, the most significant of them include: the availability of funds for its realisation, the absence of an affordable and reliable refractory system which protects the gasifier from severe conditions for more than a few years, the achieving of a sufficient purity of the syngas required for gas turbine work and also an increased load in the causticising department. These issues demand further study and the execution of new trials.

Over the next ten years, favourable conditions for the implementation of black liquor gasification may develop, since currently the amount of pulp mills with a capacity of more than 450 000 ADt/yr is 12 % and it will continue to grow. Furthermore, an urgent need to replace operating boilers is imminent because they are at the end of their operational lifecycle.

Environmental implications
The possible advantages of the BLG technique are given below.

- Increased electric power generation through the use of a combined cycle (gas turbine plus steam turbine). Theoretical balance calculations show that a BLG combined cycle concept may reach a power efficiency of about 30 % calculated on the heat value of the black liquor. This may be compared with 12 – 13 % for the conventional recovery boiler. However, at the same time the overall efficiency (power and steam) would decrease by about 5 % to about 75 %. Thus, the production of process steam decreases. In a situation with a surplus of steam, this appears to be an interesting option for an increased power production for export.
- Low emissions to the atmosphere.
- It enables pulp mills restricted in capacity, because of recovery boiler limitations, to increase production. The system is particularly beneficial in mills with a built-in but unused pulping capacity, and where fibre line modifications add more DS to the recovery system (e.g. low kappa pulping, oxygen delignification, increased recycling of effluents from the bleaching system).

Economics
No detailed and transparent data have been provided. The price of 1 MWh of power is approximately four times higher than that of steam so increasing the power to heat ratio for the pulp mills is profitable. Having the electric energy capacity equal to 2 100 kWh/ADt, half of which can be sold, the gasification combined cycle may bring additional economic benefits to pulp mills.

Reference literature
[13, Landälv et al. 2010], [54, N.DeMartini et al. 2010], [55, M.Naqvi et al. 2011], [56, Naqvi et al. 2010], [57, O.Grigoray 2009], [193, Axegård et al. 2003].

3.4.3 Selective removal of chloride and potassium by ESP ash treatment

Description
High levels of the non-process elements chloride and potassium in the kraft recovery cycle accelerate recovery boiler plugging under some circumstances. The current levels in some mills require boilers to be shut down for water washing several times a year; other mills avoid such non-scheduled shutdowns by increased soot blowing and thermal cycling. In some kraft mills, it is common practice to simply purge part of the total ash collected in the electrostatic

precipitator, but this causes a significant loss of sodium sulphate and sodium carbonate. The dumped sodium must be replaced, so there is an additional cost for make-up chemicals.

Available methods to treat ESP dust include leaching, evaporation crystallisation, cooling crystallisation and ion exchange. The first three methods operate on the basis of differences in the solubility of alkali sulphate and alkali chloride salts. The ion exchange process uses ion retardation to separate chloride from sulphate. For the latter, the treatment of ash collected from the ESP for chloride removal can be carried out using amphoteric ion-exchange resins.

Status of development
All the aforementioned systems have been installed and operated in at least in one mill on a full scale. Reported removal efficiencies and operating experiences for K and Cl removal vary.

Environmental implications
The techniques contribute to keeping the process streams closed while avoiding negative side effects. When aiming at better closure of the process streams, pulp mills have to take into consideration the non-process chemicals entering the mill with raw materials and process chemicals. Among the most harmful of these chemicals are chloride and potassium. The accumulation of chloride (Cl) and potassium (K) lowers the melting point of the recovery boiler ash, causing deposits and plugging of flue-gas passages. Also the risk of corrosion increases. All this can result in production losses. Chloride and potassium are enriched in the recovery boiler ash. Removal of chloride and potassium from the ash has been considered an attractive possibility to control the chloride level in the mill's recovery cycle.

Economics
No full-scale data have been provided. Economic benefits are that the techniques enable kraft pulp mills to reduce chemical make-up costs. The dumping of recovery boiler fly ash can be reduced.

Investment and operating costs depend on the targeted removal efficiencies for Cl and K and the treatment system chosen. The efficiencies required also depend on the mill's sodium sulphur balance.

Reference literature
[51, R.Honkanen 2010], [52, Goncalves et al. 2009].

3.4.4 Partial borate autocausticising

Description
The principal autocausticising reaction that takes place in the recovery boiler furnace occurs between sodium metaborate ($NaBO_2$) and sodium carbonate (Na_2CO_3) in the molten smelt to form trisodium borate (Na_3BO_3). The critical parameters of the process are the temperature and Na/B ratio in the black liquor. Trisodium borate reacts with water in the smelt dissolving tank to form sodium hydroxide (NaOH) and regenerate $NaBO_2$ [39, M.Michniewicz et al. 2010], [40, B.Bujanovic et al. 2003], [41, H.Tran et al. 2001]

The partial borate autocausticising process occurs when sodium borates are added to the kraft liquor at substoichiometric levels [38, M.Björk et al. 2005]. A portion of the sodium carbonate (Na_2CO_3) is causticised in the recovery boiler. The causticisation of the remaining Na_2CO_3 is completed in the conventional recausticising plant of the pulp mill with a reduced quantity of lime.

The technology may appear an attractive option, particularly for kraft pulp mills where incremental causticising and lime kiln capacity are required. Mill trials have shown that there are no major side effects on the mill operations. The major findings of the studies [37, B.Eckert et al. 2005], [40, B.Bujanovic et al. 2003], suggest that borate present in cooking liquor increases pulp yield, may decrease rejects, improves the selectivity of lignin removal and can increase pulp viscosity at the same kappa number. A great advantage of the technique is that it does not require capital investment since the autocausticising reaction occurs in the existing recovery boiler. The success of the technology depends greatly on whether the boron-containing black liquor can be effectively processed in a recovery boiler, and on the degree of completion of the reactions that produce trisodium borate (Na_3BO_3) in the boiler.

Status of development

The technology has been tested in several mill trials since the beginning of 2000. The results show that the technology works, allowing the lime consumption to be reduced by an amount proportional to the level (degree) of autocausticisation (depending on the Na/B molar ratio in the liquor cycle). No negative effect has been found on pulp properties, equipment corrosion, digester operations, pulp washing, black liquor evaporation, recausticising and lime kiln operations. Several kraft pulp mills in the US, Canada and Sweden (Stora Enso Norrsundet) already use the technique of partial autocausticisation (autocausticising level 10 – 30 %).

Environmental implications

The technique makes it possible to produce caustic (sodium hydroxide) directly in the recovery boiler and improve the lime kiln and recausticisation operations by reducing causticising loads and the amount of lime processed through the system. Promising environmental benefits are connected with a reduction of the emissions from the lime kiln and a reduced consumption of energy or fuel by the lime kiln.

Economics

Partial borate autocausticising may offer cost savings and environmental benefits to kraft pulp mills that are limited in their recausticising options by relieving production bottlenecks in the liquor cycle without the costs for the capacity growth of the conventional causticisation plant and lime kiln. The benefits are obtained through decreasing the lime kiln load and fuel usage or reducing fresh lime purchases and lime mud disposal. Some benefits also result from the increase in pulp yield at the digester and/or potential decrease in alkali charge. However, addition of borate increases the solids content in fired black liquor, especially at high levels of autocausticising and may result in a decrease in black liquor heating value and in steam production.

Reference literature

[37, B.Eckert et al. 2005], [38, M.Björk et al. 2005], [39, M.Michniewicz et al. 2010], [40, B.Bujanovic et al. 2003], [41, H.Tran et al. 2001], [48, Mao et al. 2006].

3.4.5 SNCR or SCR for reducing NO_X emissions from the black liquor recovery boiler

Description

SNCR

Injecting ammonia into hot (around 900 – 1 000 °C) flue-gases causes selective non-catalytic reduction (SNCR), in which nitrogen oxide is converted into molecular nitrogen (N_2) by reacting with ammonia. The process is used in power boilers, bark boilers, reject incinerators, glass furnaces, lime kilns and other installations. Its effectiveness and applicability for recovery boilers is still unclear.

The process utilises the upper part of the recovery boiler as a 'chemical reactor' and does not require any additional equipment downstream of the boiler. A number of injection ports for reduction chemicals have to be installed at several levels.

The reaction normally occurs within a narrow temperature band. The control of unwanted ammonia slip (NH_3 slip), good mixing of added ammonia and air, and sufficient residence time at the right temperature are the major parameters when running the SNCR technique. At temperatures that are too high the ammonia oxidises to NO_X whereas at low temperatures the reactions are too slow and ammonia leaves the boiler unreacted (ammonia slip).

SCR
Selective catalytic reduction (SCR), in which ammonia is injected in a special catalytic reactor into cooled flue-gases, is a well-known technique that is commercially in use in power boilers, but has only reached the trial stage in recovery boilers. The problem with this technique is ensuring sufficient flue-gas dust removal before the process in the catalytic reactor and the durability of the catalyst.

Status of development
SNCR
Selective non-catalytic NO_X reduction based on ammonia injection has been tested in a 2 000 t DS/d recovery boiler [46, M. Lundberg et al. 2008]. The results show good reduction rates with limited ammonia slip over the load range 60 – 100 %. For other emissions, ammonia addition had no or only a minor impact.

Special attention was paid to the ash chemistry to evaluate the potential for ammonium salt formation on the heating surfaces. Analyses of deposit samples together with thermodynamic equilibrium calculations show that this potential is limited and will not affect the deposit characteristics.

One difficulty for the application of this technique in kraft pulp recovery boilers is the varying boiler load which moves the location of the optimal temperature window for the SNCR technique to a different place in the flue-gas channel. As a result, the efficiency of the NO reduction varies. More data are also needed on the increased corrosion risk of the flue-gas channel that this technique may involve. Tests on the method are under way [225, Hupa 2005].

Computational fluid dynamics simulations showed that the penetration of the SNCR jets into the recovery boiler gas steam was poor, indicating that a limited number of injection ports were not adequate to ensure an even distribution. This suggests that significant improvements to the injection system can be made. There are no reliable data on the operational economy of the technique.

SCR
Preliminary tests on the technique have been conducted in a secondary flow separated from the flue-gases in the recovery boiler, but a full-scale demonstration is yet to be reported [225, Hupa 2005] at the time of writing (2013). SCR may be considered an option for new recovery boilers under certain conditions (low dust application after the ESP, low SO_2 necessary, new arrangement of heating surface). At least one supplier of recovery boilers offers recovery boilers with the SCR technique.

Environmental implications
Compared with conventional combustion plants, the black liquor recovery boiler has low emissions of nitrogen oxides. However, the recovery boiler is the largest source of NO_X emissions in a kraft pulp mill due to high flue-gas flows. Thus, flue-gas treatment measures applied to the recovery boiler would give the greatest effect on the total emissions. Furthermore, an increase of NO_X emissions from modern, high efficiency recovery boilers may be expected, caused mainly by the increased dry solids content of the black liquor (higher temperatures) and higher furnace loads.

SNCR
The potential reduction rate of around 30 – 50 % for SNCR applications was reported and confirmed [225, Hupa 2005] but without reporting the applied stoichiometry and the associated ammonia slip. The removal efficiency depends on the amount of ammonia injected and the operational conditions (low initial NO_X level, varying temperature, effect of other components in the gases). Unreacted ammonia remaining in the flue-gases as ammonia emissions may

restrict the use of this technique in reducing NO emissions. For recovery boilers of kraft pulp mills, there is still insufficient practical empirical data about the best location for ammonia dosing and on the prevention of overdosing (ammonia slip).

SCR
According to results achieved in other sectors (large combustion plants, the glass industry), a reduction of 70 – 90 % can be expected by the use of SCR. The removal efficiency depends on the amount of ammonia injected and the operational conditions. Unreacted ammonia remaining in the flue-gases as ammonia emissions is a factor about which there is still insufficient practical empirical data and which may restrict the effectiveness of these techniques in reducing NO emissions.

Economics
No data on investment costs have been provided. Operating costs for the system include chemical supply, electricity, heat used to evaporate injected water, and labour. Of these, the most influential factor is the price of the reducing agent (ammonia).

Reference literature
[46, M. Lundberg et al. 2008], [63, Salmenoja 2009], [225, Hupa 2005].

3.4.6 Removal of chelating agents by modest alkaline biological treatment or its recovery by use of kidneys

Description
The chelating agents EDTA and DTPA have been used for many years in the pulp and paper industry. They are applied because of their good sequestering properties, i.e. their ability to suppress the activity of the dissolved transition metal ions without precipitation. These metal ions are able to catalyse the decomposition of the bleaching agent hydrogen peroxide into radicals. Increased concentrations of chelating agents are measured in waste waters from these production processes. In waste water analyses of market kraft pulp mills, 25 – 40 % of charged chelating agents have been identified. This corresponds to EDTA contents of 10 – 15 mg/l in the effluent at a charge of 2 kg EDTA per tonne of pulp. Although EDTA is non-toxic to mammals at environmental concentrations, there is some concern about the potential of EDTA to remobilise toxic heavy metals out of sediments and the difficulties to biodegrade this substance.

Option 1
Biological treatment with and without activated sludge systems commonly used in the pulp and paper industry is successful in reducing the COD and BOD of the effluents. However, the system cannot significantly reduce the EDTA of the mill effluent. It has been found that EDTA is resistant to aerobic biodegradation in the activated sludge plant operated under normal conditions (pH 7). Furthermore, EDTA does not adsorb onto sludge and so EDTA passes through treatment plants without notable degradation. A study [154, Virtapohja et al. 1997] found the biodegradation of EDTA in a full-scale activated sludge plant under modest alkaline conditions (pH 8 – 9). An average EDTA reduction of about 50 % (about 10 % at pH 7) was obtained.

Option 2
Another technical option to reduce the discharge of chelating agents in waste water from the peroxide bleaching stages is to lower the consumption and discharge of these compounds by the use of kidneys. Kidneys could be put in operation for the recovery of EDTA from Q stage effluents (filtrates). There, it is expected that the consumption of EDTA can be reduced by 65 %. Kidney systems can also be efficient tools to remove other problematic substances like extractives and metals from bleaching filtrates.

The principle of the kidneys is that at slightly alkaline conditions (pH about 10) chemicals are dosed to the filtrate (bleach effluent). Metals bound to EDTA (or DTPA) are released, precipitated and removed with sludge ([116, Rampotas et al. 1996], [193, Axegård et al. 2003], p.90). The principle of the application of an example kidney for the recovery of chelating agents is shown in Figure 3.88.

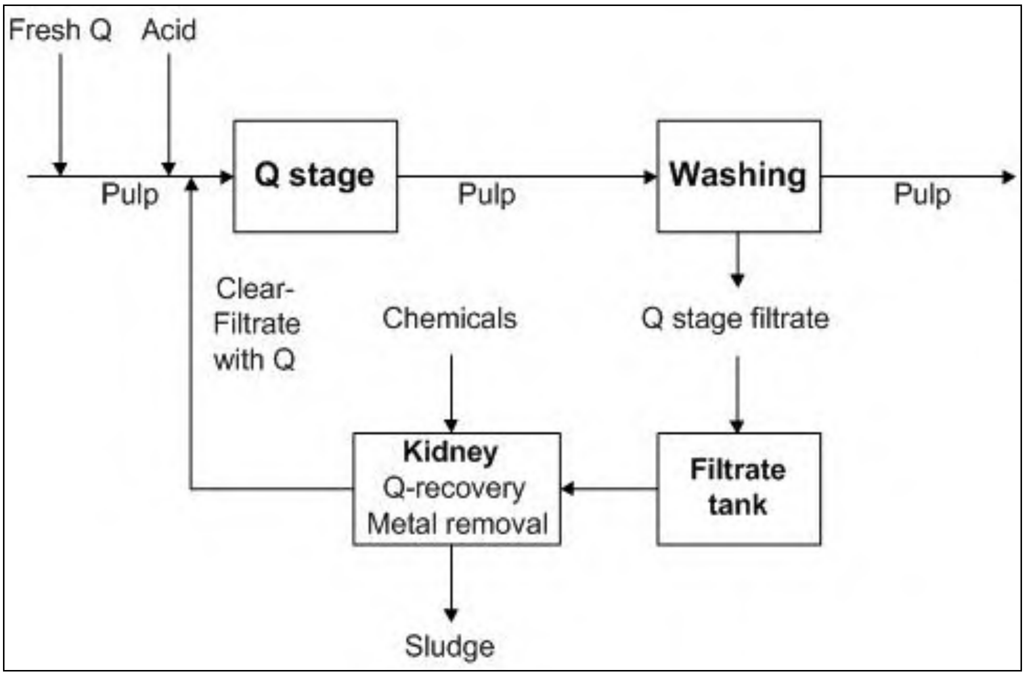


Figure 3.88: Recovery of chelating agents in bleach plant filtrates by use of a kidney

By reducing the amount of metals entering the bleach plant, a smaller charge of chelating agents is needed prior to the peroxide stage. Additionally, the recovery of chelating agents itself reduces the consumption. Expected reduction rates are over 80 % for calcium, manganese and iron. The recovery of Q results in a lower charge of fresh Q. Thus, lower levels of metal complexes will be found in the effluent.

Status of development

Option 1

The biodegradation of EDTA in activated sludge plants with specially enriched bacterial cultures (EDTA-grown sludge) or under alkaline conditions looks promising. The treatability of EDTA-containing waste waters from bleaching plants in activated sludge plants under moderate alkaline conditions has been confirmed by investigations in full-scale activated sludge plants. Process parameters like sludge retention time, temperature, sludge age, composition of EDTA complexes, etc. are very important and are still under investigation.

Option 2

No full-scale application.

Environmental implications

Option 1

In a full-scale activated sludge plant under modest alkaline conditions (pH 8 – 9), an average EDTA reduction of about 50 % (about 10 % at pH 7) was obtained. The results also indicated that the pH adjustment to 8 – 9 with calcium oxide (dosage about 90 mg CaO/l) did not interfere with the normal operation of the activated sludge plant. Concentrations of EDTA in the samples with accelerated biodegradation remained relatively constant (2 – 4 ppm). Biodegradation of EDTA increases the release of nitrogen. Since waste waters from pulp and paper mills are usually deficient in nitrogen, enhanced degradation of EDTA in activated sludge plants is therefore a clear benefit as a means to increase the level of nutrient nitrogen.

Option 2
The use of kidneys for bleach plant effluents allows for reducing the fresh water consumption by means of bleaching filtrates recirculation [193, Axegård et al. 2003].

Economics
Additional costs for the biodegradation of EDTA in activated sludge plants under alkaline conditions are primarily caused by the CaO consumption.

For the application of the bleach plant kidney system, no data on economics are available.

Reference literature
[116, Rampotas et al. 1996], [154, Virtapohja et al. 1997], [193, Axegård et al. 2003].

3.4.7 Increased system closure combined with the use of kidneys

Description
Decreasing fresh water consumption in kraft pulp production is profitable from both an environmental protection and an economical point of view, because of reduction of energy consumption as well as water and waste water treatment costs. Since it is mainly the bleach plant which constitutes the open part of the pulp mill, efforts have been made to integrate the filtrates into the recovery systems or to enhance their recirculation within the bleach plant. However, a high degree of pulp mill system closure can have negative effects since it leads to an accumulation of dissolved substances and non-process elements (NPEs) in the bleaching stages and chemical cycles (process liquors). Kraft pulp mills operating in a continual manner at a high degree of system closure (for example, with water consumption of approximately 15 m^3 per tonne of pulp or less) have to use special techniques for separation and to purge the disturbing non-process substances.

The main negative effects of a concentration of NPEs in a pulp mill are incrustation, clogging, corrosion, increased chemical ballast and decomposition of bleaching chemicals (see Table 3.34).

Table 3.34: Negative effects caused by NPEs

Negative effects	Elements
Scaling, deposits possible in all parts of equipment	Al, Si, Ca, Ba
Plugging in the recovery boiler	K, Cl
Corrosion	K, Cl
Inert compounds in the lime cycle	P, Mg, Al, Si
Less efficient oxygen and peroxide bleaching	Mn, Fe, Cu
Environmental impact	N, P, Cd, Pb
Source: [193, Axegård et al. 2003] (p. 4 – 8, 65 – 108)	

The main problems observed in extensive bleach plant closure include:

- precipitation and deposition of poorly soluble compounds with alkaline metal ions, i.e. calcium oxalate, calcium carbonate and barium sulphate;
- transition metal ions that act as catalysts in the decomposition of hydrogen peroxide;
- the negative impact of manganese ions Mn(II) on the efficiency of bleaching with oxygen-based chemicals.

The problems caused by the accumulation of NPEs can be effectively solved by application of kidney technology (purge/separation processes). These kinds of processes are known and available but the essential limitations are costs and few full-scale applications.

Status of development
With regard to closed-cycle mills for bleached pulp, areas can be found where new technology has been introduced which facilitates this goal, but also areas where more development is needed. Total system closure during pulp production – that theoretically enables the realisation of an effluent-free pulp mill – is not yet possible because the non-process elements which enter the process mostly with the wood, but also with the chemicals and the process water, accumulate in the process and must be purged out of the system.

Kidney techniques for NPEs include ([193, Axegård et al. 2003], p. 65-108) the items listed below.

- **Chip leaching.** Wood chips are normally the main source of most NPEs in a kraft pulp mill. A significant part of these ballast substances can be removed from the wood by leaching the chips with an acidic solution at 80 – 100 °C before the cooking stage. The results of the studies using different leaching liquors (water, acid, chelating compounds and $MgSO_4$ solutions) ([193, Axegård et al. 2003] p. 83 – 89) show the possibilities of removing various NPEs from industrial pine chips. Acid leaching using diluted sulphuric acid, which appeared to be the most effective, was shown to decrease the content of most of the metal ions. The content of K was decreased by approximately 75 %; Ca, Mn and Mg by approximately 70 %; Al, Ba, Cd, Co, Cu, Ni and Zn in the range of 50 – 65 %. The potential for implementation is good. The basic requirements of such a process have been largely clarified and the process is ready for industrial testing ([193, Axegård et al. 2003], p. 6).

- **Filtration of green liquor and removal of green liquor sludge.** Green liquor sludge separation and removal has been considered the important kidney for a number of non-process elements in the kraft pulp process. But it is well-known that the traditional way of separation by sedimentation is difficult and not sufficiently effective, especially in the case of an increased degree of recirculation of process streams. Much better separation results are possible by the application of filtration techniques. In the framework of the research programme KAM2, filtration properties of green liquor sludge have been studied and processes to improve this inherently difficult separation step have been suggested ([193, Axegård et al. 2003], p. 91 – 94). The addition of aluminium and calcium ions improves the filtration properties as does the addition of lime mud to the green liquor sludge.

- **Acidic lignin precipitation from black liquor.** The main purpose for lignin separation from black liquor is to recover surplus energy in the form of a solid biofuel. But, as a side effect, NPEs are removed from the pulp mill liquor cycle together with the lignin. In the framework of the Ecocyclic pulp mill project, the following processes have been studied: precipitation of lignin by acidification, separation of precipitated lignin by filtration and washing of the lignin ([193, Axegård et al. 2003], p. 95 – 96). Favourable conditions for precipitation from black liquor of about 30 % DS have been established as well as the dewatering and washing properties of the precipitated lignin. Important parameters are the precipitation temperature, the ionic strength and the pH. The method is ready for testing on a pilot scale.

- **Membrane fractionation of kraft black liquor lignin.** The studies ([193, Axegård et al. 2003], p. 97 – 100) have shown that it is possible to successfully fractionate and concentrate black liquor by ultrafiltration with polymeric and ceramic membranes. Ceramic membranes maintain favourable properties at high temperatures and high alkalinities. An attractive option is to remove lignin from the digester circulation, which might increase the pulping and bleaching performance. The method is ready for testing on a pilot-scale mill.

- **Separation of metal ions from bleaching plant filtrates – kidneys in bleach plant.** Internal bleach plant closure to reduce water consumption by a counter-current recycling of filtrate leads to an increase in water temperature and an increase in the concentration of inorganic and organic compounds in the bleach plant. The proposed solution is to introduce new kidneys to the bleach plant to avoid potential process problems. For the D stage filtrate and filtrates from other acidic stages the 'Champion's process concept' can be applied ([193, Axegård et al. 2003], p. 79). It includes the removal of multivalent metal ions (Ca^{2+}, Mg^{2+}, Mn^{2+}, etc.) using a cation exchange process. The purified filtrate can be recycled to the bleach plant. Another method used to purify acidic or almost neutral bleach plant filtrates, rich in dissolved NPEs, is to adjust the pH of the filtrate to about 11 (at 60 °C) using lime mud, lime or white liquor. A large number of metal ions will then form slightly soluble compounds that can be separated by filtration or flotation. Neutral and alkaline filtrates can be purified (mainly from organic substances) with the methods of ultra- and nano-filtration ([193, Axegård et al. 2003], p. 104 – 106). However, the application of these techniques is, so far, at the stage of laboratory-scale investigations.

- **Removal of chloride and potassium by ESP ash treatment.** Different techniques which are already used in some pulp mills (see Section 3.4.6) could also be considered NPE kidneys. In the KAM2 project another new technique – electrodialysis – has been studied ([193, Axegård et al. 2003], p. 100 – 102). Electrodialysis is a separation method that uses electrical potential difference as its driving force. The separation mechanism is based on the use of ion-selective membranes and an electrical field transverse to the membrane. This technique is promising for the pulp industry not only for ESP dust treatment but also for removal of chlorides from bleaching filtrates.

Environmental implications
The developments towards closed-cycle mills are aiming to virtually eliminate the discharges of organic and inorganic material to water and to minimise the dilution of energy released within the system.

Economics
No data available.

Reference literature
[193, Axegård et al. 2003].

4 THE SULPHITE PULPING PROCESS

The production of sulphite pulp is much smaller than the production of kraft pulp. The main reason for the more limited applicability of sulphite pulps is that the strength properties of the pulps are generally not as good as those of kraft pulp, although for some speciality pulp applications sulphite pulp provides other advantageous properties. No new sulphite pulping plant has been built for decades. Investments and activities to expand the product spectrum (use of by-products), improve pulp quality or develop new products have been the main focus.

The sulphite process is characterised by its high flexibility in terms of the cooking conditions and the product qualities manufactured. In principle, the entire pH range can be used for sulphite pulping by changing the dosage and composition of the chemicals. Thus, the use of sulphite pulping permits the production of many different types and qualities of pulps for a broad range of applications.

4.1 Applied processes and techniques

In Europe (excluding Russia, Belarus and Turkey), there are 18 chemical sulphite mills in operation (2010). This chapter focuses on the manufacturing of pulp for papermaking (13 mills) but also gives a brief outline of some special pulping methods such as the production of dissolving pulp for the textile industry (three mills in AT, ES and SE) and speciality pulp for chemical applications (two mills in FR and NO). Neutral sulphite semi-chemical (NSSC) mills are briefly described. This section also includes a short presentation of the manufacturing of bleaching chemicals and the production of by-products.

Because of the similarities between sulphite and kraft pulping, a number of the measures for kraft pulping are valid in most respects for sulphite pulping too. For those techniques the reader is referred to the respective sections in the kraft pulping chapter (Section 3.3). Concerning techniques to consider in the determination of BAT for papermaking the reader is referred to Section 7.3, which applies to all integrated pulp and paper mills.

At the moment, there is only one integrated sulphite pulp mill in Sweden (Nordic Paper, Säffle) which produces some unbleached sulphite pulp in small quantities (and the 'unbleached' sulphite pulp is delignified in an ozone stage followed by an extraction stage). All the other sulphite pulp mills in Europe produce bleached sulphite pulp. Three mills produce market sulphite pulp for papermaking (AT, CZ, PT), one from hardwood (eucalyptus) and two from softwood. Neutral sulphite semi-chemical pulp (NSSC) mills, using a combination of sulphite and mechanical pulping, manufacture unbleached pulp only (fluting).

The sulphite process can be distinguished according to the chemical pulping technology (pH, base used) and the products manufactured (paper pulp, viscose pulp). The pulp grades can be divided into three groups: pulp for papermaking (acid bisulphite, magnefite pulp), dissolving pulp for textile production and speciality pulp for chemical applications. In Table 4.1 the different types of sulphite pulping that are operating in Europe are compiled.

Table 4.1: Main sulphite pulping processes in Europe

Process (1)	Number of mills in Europe	pH	Base	Cooking temperature (°C)	Pulp yield (%)	Products
1. Acid (bi)sulphite	11 mills	1 – 2.5	mainly Mg^{2+}, Ca^{2+} (1 mill, IT),	125 – 155	40 – 54	Tissue, printing paper, special paper
2. Bisulphite (magnefite)	2 mills (AT, SE)	3 – 5	Mg^{2+}	150 – 170	50 – 65	Printing paper
3. Dissolving pulp for the textile industry	3 mills (AT, ES, SE)	1 – 2.5	Mg^{2+}, Na^+, Ca^{2+}/Mg^{2+}	150	35 – 38	Textile production (viscose and rayon)
4. Speciality pulp for chemical applications	2 mills (FR, NO)	1 – 2	NH_4^+, Ca^{2+}	125 – 150	30 – 55	Chemicals, filters and materials
5. Neutral sulphite (NSSC)	6 mills (BG, 2 in FI, PL, 2 in SE)	5 – 7	Na^+, NH_4^+	160 – 185	75 – 90	Corrugated medium, fluting

NB:
(1) The processes are further explained in Section 4.1.1.

The sulphite cooking process is based on the use of aqueous sulphur dioxide (SO_2) and a base – magnesium, calcium, sodium or ammonium. The specific base used will impact upon the options available within the process with respect to the chemical and energy recovery system and water use. The use of the relatively cheap calcium base has decreased (three mills in Europe still use calcium as a base (ES, IT, NO)) because the cooking chemicals cannot be recovered economically. The use of calcium as a chemical base does not allow the recovery of the used chemicals and organic substances in a recovery boiler, but the spent cooking liquor can be recovered as products (see Section 4.1.5). In Europe there is one sulphite pulp mill (FR) using ammonium as a base. The dominating sulphite pulping process in Europe is magnesium sulphite pulping (around 11 mills), with just one mill using sodium as a base (SE). Both magnesium and sodium bases allow chemical recovery. The lignosulphonates, sugars and other substances generated in the cooking liquor can be used as a raw material for producing different chemical products.

4.1.1 The major groups of sulphite pulp mills in Europe

The basic characteristics of the different types of mill are outlined in the following five sections.

4.1.1.1 Acid bisulphite pulping for papermaking

In Europe, there are around 13 mills that produce paper grade pulp with the acid bisulphite method. Acid processes are those in which the pH is 1 – 2.5. Sulphite pulping for papermaking derives its name from the use of a bisulphite solution as the delignifying medium. The cation used for papermaking pulp is usually magnesium (11 mills in Europe) and in one case calcium (IT). Most of the paper pulp manufacturers are integrated. However, single mills produce market pulp.

Calcium is only used as a base in one mill in Europe, which manufactures paper grade pulp for fine and speciality paper (IT); the other calcium-based mills manufacture dissolving pulp (ES) and speciality pulp (NO). Calcium sulphite differs from the other sulphite cooking processes as the cooking has to be done at a very low pH level (about 1.5) in order to avoid precipitation of calcium sulphite.

4.1.1.2 Magnefite process

The magnefite process is operated in two paper pulp mills in Nymölla, SE, and Gratkorn, AT. The magnefite process uses a higher pH range (3 – 5) than the acid sulphite process, which is operated at a pH value of 1 – 2.5. This results in softer cooking conditions with increased pulp strength properties and a slightly higher yield compared to the acid sulphite process. The two magnefite mills in Europe use the magnesium bisulphite process.

There are two major technical differences to consider between magnefite pulping and the acid bisulphite process.

- In the magnefite process, a pH value of 4 can be achieved in the white liquor preparation without SO_2 reinforcement measures. The operation of a pressure storage tank for sulphur dioxide is therefore not necessary.
- The SO_2 in the white liquor occurs in the bisulphite form.

The other pulp production steps are similar to the acid sulphite process. The kappa numbers of unbleached pulp after magnefite cooking are higher than after acid cooking: the magnefite process is operated at kappa numbers 21 to 26 for paper pulp. In comparison, kappa numbers 14 to 16 are normally reached with the acid sulphite process in integrated production (e.g. Hallein and Neusiedler, AT; Alfeld, Stockstadt and Ehingen, DE). However, one mill that produces market pulp from hardwood also cooks at kappa range 20 – 22 to meet the required strength properties and compensate for the strength losses during drying of the pulp.

As a consequence of the higher kappa numbers before bleaching, the bleachability of such pulps is not as good as for others cooked at a lower kappa number. Longer bleaching sequences and/or higher bleaching chemical charges are therefore necessary in order to achieve a high level of brightness of the pulp. This causes higher loads of COD and BOD in the effluents from the bleaching stages. Magnefite pulp mills operate an oxygen bleach stage (EOP_{MC}) before entering the two-stage peroxide bleaching.

4.1.1.3 Dissolving pulp for the textile industry

In Europe, there are three companies manufacturing dissolving sulphite pulp (in AT, ES and SE). All three use a different base in the cooking plant: magnesium, a mix of calcium and magnesium, and sodium.

In principle, the process is very similar to the manufacturing of sulphite pulp used for paper manufacturing. Producers of dissolving pulp are producing low kappa products that are predominantly sold to the viscose textile industry. For the manufacturing of dissolving pulp, the same chemicals are used as in the common acid bisulphite process. Therefore, the chemicals and energy recovery system is very similar. The major differences can be found in cooking and bleaching. The aim of cooking in dissolving pulp manufacturing is to achieve a low viscosity, i.e. a short molecule chain in the cellulose. This is adjusted in the cooking plant and also in the bleaching.

In one of the European dissolving sulphite pulp mills (Lenzing, AT, manufacturing viscose fibres) the delignification of hardwood (beech) is brought down to a kappa number of 4 – 7 before bleaching. There are no effluents before the pulp enters the bleach plant. The bleaching sequence of the plant is carried out in three stages: EOP – Z – P (TCF bleaching).

In the first bleaching stage consisting of oxygen and peroxide delignification and alkaline extraction, the kappa number is decreased to 2 and a α-cellulose content of 91 % is achieved. Around 50 kg NaOH per tonne of pulp (oven dry) is used. The releases of this bleaching stage (COD load approximately 85 kg/t) are treated in an evaporation plant. The concentrates are incinerated in a soda boiler. This eliminates the bulk of the pollution load from the bleach plant.

The second bleaching stage uses ozone as a bleaching agent. The last bleaching stage uses peroxide which brings the kappa number down to 0.5 (>90 % ISO, α-cellulose content >91 %). The COD load from the second and third bleaching stage is 15 kg/t before treatment and is purified in a biological waste water treatment (reduction rate >90 %).

Besides the bleach plant, the major source of water pollution is the condensates from the evaporation plant. The example pulp mill extracts acetic acid and furfural as valuable products from the evaporator condensates, thus reducing the COD load of the condensates by 75 %. The remaining pollution load is 30 kg COD/t which is treated in the biological waste water treatment (reduction rate >90 %) together with the other partial waste water streams.

The initial pollution load of the waste water from dissolving sulphite pulp mills depends on the amount of alpha-cellulose to be achieved and on the internal measures applied for the reduction of emissions. A higher alpha-cellulose content corresponds to higher product qualities and a higher alpha-cellulose content of the pulp means a higher dosage of NaOH. This results in lower yields and higher pollution loads in water. For instance, the use of 90 – 100 kg NaOH/ADt of pulp to produce pulp with an alpha-cellulose content of 92.5 % would double the organic load in the effluents as mentioned above (and reduce the yield by 5 %).

The manufacturing of dissolving sulphite pulp involves a combination of delignification and finishing.

4.1.1.4 Speciality pulp for chemical applications

In Europe, there are two companies manufacturing speciality sulphite pulp (in FR and NO), one using ammonium and one using calcium as a base. Due to significant differences in the processes and end products, the production of speciality pulp is distinguished from the production of paper grade pulp and dissolving pulp.

Speciality pulp means pulp that can be used after modification in many sectors of the chemical industry. The major applications are the following.

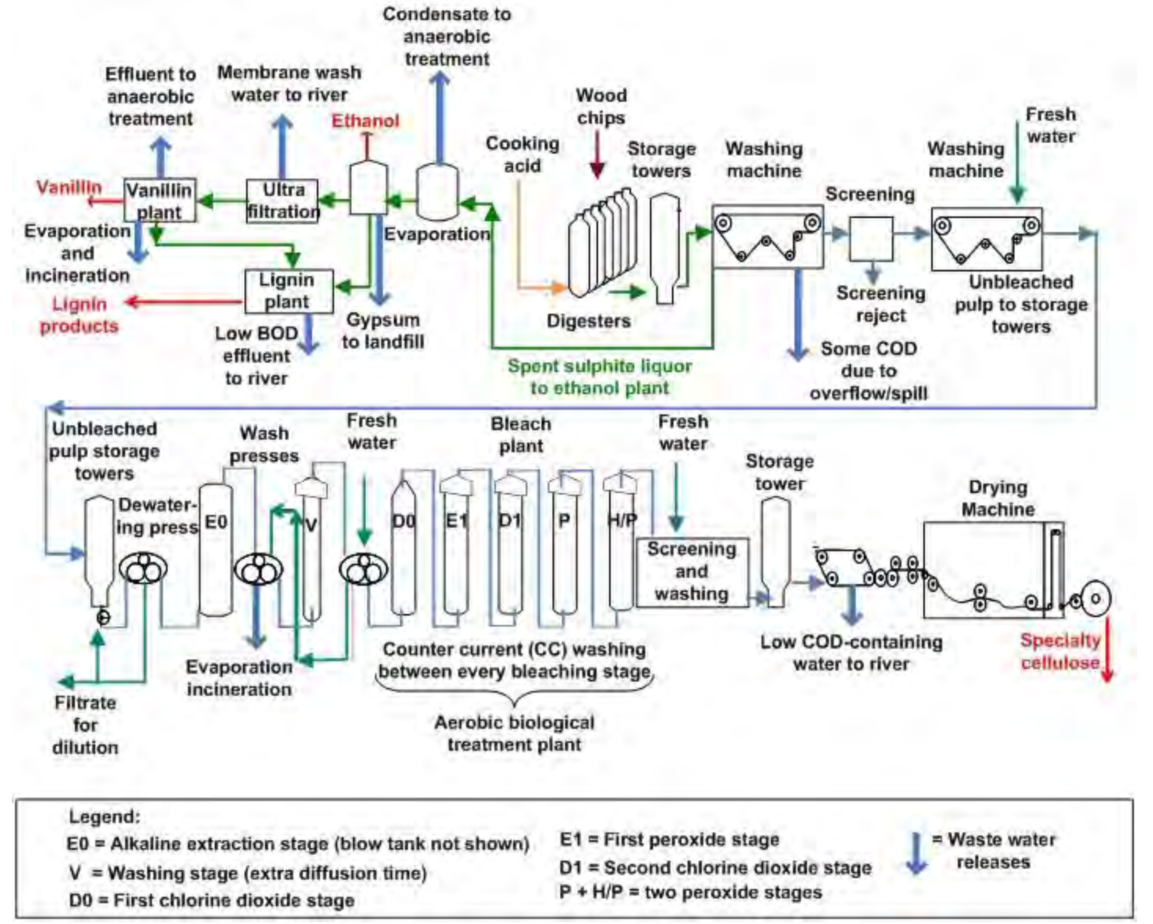
- Cellulose ethers (methyl-, hydroxyethyl- or carboxymethyl-cellulose) most of which are water-soluble. Thanks to this property, these products are used in pharmaceutical, food, cosmetics, paint and construction markets.
- Cellulose esters (cellulose acetate and nitrocellulose) with applications in explosives, paints, varnishes, filters and plastics.
- Microcrystalline cellulose for food and pharmaceutical applications.

The production of pulp for these end uses requires a highly flexible plant that is able to handle very low to very high kappa levels and which produces pulp with low to high alpha or purity levels.

In this sense, a speciality pulp mill is a dedicated multiproduct mill with a flexible process. The process is slightly different from the majority of dissolving pulp producers, as the latter only produce low kappa products (single products) that are predominantly sold to the viscose textile industry.

The adjustment of the viscosity is carried out by modifications in the cooking phase (low to high kappa number) and in the bleach plant (by use of peroxide and hypochlorite). The production of high viscosity pulp, as is needed by the cellulose ether producers, requires very careful cooking which results in very high unbleached kappa levels. The further processing of such high kappa material requires some special conditions when it comes to the bleaching process. A traditional oxygen stage (see Section 4.3.3) is not very well suited due to the viscosity loss that results from use of oxygen. For the same reason, use of ozone is excluded. An additional negative effect of the use of oxygen is the stabilisation of hemicellulose, making it difficult to reach the desired alpha level in the hot alkali extraction stage.

Delignification is instead obtained in the hot alkali extraction stage with the use of NaOH, in parallel with the extraction of hemicellulose. The amount of reactive depends on the desired alpha-cellulose content. The hot alkali extraction constitutes the main part of the COD load from the bleaching sequence. Due to the high unbleached kappa level, the production of high viscosity products results in a higher COD than production of paper- and viscose dissolving pulp (or low viscosity speciality pulps). The remaining lignin has to be removed using one or more steps with chlorine dioxide. Figure 4.1 presents the production scheme of a sulphite mill manufacturing speciality pulp for chemical applications. The major flows of fibres, spent liquor, input fresh water and waste water releases can be seen.



Source: [239, Garseg 2009] amended by the EIPPCB

Figure 4.1: Process flow of a sulphite mill producing speciality pulp and various products based on the conversion of the spent sulphite liquor

An applied bleaching sequence is, for example, E-D-E/P-D (French mill) or the one shown in Figure 4.1. In a 100 % speciality cellulose dedicated mill, the COD load from the hot alkali extraction stage represents a very large amount of organic substances that cannot be efficiently treated by biological treatment. Therefore, in Europe, sulphite mills concentrate the effluent flow from the extraction stage in an evaporation plant (see Figure 4.1). The concentrated liquor is then burnt in a soda boiler (internal or external plant). The evaporation of dissolved matter from the extraction stage is a very specialised operation that is difficult to control. There is a risk of clogging in the evaporation plant if operational conditions are not well managed. Frequent cleaning of the evaporators is needed.

Due to the high unbleached kappa level, the production of high viscosity products results in a higher initial COD than the production of paper pulp. The higher AOX level is caused by the chlorine dioxide bleaching stages.

The production of speciality pulp includes products with very low viscosity. For low viscosity levels in the cellulose, hydrogen peroxide can be used to adjust the viscosity of the pulp. For pulps with low viscosity, oxygen may be used in addition. In order to produce these products with a low level of viscosity variation, hypochlorite is used in a few cases.

Speciality pulp mills have to produce a large range of products for different markets. Consequently, the balance between low and high viscosity grades often changes from year to year. This changeable situation may induce significant variations in emission levels.

4.1.1.5 Neutral sulphite semi-chemical pulp (NSSC)

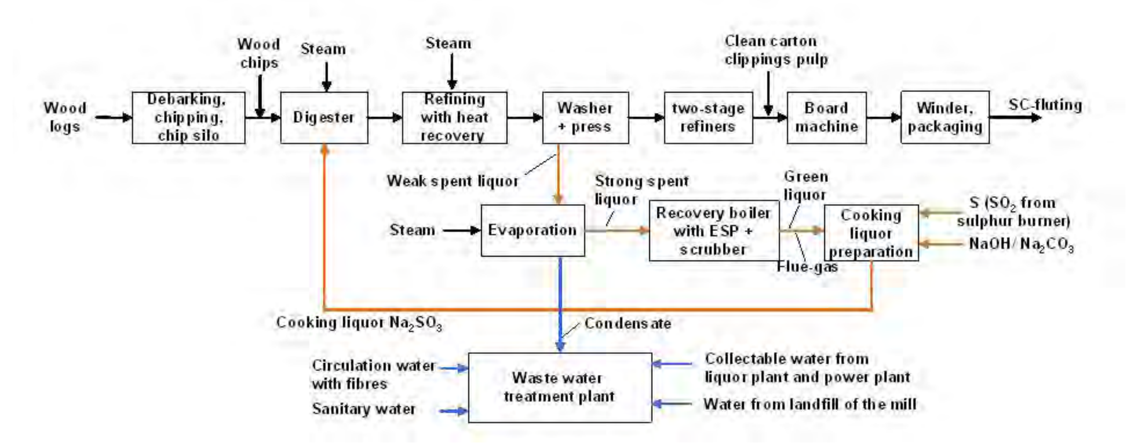
Six NSSC mills are operating in Europe, three of which also manufacture kraft pulp at the same site (Mondi Swiecie mill, in PL; Gruvön and Skärblacka mill in Billerud, SE). The basic concepts and techniques are the same in sulphite and NSSC pulping. However, there are important differences to be taken into account: the operation of refiners, the fact that there is no need for bleaching and that the chemical recovery cycle is different.

Chemical pulps are made with little or no mechanical work to liberate the fibres from the wood, but they have a high degree of organic dissolution and a relatively low yield from wood (around 50 %). Mechanical pulps are made with high energy input; very little organic dissolution occurs, resulting in a high yield from wood. Semi-chemical pulps are made by combining the two principles of chemical and mechanical pulping. The most common type of semi-chemical pulp in Europe is the NSSC pulp. The process is mainly applied to produce special pulps for board manufacturing; the most common application is the production of corrugating medium (fluting, the inner part of corrugated board). Pulping yields are frequently in the range of 75 – 85 % from wood, but can be lower in certain applications. The yield depends on cooking time and temperature. For the manufacture of fluting from NSSC pulp, bleaching to high brightness and purity is not required. Therefore, all NSSC mills in Europe manufacture unbleached pulp.

The pulping process [261, Papermaking Science & Technology 2000] begins with a chemical phase similar to chemical pulping during which the chips are partially digested in a digester using the sulphite chemistry at neutral or close to neutral pH to weaken the bonds between the fibres and lignin. Sodium (Na_2SO_3) and ammonium are the only possible bases due to the pH requirement. The idea with this mild chemical pretreatment at elevated pressures and temperatures (160 – 190 °C) is to break just enough bonds in the wood matrix to enable fibres to be liberated without extensive damage while applying moderate mechanical energy during defibration.

First, the chips are presteamed and heated to ~100 °C in atmospheric or pressurised steaming vessels. Then, the presteamed chips are transported to a pressurised impregnation vessel by a plug screw conveyer. Chips are impregnated with a solution of sodium sulphite and carbonate or bicarbonate. Impregnation time is short (5 – 15 minutes) at a temperature of ~100 °C. About 1 – 1.5 m^3/t pulp of cooking liquor penetrates into the wood. The impregnated chips are allowed to drain so that they can be transferred without excessive amounts of free liquid into a vapour phase cooking zone in which they are heated to cooking temperature (165 – 185 °C) by direct steam. The cooking time can vary between 5 and 60 minutes. The cooked chips are blown directly to a pressurised defibrator where the softened chips are defibrated under high pressure and temperature to form a raw pulp which is subsequently screened and washed. After the refining step, dissolved organic materials and spent inorganic chemicals are washed out of the pulp. Spent liquor and the washing effluents are recovered and sent to the chemical and energy recovery units. The spent liquors are regenerated into new cooking chemicals either in a separate spent liquor regeneration system (e.g. SE Heinola, FI) or in a cross-recovery of spent liquors between the sulphite and kraft pulp mill (e.g. Gruvön mill, SE). One of the stand-alone plants has no chemical recovery. After the brown stock washing there are further refining steps to achieve the final pulp properties. The refined pulp may be mixed with other fibres before it is used for papermaking.

Figure 4.2 presents the production scheme of a NSSC mill in Europe. The major flows of fibres, spent liquor, chemical and energy recovery, flue-gas and waste water are shown. However, the reader should bear in mind that NSSC mills may differ from one another (base, chemical recovery system).



Source: [238, Stora Enso Oyj Heinola Fluting Mill 2009]

Figure 4.2: Production scheme of a neutral sulphite semi-chemical mill (300 000 t/yr) with chemical and energy recovery units

The chemical recovery of NSSC mills may be somewhat different from mill to mill. This is also reflected by the fact that the recovery process of the mill shown in Figure 4.2 is unique in Europe.

4.1.2 Technical processes and units

Sulphite pulping consists of three main entities: the fibre line, the chemical and energy recovery units (excluding calcium sulphite pulping where recovery is not economically possible but where the spent cooking liquor can be evaporated and the components used for other purposes) and waste water treatment plant. As in kraft pulping, some auxiliary systems like reject handling, manufacturing of bleaching chemicals and power generation are connected to the main process steps. Figure 4.3 gives an idea of what an integrated site for the production of sulphite pulp and paper may look like. The different process units are discussed in detail in this chapter.

Source: [246, Sappi Ehingen 2009]

Figure 4.3: Aerial view of an integrated sulphite pulp mill producing coated fine paper including the power plant (centre) and the waste water treatment plant (back right)

In many respects the kraft and sulphite processes have similarities, not least regarding the possibilities of taking different internal and external measures to reduce emissions to the environment. Due to these similarities, only some process steps for sulphite pulping technology are discussed in detail. For process steps for which the principles are similar or which are even identical to kraft pulping, the reader is referred to the corresponding sections:

- wood handling (Sections 3.1.1 to 3.1.3);
- washing and screening (Section 3.1.5);
- bleached stock screening (Section 3.1.8);
- drying (Section 3.1.9, mainly for market pulp; however, there are a few integrated pulp mills that dry the pulp before using it for papermaking because of its better dewatering characteristics).

For these sections, only some remarks are made regarding the extent to which sulphite pulping differs from the situation described for kraft pulping. The focus in this document is on the differences between kraft and sulphite pulping.

The major differences between the two chemical pulping processes from an environmental point of view are to be found in the chemistry of the cooking process, the chemical recovery system and the fewer bleaching sequences and chemicals required because of the better initial brightness of the sulphite pulp (lower amounts of chromophores in the sulphite pulps). Furthermore, the sulphite process normally releases less odour emissions compared to the kraft process. These differences result in different emission ranges and some differences concerning the abatement techniques applied.

The main unit processes for the manufacture of magnesium sulphite pulp are shown in Figure 4.4. For mills that manufacture speciality pulp for different chemical applications and for neutral sulphite semi-chemical (NSSC) pulp, the reader is referred to Figure 4.1 and Figure 4.2. For the manufacture of calcium sulphite pulp, the main unit processes are roughly the same but as the recovery of chemicals is not economically possible, most plants utilise parts or all of the spent sulphite liquor to produce ethanol, lignosulphonates and other products (see Figure 4.9 in Section 4.1.5).

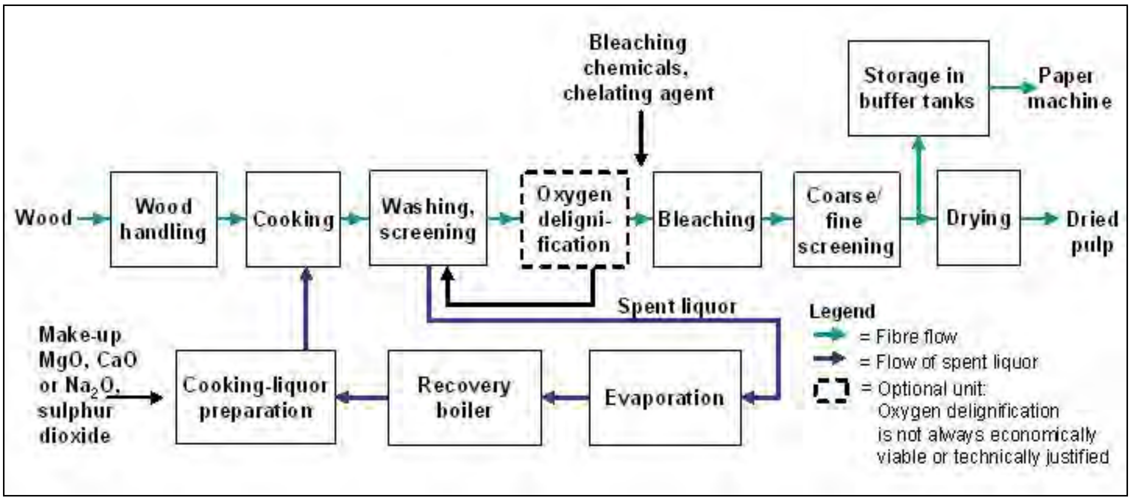
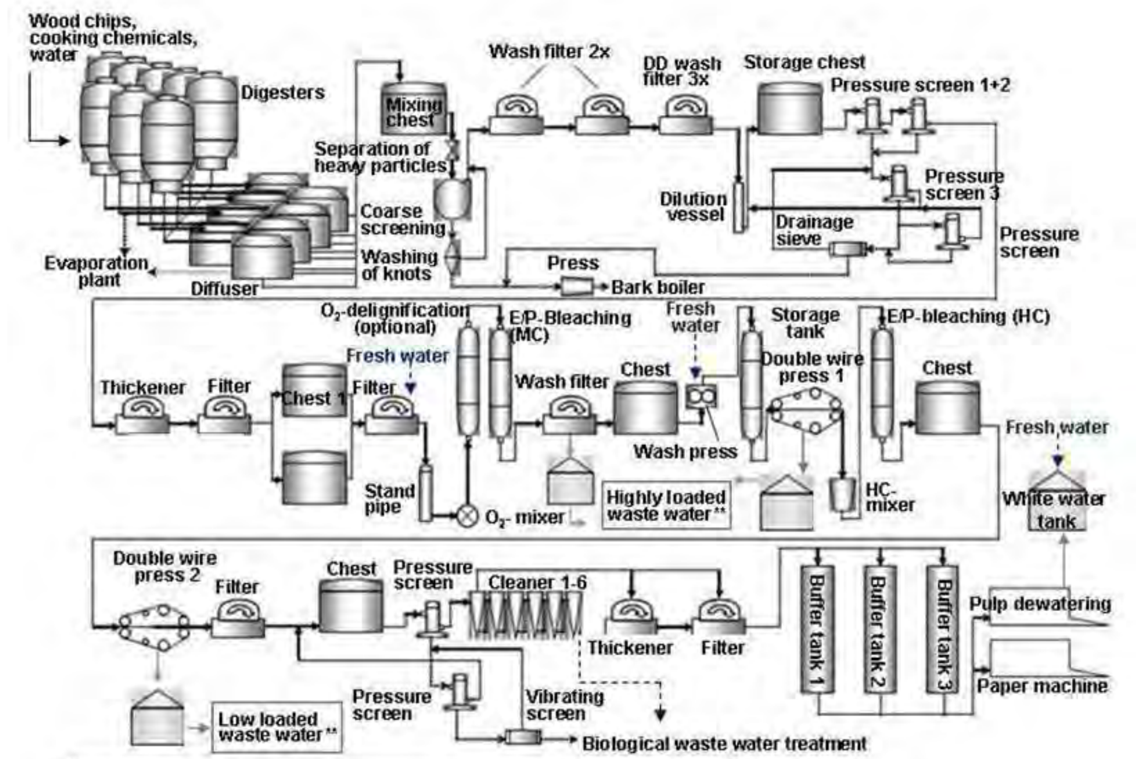


Figure 4.4: **Main processes for the manufacturing of magnesium sulphite pulp showing the fibre line operations and the chemical and energy recovery**

4.1.3 Fibre line operations

In sulphite pulping, wood pulp fibres are manufactured by chemically dissolving lignin from the wood. Before the wood is treated chemically to form fibrous pulp, the wood is mechanically debarked, cut into chips and screened. Chips and sawmill residues are also used. Lignin that keeps wood cells together forming the original wood structure and some carbohydrate material are dissolved from wood chips during cooking in aqueous solutions of acidic components at an elevated temperature and pressure. Sulphite or semi-chemical processes mainly use the HSO_3^- ion as the active component. The spent inorganic and the dissolved organic materials are separated from the pulp in multistage counter-current washing systems operated to achieve the cleanest pulp and minimal dilution of the spent liquor. In most plants, the spent liquor is processed in the chemical regeneration system of the mill (see Section 4.1.4). Discharged pulp will also contain solid impurities, mainly incompletely delignified wood, some knots, and other solid materials. These have to be separated out by screening, and the rejects are usually reprocessed to reduce raw material losses. In most cases, the washed pulp is bleached for use in high-quality white paper and board products. Only NSSC mills do not normally bleach the pulp. Bleaching effluents contain the dissolved organic material and the spent chemicals from bleaching. In most cases, these effluents do not go to the chemical recovery system of the mill but are treated biologically before discharge. It is therefore important that effluent volumes are minimised and that they receive proper physical and biological treatment before being released to receiving water bodies.

Bleached pulp is either dried and packed for shipment, or is pumped as a slurry to an integrated paper mill. Figure 4.5 shows a typical fibre line of a sulphite pulp mill.



Notes:
** Different options for gathering the separate waste water streams

Fresh water — Fresh water is used only at the end of the brown stock washing, in the wash press after the first bleaching stage and at the white water tank to stabilise the water level

Source: [245, van Tuijl 2009]

Figure 4.5: Typical fibre line of a sulphite pulp mill manufacturing pulp for papermaking

4.1.3.1 Wood handling

See Section 2.3.1.

4.1.3.2 Cooking and delignification of unbleached pulp

In the manufacturing of conventional unbleached pulp, the lignin is extracted from the wood using a concentrated cooking liquor with magnesium sulphite and magnesium bisulphite as active constituents. In the cooking stage the wood chips and the liquors are charged into a batch digester where the cooking is carried out at an elevated temperature and pressure. When the desired residual lignin content (kappa number) is reached, the contents are discharged to a blow tank or to diffusers. The cooking kappa number plays a major role in the discharges to the waste water treatment plant. Lower kappa numbers mean less residual lignin to be removed during bleaching and thus less organic loads to be treated in waste water treatment plants. The cooking kappa number is also one of the parameters that sets the conditions for the final pulp quality needed for the specific paper end use.

A batch digester plant consists of a series of batch pressure vessels, which are operated according to a certain cooking program. Cooking can also be carried out in a continuous digester, but this has been practised with sulphite pulping much less than with kraft pulping (the principles are the same and the reader is referred to Section 3.1.4).

The acid calcium bisulphite process (three mills in Europe: one dissolving pulp, one speciality pulp and one pulp for papermaking) differs from the other sulphite cooking processes, as the cooking has to be done at a very low pH level (about 1.5) in order to avoid precipitation of calcium sulphite. The challenge of the calcium process is scaling in the pipes and washing units due to the undesired formation of gypsum. As the scaling increases with the decreasing kappa level, digestion to very low kappa levels must be avoided. The low pH has some advantages in a biorefinery concept (low hemicellulose level, advantageous properties of lignosulphonate). For more details on the use of the biorefinery concept the reader is referred to Section 4.1.5.

When cooking is complete, the contents of the digester are transferred to an atmospheric tank usually referred to as a blow tank (the digester content may also be pumped to diffusors). The pulp is then pumped from these tanks to the screening and brown stock washing.

4.1.3.3 Screening and washing of unbleached pulp

After the cooking, the pulp is screened with pressure screens with slots, holes or centricleaners and washed in wash presses, screw presses, wash filters, drum washers or chemiwashers. Screening is mostly carried out in a cascade. To reduce the loss of fibres, the separated knots can be washed in a knot washer. The objective of screening is to separate knots and fibre bundles from the main pulp stream with a series of vibrating pieces of equipment, filtration through pressure screens and the centrifugal separation of fibres and other particles with different specific weights (see Section 3.1.5).

During the multistage washing, the cooking liquor which contains dissolved wood substance is separated from the pulp, and spent or weak liquor is obtained. Low dilution factors of the weak liquor and a low COD carry-over from the washers to the bleach plant are advantageous conditions for reaching lower emissions to water. Coarse rejects and other rejects from the screening are normally dewatered and burnt in the boiler house or recycled into the process. After the first washing cascade, it is beneficial for environmental and quality reasons to store the washed pulp in towers or chests which leach the pulp for both lignin and metal contents. After the storage towers, the pulp is screened and washed further before going into the first bleaching stage. In Figure 4.6 examples of a wash filter and a wash press are shown.

Figure 4.6: **Example of a wash filter (left) and a wash press (right) in brown stock washing**

4.1.3.4 Oxygen delignification and bleaching

In most cases, the cooking, screening and washing of the pulp is followed by bleaching; in a few cases, oxygen delignification (for a detailed description see Section 4.3.3) is applied before bleaching. The bleaching of pulp primarily increases the brightness of pulp and secondarily removes non-fibrous particles and extractives from it.

In European sulphite pulp mills, bleaching is carried out without the use of molecular chlorine (Cl_2). Except for two pulp mills that manufacture elemental chlorine free (ECF) pulp, all sulphite mills in Europe that produce pulp for papermaking and dissolving pulp are totally chlorine free (TCF) pulp mills. For ECF bleached sulphite pulp, chlorine dioxide (ClO_2) is used as a bleaching chemical in one or more bleaching stages combined with the application of hydrogen peroxide (P) in other bleaching stages. An example of the bleaching sequence of a mill that manufactures ECF paper pulp is given in Table 4.2. The bleaching stages are designated using symbolic shorthand according to the bleaching agent that is applied: oxygen (O), hydrogen peroxide (P) or combinations (OP), chlorine dioxide (D).

Table 4.2: **Example for an ECF bleaching sequence for sulphite paper pulping**

Parameter or chemical used	Unit	O	EOP	D	PO(P)	P
pH		10.5 – 11.0		4.5 – 5.2	10.6 – 10.9	9.5 – 10.1
NaOH	kg/t	Max. 12.5	Max. 7	--	6 – 10	2 – 4
H_2O_2	kg/t	--	Max. 7	--	6 – 10	2 – 4
O_2	kg/t	12.5	Max. 7		1 – 3	--
H_2SO_4	k/t	--	--	1.6	--	--
EDTA	kg/t	--	--	1.15	--	--
Talcum	kg/t	--	--	4.2	--	--
ClO_2	kg/t as active Cl_2	--	--	(*) Max. 4.2 (**) Max. 8.5	--	--
Kappa number		6.8 – 7.5	3.5 – 4.0			ECF: 0.8 – 1.2

NB: Depending on the dosage of ClO_2 to the D stage, the pulp can be produced with:
(*) parameters similar to those of TCF pulp with OX values in the pulp of <30 ppm, or
(**) as classic ECF pulp (OX <100 ppm). See column of the D bleaching stage.

Source: [243, Biocel Paskov 2009]

For the manufacture of speciality pulp (see Section 4.1.1.4), TCF bleaching is not yet feasible because of the need for the pulp that enters the bleach plant to have a significantly higher kappa number when producing high viscosity pulp. In order to reach a sufficient purity and brightness level, one or two chlorine dioxide stages are operated. Many of the speciality pulp applications demand very high levels of brightness (up to 94 – 95 % ISO) as well as difficult combinations of brightness and viscosity which are not yet possible to obtain without the use of chlorine dioxide. As a consequence of the use of chlorine dioxide, a complete counter-current washing cycle cannot be applied as effluents which contain residual chlorine dioxide cannot be sent for incineration (as is done for the hot alkali extraction stage effluents). Due to this, the effluents from the bleach plant are sent directly to the effluent treatment plant. For the production of very low viscosity pulp (viscosities down to 300 ml/g) and speciality pulp with a very low variation in viscosity, a hypochlorite (e.g. NaOCl) can be used as the bleaching chemical, as is done in one mill.

For TCF bleaching, usually oxygen, sodium hydroxide, hydrogen peroxide and sometimes peracetic acid are used as bleaching chemicals. In most mills, chelating agents such as EDTA or DTPA are added as complex formers (0.5 – 2 kg/t). A few mills do not use chelating agents. The bleaching chemicals used are usually bought from external chemical suppliers.

The bleaching is carried out in a sequence of two or more bleaching stages where oxygen (optional) and peroxide are added. In the first stage of a two-stage bleaching sequence, the pulp is heated up to 60 – 80 °C and sodium hydroxide, oxygen (O) and/or peroxide (P) are added. The first bleaching stage reduces the residual lignin by 45 – 55 %. The bleached pulp is then pumped to washing filters, washing presses, double wire presses or other dewatering units in order to reduce the carry-over of undesirable substances from the first bleaching stage and to further dewater the pulp. In several European sulphite mills the second peroxide bleaching stage (EP) is carried out as high consistency bleaching (symbolic shorthand: EP(HC) = 35 – 40 % DS). Advantages of HC bleaching are energy (steam) savings because of the high pulp density, lower COD emissions due to the soft bleaching conditions, low pulp losses in the bleaching stage and lower consumption of bleaching chemicals. After the second bleaching stage, the pulp is diluted with water and another washing step takes place. In the sulphite process, the specific process heat and power demand for TCF bleaching is lower than that needed for ECF bleaching.

Examples of typical bleaching sequences and the discharge of organic substances, measured as COD, from the bleach plant before treatment in European sulphite pulp mills are compiled in Table 4.3. The organic load (kg COD/ADt) does not include the condensates as they are mostly treated separately. For the designation of the bleaching stages symbolic shorthand is used according to the bleaching agent that is applied: oxygen (O), hydrogen peroxide (P) or combinations (OP), ozone (Z), acid stage where chelating agents are used for the removal of metals (A-Q or Q), extraction stage using sodium hydroxide (E), chlorine dioxide (D), hypochlorite (H), peracetic acid (Paa).

Table 4.3: Bleaching sequences used in European sulphite pulp mills and the COD discharge from the bleach plant before treatment

Cooking techniques, major product and base	Kappa number	Bleaching sequences	COD from the bleach plant (kg/t)	Example mills
Magnefite softwood pulp, paper, Mg	20 – 23	(O+P)-Q-(Paa-P)	120	Mill 1, SE (2)
Magnefite hardwood pulp, paper, Mg	20 – 23	(O+P)-Q-P	125	Mill1, SE (2)
Sulphite, paper, Mg	14 – 16	EP-EP (HC)	50 – 60	Mill 2, DE
Sulphite, paper, Mg	11 – 13	EOP-Q-EP-EP	35 – 50	Mill 3, AT
Sulphite, paper, Mg	24	Q-Z-EP (1)	110 – 130 (1)	Mill 4, SE
Sulphite, paper, Mg	12 – 15	O-EOP-D-PO(P)-P	15 – 25	Mill 5, CZ
Sulphite, paper, Ca	10 – 14	EP (MC) -EP	60 – 75	Mill 6, IT
Dissolving pulp, Mg	4 – 7	E – O/P – Z – P & E/O/P – Z – P	100	Mill 7, AT
Dissolving pulp, Ca/Mg	5 – 9	Z(HC)-(EOP)-(PO)	90 – 280	Mill 8, ES
Speciality cellulose, NH_4	7 – 60	E-D-E/P-D	130 – 400	Mill 9, FR
Speciality cellulose, Ca	10 – 60	E-D-E-D-P-H/P	30 – 600	Mill 10, NO

NB:
Data are derived from personal communication with operators of the mills.
(1) In the mill a new sequence (AQEpP) will start, thus reducing the COD discharge from the bleach plant by sending more filtrate back in the fibre line and finally to the recovery system.
(2) There are two pulp production lines in the mill (Stora Enso Nymölla): hardwood and softwood.
(3) The level of COD load is reflected in the alpha-cellulose content in the final product, where a low COD load corresponds to a low alpha-cellulose content in the final product, and a high COD load corresponds to a high alpha-cellulose content. [Comment CEPI D1]

During the manufacture of dissolving pulp and speciality pulp, particularly harsh conditions (high temperature, high sodium hydroxide charge) are applied in a special extraction stage in order to achieve the desired alpha-cellulose content. As a consequence, considerable yield is lost and large quantities of COD are released from this stage. The degree to which the lignin is extracted from the wood in the cooking stage (kappa number) determines the amount of lignin to be removed in the subsequent bleaching stages. For the manufacture of dissolving pulp the increase in alpha-cellulose content at the hot alkali E stage determines the COD load. Most of the effluents from the bleach plant are then sent to the waste water treatment plant.

4.1.3.5 Final screening and drying

After bleaching there is generally a final screening of pulp (see Figure 4.7). The rejects are burnt in the biomass boiler house or can be used at the waste water treatment plant for better dewatering of biological sludge. The pulp to be sold externally (if it is not used for the manufacturing of paper at the same mill site) is dried and the remaining pulp is pumped to the paper mill for the manufacture of different paper grades (fine paper, tissue, etc.). Pulp drying is not only carried out if market pulp is produced but also in order to optimise the fibre properties for the sheet formation and the dewatering in the paper machine. Sulphite pulp mills are mainly integrated mills manufacturing paper at the same site.

Source: [242, Sappi Ehingen 2009]

Figure 4.7: **Pressure screens for final screening**

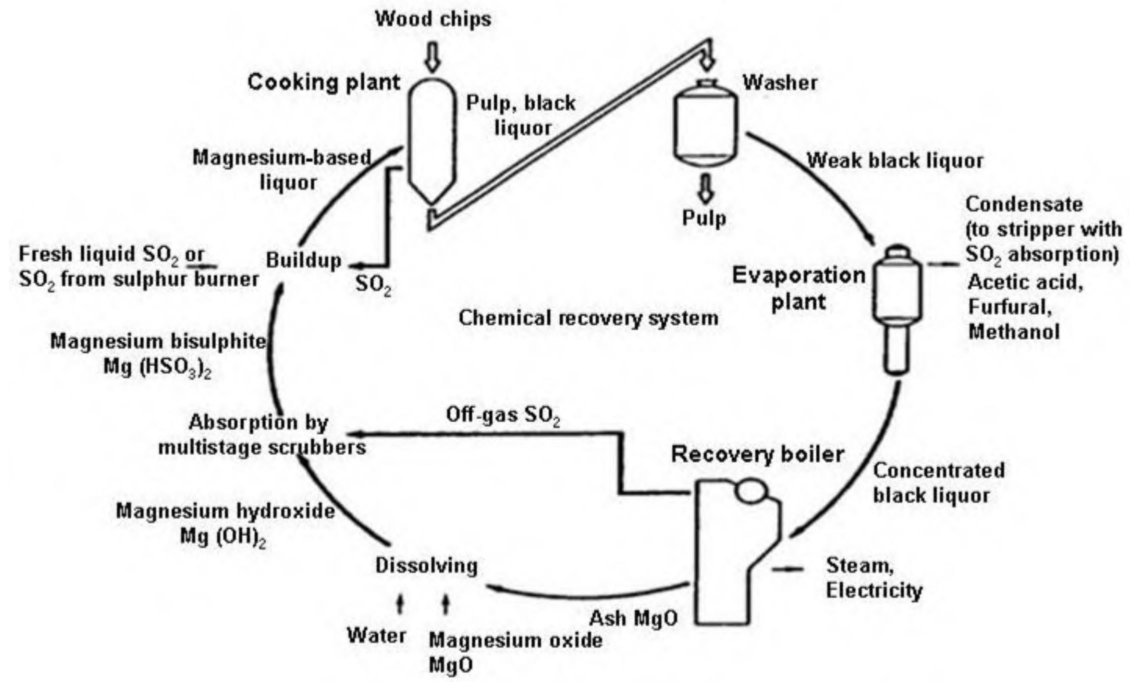
4.1.4 Chemical and energy recovery system

For sulphite or magnefite pulp mills using magnesium as a base, the preferred option is to recover the cooking chemicals and to make use of the organic compounds in the spent sulphite liquor (SSL) as a source of energy (for calcium sulphite mills, the reader is referred to Section 4.1.5). The cooking chemical recovery includes evaporation of the spent liquor to concentrated liquor, combustion of the concentrated liquor and preparation of new cooking acid from recovered chemicals. The degree of liquor recovery is 97 – 98 %.

The recovery of chemicals from the unit processes for unbleached pulp consists typically of the following major principles.

- Counter-current washing and evaporation of weak cooking liquor.
- Incineration of the concentrated liquors (biofuel) in a recovery boiler where substantial amounts of energy can be produced for steam and power generation for the pulp mill and partly the paper mill.
- During combustion, solid magnesium oxide (ash) and gaseous sulphur dioxide are formed. The magnesium oxide is separated from the flue-gases in electrostatic precipitators or multicyclones and converted to magnesium hydroxide by dissolving it in water. In a few pulp mills, the flue-gas of the recovery boiler is treated in a multicyclone system followed by a wet scrubber thus providing similar separation efficiency as an electrostatic filter.
- This slurry is used to absorb the sulphur dioxide and trioxide from the flue-gases from the recovery boiler and the collected gases from digesters, washers and evaporators by use of multistage venturi scrubbers. The liquid from the flue-gas purification is clarified (sedimentation or filtration) and reinforced with sulphur dioxide from either combustion of elemental sulphur in a sulphur burner or addition of liquid sulphur dioxide. The freshly formed cooking acid (magnesium bisulphite) is pumped into the digester house after separation of soot particles and other undissolved impurities.
- The operation of a stripping column to recover the sulphur dioxide dissolved in the condensate from the evaporation plant increases the recovery of SO_2. Higher concentrations of SO_2 may disturb the biomass in the anaerobic waste water treatment plant. By stripping them out of the condensate, they can be reused in the cooking plant.

An overview of the recovery cycles of chemicals and energy is presented in Figure 4.8 illustrating the main process steps and their functions.



Source: [6, BMU Austria 1995] modified by EIPPCB

Figure 4.8: Recovery cycles of chemicals and energy for a magnesium-based sulphite mill

Magnesium-based mills have difficulties in recycling water from stages where sodium hydroxide is used to control the pH. A key issue for sulphite mills is the separation of effluents which contain different chemical bases. For instance, sodium hydroxide may be needed to achieve the required pH conditions in some bleaching stages. In that case it is not possible to lead the bleach plant effluents back to the recovery units due to the large amount of sodium ions which may disturb the operation of the recovery boiler.

Besides the recovery of cooking chemicals, the recovery boiler(s) produce steam. Often sulphite pulp mills operate auxiliary boilers burning bark, oil or other fuels. In these boilers, knots, rejects and sludge from the effluent purification may also be burnt. The steam from the boilers is lead to counter-pressure turbines where electrical power is produced.

4.1.5 Processing of by-products of sulphite pulping

During cooking, hemicellulose and lignin are released to the cooking liquor. The spent sulphite liquor (SSL) can be sent to the chemical and energy recovery units directly (see Section 4.1.4) or can be separated and utilized to produce other products. Some sulphite pulp mills, especially those that use calcium as a base in the cooking process but also single mills that use sodium, ammonium or a mix of calcium and magnesium, manufacture pulp and additionally several other products. Pulp mills that convert most of the spent sulphite liquor into various products are referred to as 'biorefineries'. Figure 4.9 shows an example of a mill where all SSL is converted into saleable products (Borregaard, NO).

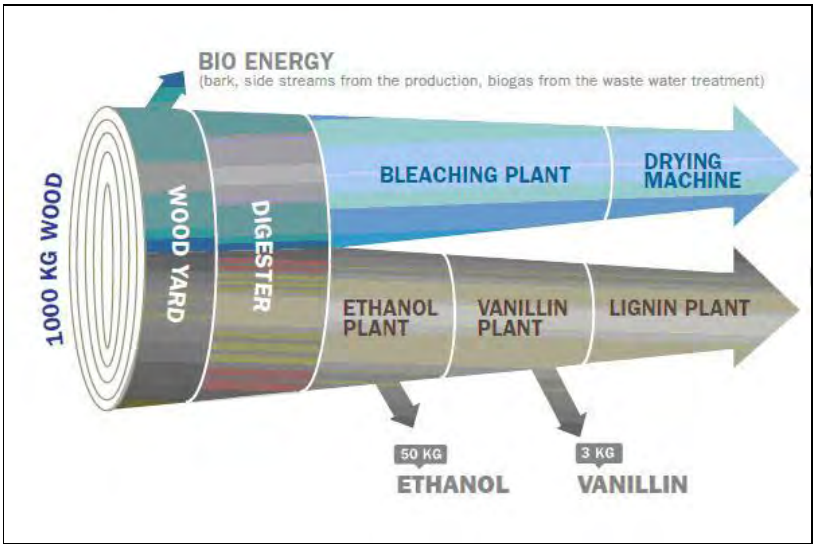


Figure 4.9: **Basic principle of the flow of pulp and spent liquor in mills applying the biorefinery concept**

Examples of by-products are lignosulphonates, ethanol, fodder yeast, soda, vanillin, acetic acid and furfural.

Lignosulphonates

Lignosulphonates, which make up around 70 % of the SSL, are used as an additive or process aid in several industries. Lignosulphonates are also used as a binding agent in, for example, feed pellets and mineral briquettes or as a dust abatement agent used on roads. Chemically treated lignosulphonates are efficient dispersants for water reduction in concrete, the production of bricks and other ceramic products, and also in the production of dye pigments. This market is growing, especially chemical applications such as concrete, black carbon, tannins and others. Lignosulphonates are considered as 'derived from naturally occurring polymer' and as such are exempted from the REACH regulation.

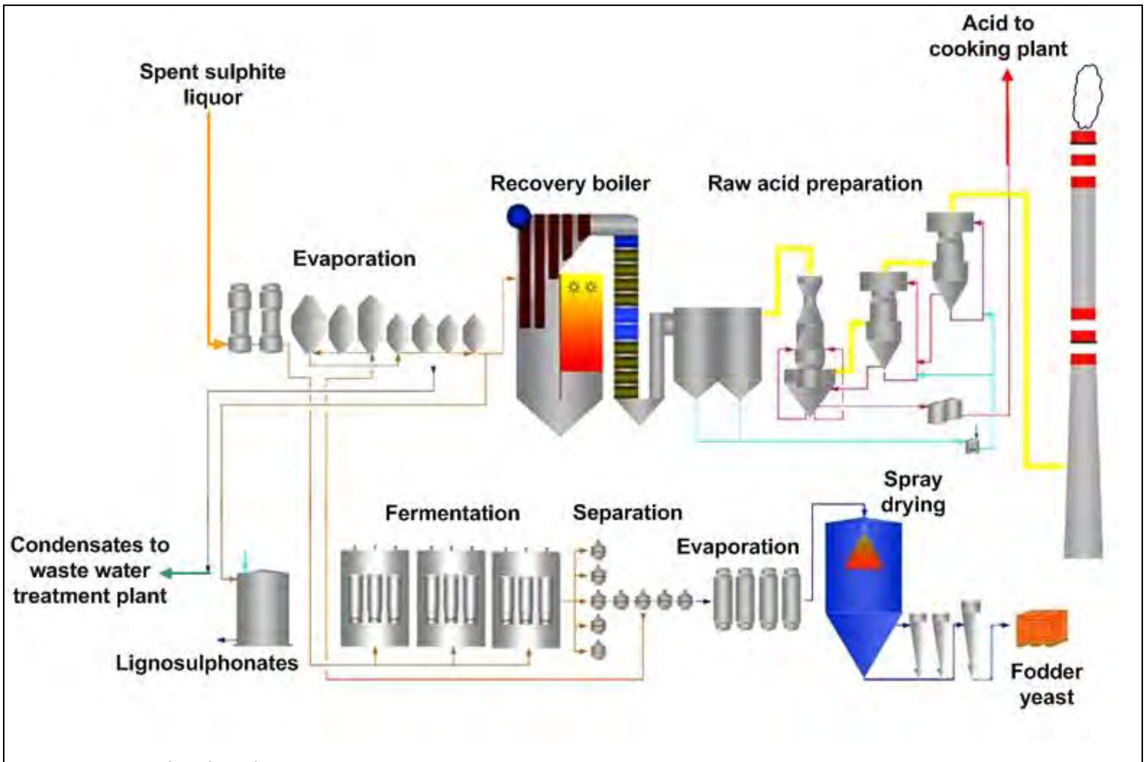
Ethanol

A part of the hemicellulose generated from softwood can be fermented and distilled into ethanol. In the past, most sulphite pulp mills also operated ethanol production units. With the introduction of chemical and energy recovery systems, most mills abandoned ethanol production. Climate policies and recent regulations on renewable fuels have made ethanol production more attractive again.

In the fermentation process, ethanol and carbon dioxide are produced. The ethanol is distilled in order to meet the required strength and quality. While distilling the ethanol, combustible substances such as methanol are removed from it. They are either sold, sent to the effluent treatment plant or combusted in the mill which results in energy being recovered. The carbon dioxide produced can be collected and sent to a carbon dioxide recovery plant (example: Domsjö Fabriker, SE) where it is purified and condensed to carbonic acid.

Fodder yeast

Hemicellulose can also be used as raw material for biotechnological production of fodder yeast (see Figure 4.10). The yeast is produced based on clean cultivation using a fermentation process. Fodder yeast supplied in dry form is mainly used in the production of feeding mixtures for livestock and pet food for domestic animals.



Source: [241, Biocel Paskov 2009]

Figure 4.10: **Scheme of the manufacture of fodder yeast and separation of lignosulphonates from the spent sulphite liquor**

Soda

Soda may occur as a by-product when hemicellulose extraction is carried out in a hot alkali extraction stage using NaOH (approximately 30 – 130 kg/ADt pulp) in order to achieve an α-cellulose content well above 90 %. This solution with a high organic load can be treated in a biological waste water treatment plant (together with other alkaline effluents from the bleach plant). In at least three mills in Europe (in AT, FR and NO) however, the high organic load effluent which contains sodium is concentrated by evaporation and subsequently burnt in a molten ash chamber boiler (see Section 4.3.13). The slag and the filter ash consist mainly of sodium which can then be used for neutralisation of the acid influent flows of the biological waste water treatment plant. The investment and operating costs of this technique are relatively high (due to an unfavourable energy balance).

Vanillin

Lignosulphonates are also used as a raw material for manufacturing vanillin. The process starts with a catalytic, high-pressure cracking of the lignosulphonate, followed by several purification steps. Vanillin is one of the most common flavours and fragrances used, with a large variety of applications.

Acetic acid and furfural

These two products are examples of what can be extracted from the SSL. However, the manufacturing and capital costs will today, most probably, exceed the income.

Characteristics of the 'biorefinery concept'

For calcium sulphite mills, the recovery of cooking chemicals is not economically viable. The associated high emissions of organic substances have motivated some sulphite mills that used calcium as a base to shift to another base, in most cases to magnesium, as MgO as a base allows the establishment of a chemical and energy recovery cycle. Other calcium-based mills have closed down their production. However, a few mills have spotted large market opportunities from using calcium as a base and have adopted the 'biorefinery concept': recovery of the spent sulphite liquor as a basis for making saleable products.

The conversion of SSL into saleable products requires additional process lines, including washing and purification steps. When the valuable components of the SSL have been extracted and converted into products, the remaining process water which still has a high organic load (e.g. in the case of a speciality pulp producer, around 4 500 mg COD/l) is sent to the biological effluent treatment plant.

Many of the products produced from the spent sulphite liquor are substituting petrochemical products in the final end use. This is especially the case for ethanol, lignosulphonate and vanillin which constitute the majority of the volume produced from spent sulphite liquor in the biorefinery concept. Lignin substitutes superplasticisers in concrete, ethanol substitutes ethanol from ethylene and also ethanol made from sugar cane and vanillin substitutes synthetic vanillin, which is typically made from guaiacol (which is a phenol derivative). The effect on the climate of the wood-based products is considerably lower than from the petrochemical alternatives.

In a biorefinery, the tonnage of saleable products per unit of wood used is much higher than it is in a traditional pulp mill of a similar size; in some cases, nearly twice the tonnage.

4.1.6 Preparation and handling of sulphur dioxide and bleaching chemicals

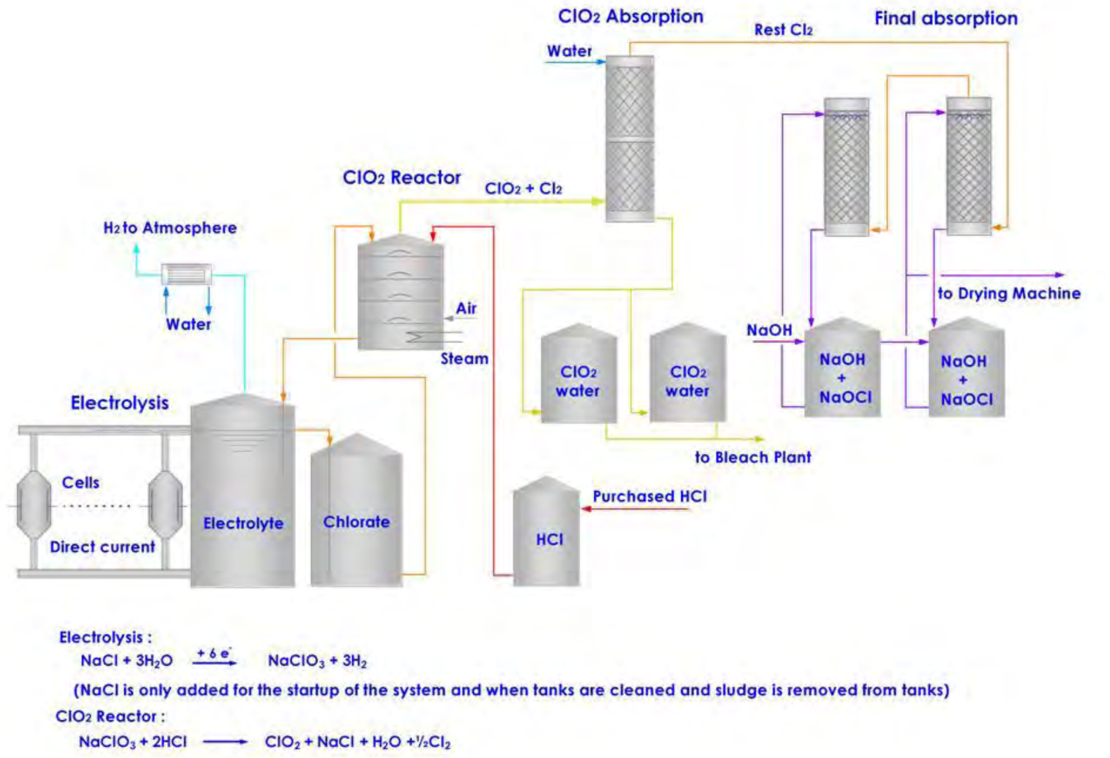
Most sulphite mills are handling liquid sulphur dioxide. In case of accidents, the use of liquid SO_2 constitutes a risk that can lead to serious damage to health and the environment. If companies store and handle more than 200 tonnes of SO_2, the extended safety obligations of Council Directive 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances apply [214, Seveso II Directive (96/82/EC) 1996]. In order to guarantee the safety of the site, a number of responsibilities have to be met. For example, the plant must be registered with the authorities, security reports must be drafted periodically, internal and external contingency plans are mandatory and a sufficient safety distance to housing areas has to be maintained. These plants also undergo regular safety inspections. Extensive technical and organisational safety measures reduce the remaining risk of an accident. Normally companies have automatic alarms installed to detect accidental losses of SO_2, and the pipes for the transport of the liquid SO_2 are equipped with a monitoring system for leakage.

Another option for the preparation of SO_2 other than handling liquid SO_2 is the combustion of solid sulphur in a combustion chamber (sulphur burner) and the absorption of the generated SO_2 gas. The advantage of this option is that the Seveso II Directive does not apply and that the energy released during the exothermal reaction is recovered in a small heat recovery boiler that produces steam (there is an example of a mill that manufactures 140 000 tonnes/year: 1.3 tonnes of steam/hour, 12 bar, 220 °C). A number of mills in Europe use this alternative.

In the bleach plant, mainly sodium hydroxide (NaOH), hydrogen peroxide (H_2O_2) and sulphuric acid (H_2SO_4) are used. Peroxide is used as a bleaching agent, NaOH in order to adjust the pH value needed for the process. Sulphuric acid is applied for acidification after the alkaline bleaching stages. The delivery of the chemicals is normally effected by railway, road, tanker or ship, or they are produced on site. The concentration of the substances upon delivery is 50 % for NaOH, 49 % for peroxide and between 70 % and 98 % for sulphuric acid. Hydrogen peroxide and sulphuric acid are used in undiluted form, NaOH is used as a diluted solution (10 – 18 %). In order to avoid unwanted releases to the soil, groundwater or nearby water bodies, the chemicals are stored in double-walled tanks or tanks with sufficient capacity to contain the stored chemicals. The storage tanks are located above collection basins capable of containing potential leaking liquids.

If chlorine dioxide is used as the bleaching chemical (ECF bleaching), different techniques can be used for the preparation of ClO_2 on site (see also Section 3.1.12.1). The preparation of chlorine dioxide by the Kesting method (used e.g. in the sulphite pulp mill Biocel Paskov A.S.)

is one of the methods which does not cause significant impacts on the environment (see Figure 4.11).



Source: [240, Biocel Paskov 2009]

Figure 4.11: Preparation of chlorine dioxide by the Kesting method

In this case, chlorine dioxide is prepared by the electrolysis of NaCl and the intermediate formation of $NaClO_3$. On the whole, 1 – 2 tonnes/day of one input chemical (HCl) are used for the production of 1 – 2.4 tonnes/day of ClO_2, depending on the pulp sort manufactured. NaCl is used only for the start-up of the system (approximately 30 tonnes). The chlorine dioxide production system is nearly closed. Once per year during shutdown, the tanks are cleaned and sludge is removed from the tanks. In this case, or if a leakage occurs, approximately 1 – 2 tonnes of NaCl are added to the system. Sometimes, NaOH or HCl is added to adjust the pH. ClO_2 in water concentrations of 1.5 – 4.5 g ClO_2/l is used in the bleach plant. After the last absorption stage, the generated NaOCl (around 18 m^3/day) is used internally for the disinfection of the drying machine process water. The formation of chlorate, which is toxic to bacteria and plankton at levels of about 3 – 4 mg/l, is not measured because of the small amount of chlorine dioxide that is used in the bleach plant of this example sulphite mill.

4.2 Current consumption and emission levels

This section refers to all types of sulphite pulp mills including NSSC mills.

4.2.1 Overview of input/output for the production of sulphite pulp

An overview of the raw material and energy input as well as the output of products, by-products and the major releases (emissions, waste, etc.) of the production of sulphite pulp is presented in Figure 4.12. The process design, the type of mill, the cooking and bleaching concept and the marketing strategy of the mill lead to different emissions to water (e.g. AOX, chlorate, chelating agents). The amount and type of products and by-products depend on the type of mill (see Section 4.1.1), the business strategy and the marketability of the by-products.

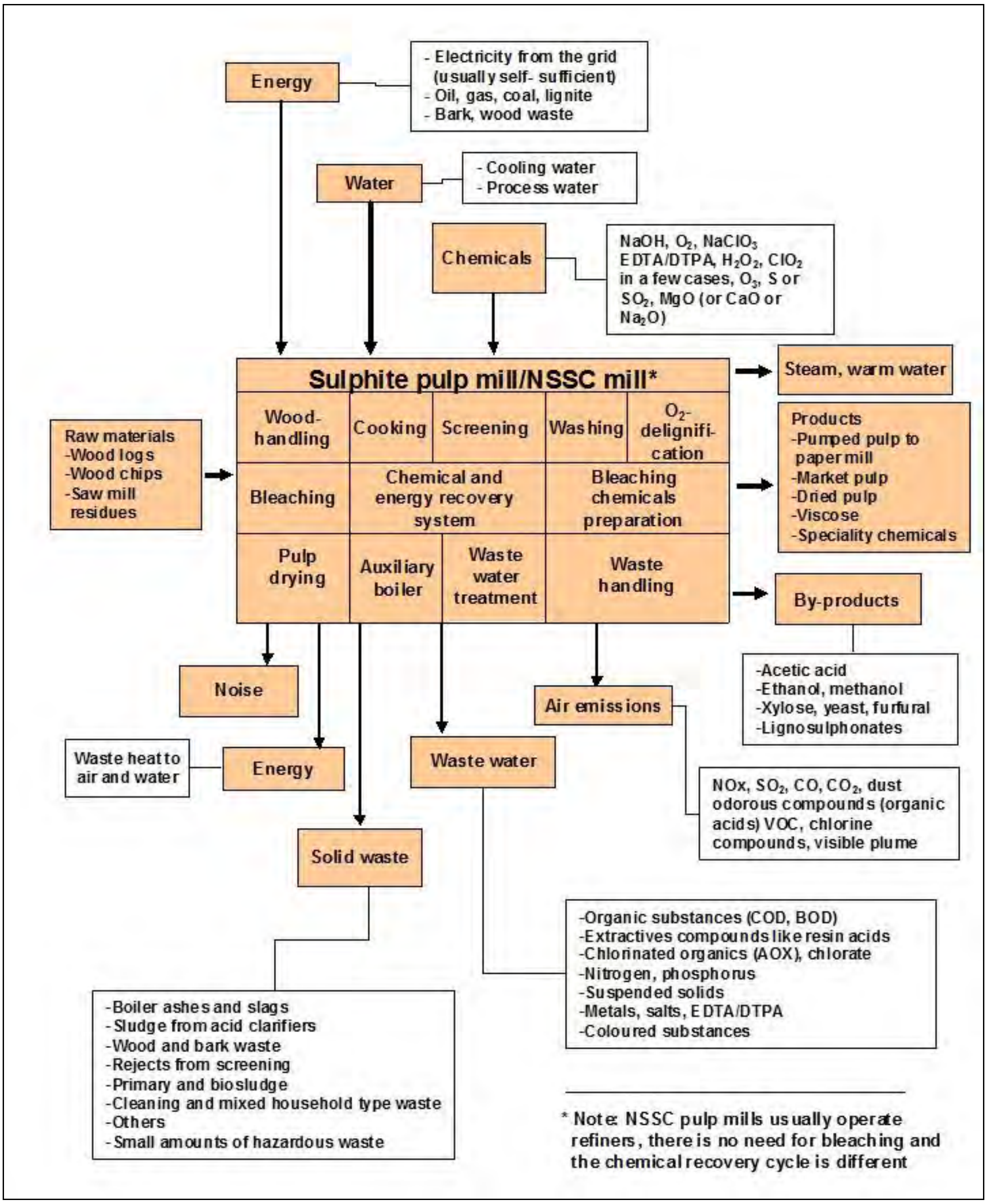


Figure 4.12: Mass stream overview of the inputs and outputs of a sulphite pulp mill

Table 4.4 shows yearly averages from three integrated acid magnesium bisulphite mills manufacturing pulp for papermaking in Germany. Therefore, the data do not represent the whole range of emission levels of sulphite pulp mills. However, the data give an overview of the major input flows (raw materials, fuels and water used) and emission loads to water and air including residues that can be expected at a typical sulphite pulp mill.

Table 4.4: Annual average specific input/output data from three integrated sulphite pulp and paper mills manufacturing together about 462 000 ADt/yr

Input (3 example mills, data from 2008)			Output (3 example mills, data from 2008)		
Raw materials	**Value**	**Unit(1)**	**Product**	**Value**	**Unit**
Wood (oven dry)	~ 2.1	t/ADt	Bleached pulp	1	ADt
SO_2 as S	28 – 32	kg/ADt			
MgO	9.5 – 24	kg/ADt	**Emissions after treatment**		
NaOH	26 – 30	kg/ADt	CO_2	No data	kg/ADt
H_2SO_4	4	kg/ADt	CO_2, regenerative	No data	kg/ADt
H_2O_2	21 – 26	kg/ADt	NO_X	0.96 – 1.9	kg/ADt
DTPA	1.3 – 3	kg/ADt	CO	0.03 – 1.12	kg/ADt
Energy			SO_2-S	0.77 – 1.11	kg/ADt
Oil	No data	MJ/ADt	Dust	0.03 – 0.07	kg/ADt
Coal	No data	MJ/ADt	COD	21 – 25.5	kg/ADt
Natural gas	No data	MJ/ADt	BOD_5	0.45 – 1.2	kg/ADt
Purchased electricity	No data	kWh/t	Suspended solids	0.4 – 1.2	kg/ADt
Total primary energy (2)	No data	kWh/t	AOX	<0.002	kg/ADt
			N_{inorg}	0.09 – 0.4	kg/ADt
			Total phosphorus	0.01 – 0.06	kg/ADt
			Waste water flow	43.5 – 65	m^3/ADt
Water use			**Residues**		
Raw/fresh water	43.5 – 65	m^3/ADt	Sludge (90 % dry solids)	24 – 29	kg/ADt
			Ashes from power boiler and desulphurisation	13 – 33	kg/ADt

NB:
(1) ADt = air dry tonne of pulp.
(2) Air emission from purchased electricity is not included.
(3) Air emissions refer to the recovery boiler only. Emissions from bark and auxiliary boilers are not included.
(4) Data refer to the pulp mill only. Emissions from paper manufacturing have to be considered separately.

Source: [236, COM 2009]

The data refer only to the pulp production, i.e. paper production is not included. The data for emissions to water represent the situation after biological treatment. The air emissions data refer to the situation after abatement.

For sulphite mills manufacturing dissolving pulp, the consumption and emission levels are different with regard to a number of aspects: the wood input is remarkably higher (2.6 tonnes/bone dry tonne of pulp), as is the NaOH dosage which is required to achieve purified pulp with a high alpha-cellulose content. Using second-hand caustic from the viscose plant, one dissolving pulp mill adds up to 80 kg NaOH/ADt of pulp. In terms of the energy balance, the pulp mill generates 140 % of its own energy consumption, delivering the excess to the mill that manufactures the viscose fibres.

4.2.2 Consumption and emission levels arising from process units

This section refers to all types of sulphite pulp mills, including NSSC mills.

In sulphite pulping, energy consumption, waste water effluents, emissions generated from the handling of the spent liquor (if calcium is used as a base) and the emissions to air are the main points of interest. For the neighbourhood, odorous gases, noise or annoyances associated with transport of the raw materials and end products may also raise concerns. The most relevant consumption of raw materials and emissions to water, air and soil (waste) as well as energy aspects are discussed below covering the following aspects:

- wood consumption;
- consumption of chemicals;
- energy demand;
- water use and waste water emissions from different process steps and the whole effluent including:
  - washing losses
  - discharges from the bleach plant
  - condensates from evaporators
  - spillages
  - discharges of nutrients
  - discharges of chelating agents
  - chlorine compounds from bleaching and bleaching chemical preparation (only for the very few ECF pulp mills)
  - discharges of metals (depending on the wood source used);
- emissions to the atmosphere from point sources (recovery boiler, auxiliary boilers);
- odorous gases and diffuse emissions;
- solid waste generation;
- noise.

Where data are available, information on emissions to water, air or soil (waste) are given before and after external treatment.

4.2.2.1 Wood consumption

Softwood (mainly spruce) and hardwood (mainly beech, or eucalyptus) can be used as raw material in the sulphite pulping process. Logs, chips and sawmill residues are used. A few mills use sawmill residues only. The use of wood and the yield for production of bleached pulp is dependent on the selectivity in delignification and bleaching, the wood species used, and the type of sulphite pulping applied (see Section 4.1.1).

The wood required for the manufacturing of one tonne of bleached sulphite pulp for papermaking is normally 1.8 – 2.1 bone dry tonnes of wood/ADt of pulp.

Due to the slightly higher yield of the magnefite process (compared to the acid sulphite process), the wood consumption is slightly lower. Magnefite pulps differ from sulphite pulps in that they have the possibility to use pine.

For dissolving pulp (viscose production), the wood input is remarkably higher: around 2.6 bone dry tonnes of wood/ADt of pulp is used in a mill due to the lower yield.

For speciality pulps, the wood consumption varies in a large range depending principally on the level of hemicellulose extraction: 2.2 – 2.8 bone dry tonnes of wood/ADt of pulp. Wood species and products manufactured also affect the ratio.

A NSSC pulp mill reported a wood consumption of 2.4 – 2.9 m^3 of unbarked wood/ADt of pulp. This corresponds to about 1.1 bone dry tonnes of wood/ADt of pulp. The main raw material in this case is birch. Spruce, aspen, alder or logging residues can also be used. The yield for production also depends on the wood species used.

4.2.2.2 Consumption of chemicals

Consumption of chemicals varies from mill to mill to a certain extent. However, the typical consumption of the main chemicals for sulphite pulp production is reported in Table 4.5.

Table 4.5: Consumption of main chemicals in sulphite pulp production

Chemicals used for bleached Mg-sulphite pulp production	Amount [kg/ADt]
NaOH	10 – 55
O_2	0 – 15
H_2O_2 (100 %)	10 – 40
EDTA or DTPA	0 – 3
O_3 (^{1})	0 – 5
S (mills use either solid S or liquid SO_2)	20 – 40 (up to 90)
SO_2 (mills use either S or SO_2)	0 – 70
MgO	15 – 25
Defoamers	1.31 (1 mill)
Dispersing agent for resins	0.43 (1 mill)
Cleaning agents	NA

NB:
(^{1}) Ozone is normally not used in sulphite pulp mills. However, two mills that are manufacturing dissolving sulphite pulp and one that produces paper grade pulp have implemented an ozone bleaching stage.
(^{2}) NSSC mills do not use bleaching chemicals or complexing agents (unbleached pulp). The main chemicals are NaOH or $NaCO_3$ (cooking based on Na) and S or SO_2.

A Swedish magnefite pulp mill producing bleached pulp for fine paper manufacturing reported the following chemical consumption per tonne of pulp as 50 kg of sodium hydroxide, 14 kg of oxygen, 1.8 kg of EDTA, 2 kg of peracetic acid (softwood) and 37 kg of hydrogen peroxide. The bleaching sequences are (E + O) Q (E + O + P) (O+P)-Q-(Paa-P) for softwood and (O+P)-Q-P for hardwood.

4.2.2.3 Energy consumption

In sulphite pulp mills, the majority of thermal energy is consumed for heating the digesters, during bleaching (heated process in order to accelerate and control the chemical reactions), pulp drying (if it applies) and for the evaporation of the weak liquor to 58 – 60 % dry solids content. Electrical energy is mostly consumed for the transportation of materials and water (pumping) and to maintain the pressure in the digesters and the bleach plant.

The manufacturing of bleached sulphite pulp consumes about 7.5 – 16.5 GJ/ADt of heat energy (excluding steam for the production of electrical power). The lower levels are achieved when paper pulp is produced and the drying of pulp is not included (pumpable pulp). The consumption of electrical energy is 550 – 900 kWh/ADt [236, COM 2009]. The energy consumption for pulp drying is about 25 % of the heat energy and 15 – 20 % of the electrical energy. Around 50 % of the electrical energy consumption is used for pumping. If ozone is used in bleaching, the total consumption of electrical energy may reach 990 kWh/ADt.

The energy consumption depends on the process configuration, process equipment, process control efficiency and product portfolio.

Table 4.6 below exemplifies the reported net energy consumption for some European sulphite pulp and paper mills as heat (excluding that for back-pressure power generation) and electrical power for non-integrated or integrated sulphite pulp production. In the latter case, energy data refer to pulp production only.

Table 4.6: Example energy consumption of some European sulphite pulp and paper mills in 2008

Pulp grades	Process heat [GJ/ADt]	Electric power [kWh/ADt]
Production of bleached sulphite pulp; for integrated mills data refer to pulp manufacturing only (pumpable pulp)	7.5 – 8.5	550 – 750
Production of bleached sulphite pulp; data refer to air dry pulp (including drying machine): manufacturing of by-products may also be included	13.5	880
Production of bleached sulphite pulp for viscose and chemical applications; data refer to air dry pulp (including dryers)	16.5	900
Source: [236, COM 2009]		

No data were provided about the status of the energy efficiency of the presented mills. From available data derived from filled-in questionnaires, Table 4.7 and Table 4.8 summarise the energy consumption for two different types of mills by subprocess. Thus, the main energy-consuming process stages can be identified. It is clear that energy reporting still differs from mill to mill and includes different equipment with different levels of detail. The figures represent stepwise modernised mills which were built many decades ago and subsequently updated and retrofitted (reference year: 2008). A newly built or more recently modernised existing mill would most probably have lower values.

Table 4.7: Energy consumption for the production of bleached sulphite pulp

Process unit	Process heat (steam) total net consumption [GJ/ADt]	Electric power net consumption [kWh/ADt]	Remarks
Wood room	0.185	14	Handling, debarking, chipping
Cooking	2 314	129	
Washing and screening	-	-	No data; normally around 45 – 55 kWh/ADt
Bleaching	1 456	248	No O_2 delignification
Bleach stock screening	-	-	No data; normally around 30 – 40 kWh/ADt
Pulp drying	-	-	Data refer to pumpable pulp; pulp drying consumes approx. 2.8 – 3 GJ/ADt and 100 kWh/ADt of power
Evaporation and stripping	3 840	42	Data without stripping
Recovery boiler	0.291	286	Including flue-gas desulphurisation
Auxiliary boiler	-	-	Associated with paper production
Effluent treatment	-	-	No information provided; normally between 9 and 15 kWh/ADt
Bleaching chemicals preparation	-	-	No information provided
Miscellaneous, pulp mill	-	12	Not further specified
Total pulp mill	**8 086**	**731**	

NB: Similar percentage of hardwood and softwood used; data refer to 'air dry tonne' but the process ends with pumpable pulp production.

Source: [236, COM 2009]

As indicated in the right-hand column of Table 4.7, the data set is not complete. The system boundaries and processes referred to are not always transparent. Data refer to pumpable pulp, i.e. the pulp dryer is not included. The energy consumption figures can only give a rough indication of the major energy consumers in a sulphite pulp mill manufacturing paper pulp and approximate total net energy consumption values.

In contrast to Table 4.7, Table 4.8 includes pulp drying, the power consumption of the energy plant, raw water and waste water treatment and a large amount of energy which is consumed by miscellaneous processes including losses and possible measurement errors.

Table 4.8: Reported energy consumption for the production of bleached sulphite pulp

Department	Process heat (steam) total net consumption [GJ/ADt]	Electric power net consumption [kWh/ADt]	Remarks
Wood room		36.3	Handling, debarking, chipping
Cooking	2 577	124.5	
Washing and screening	---		
Delignification	0.421	140.0	
Bleaching	0.266		
Bleached stock screening	---	119.4	
Pulp drying	3 024		
Evaporation & stripping	4 118	104.2	
Recovery boiler	0.197	18.5	
Auxiliary boilers		75.4	Energy plant
Secondary recovery	0.068	32.2	
Raw and waste water treatment	--	75.4	Not specified
Preparation of bleaching chemicals	0.182	92.9	Not specified
Miscellaneous, pulp mill	2 705	60.8	Unmeasured losses, measurement errors
Total pulp mill	**13 656 (*)**	**879.6**	

NB:
Mostly softwood used; data refer to air dry tonne of pulp and include the pulp dryer and the manufacturing of by-products.
(*) In this case, the sum reported by the mill operator does not add up. The sum for adding the energy consumption of different departments is very difficult to establish because of the challenge measuring the process heat of all different departments. When mapping the electrical power, the total sum rarely adds up because different process cycles may be operated during the mapping. These table can therefore only give an indication of the main energy consumers in a mill.
Source: [236, COM 2009]

Sulphite pulp mills are energy-intensive installations. At the same time they produce steam and electrical power on site by use of mostly regenerative fuels. Non-integrated sulphite pulp mills are around 90 % energy self-sufficient (when they operate chemical and energy recovery units). This is mainly because of the energy recovery by burning off around 50 % of the incoming wood in the recovery boiler (concentrated black liquor) and the use of bark as auxiliary boiler fuel. Furthermore, secondary energy from different process steps can be recovered as warm and hot water (40 – 80 °C). In mills that operate a recovery boiler, fossil fuels are mainly used as support fuel, in case of disturbances and for start-up and back-up fire in the recovery boiler (e.g. oil or natural gas) and in the auxiliary boiler(s). Fossil fuels are also used when the SO_2 absorption scrubber is stopped for cleaning.

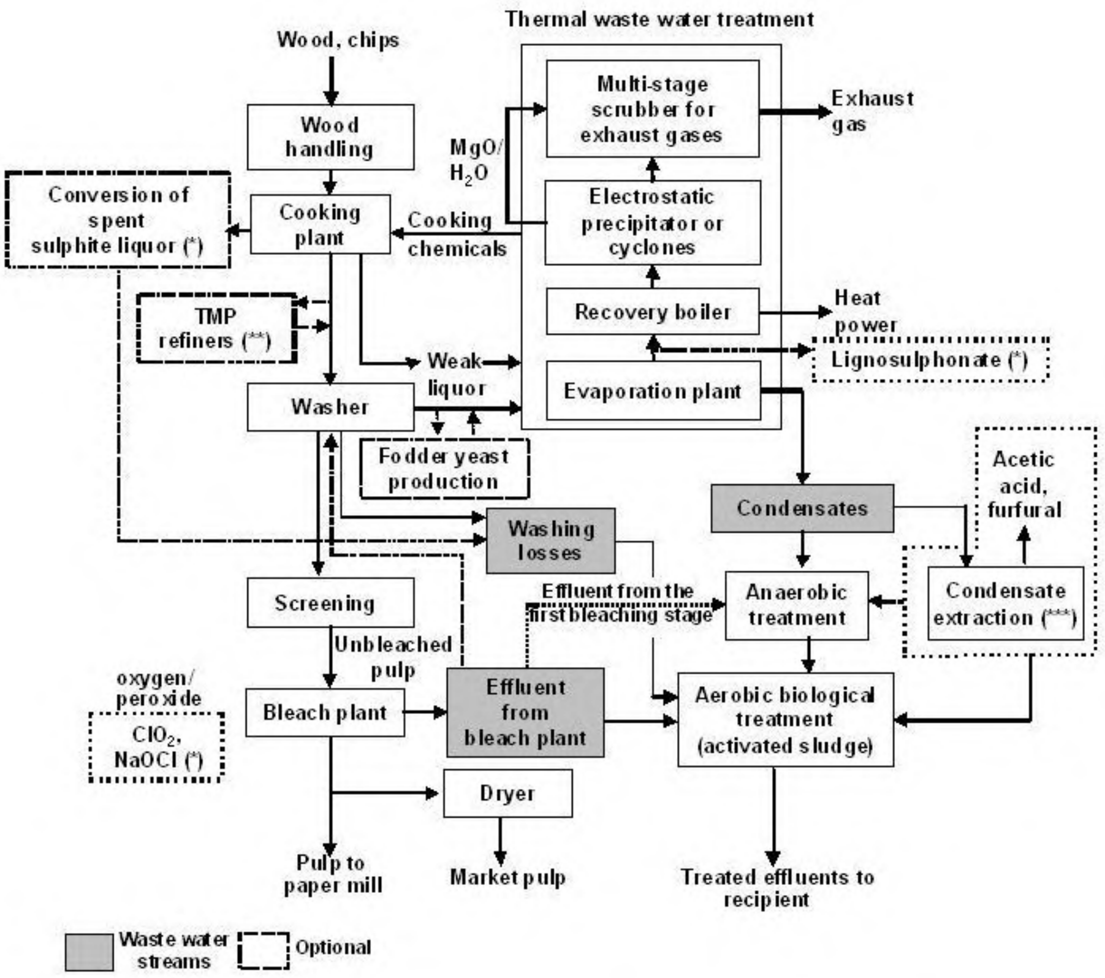
The recovery boiler acts as a power station where the concentrated spent sulphite liquor is burnt. Generated heat is utilised for the generation of high-pressure, superheated steam. Part of the energy content in the high-pressure steam is utilised for generating power in a back-pressure turbine. Medium-pressure steam extracted from the turbine and low-pressure exit steam are utilised for covering the heat energy demand in the pulp process. Sulphite pulp mills that operate recovery boilers are nearly electricity self-sufficient and only need a limited supply of fossil fuel-based power.

The few mills in Europe that do not run recovery or biomass boilers have to generate steam and electricity entirely from fossil fuels.

In an integrated pulp and paper mill, the excess heat produced by the pulp mill is not enough to cover the energy consumption of the paper production. The additional demand for heat has to be met by heat produced in wood/bark boilers and auxiliary boilers. Fossil fuel is used as support fuel in bark and sludge boilers and as the main fuel in auxiliary boilers as well. Peaks in energy consumption are often satisfied by using a steam block fed with fossil fuels.

4.2.2.4 Waste water flow and emissions to water

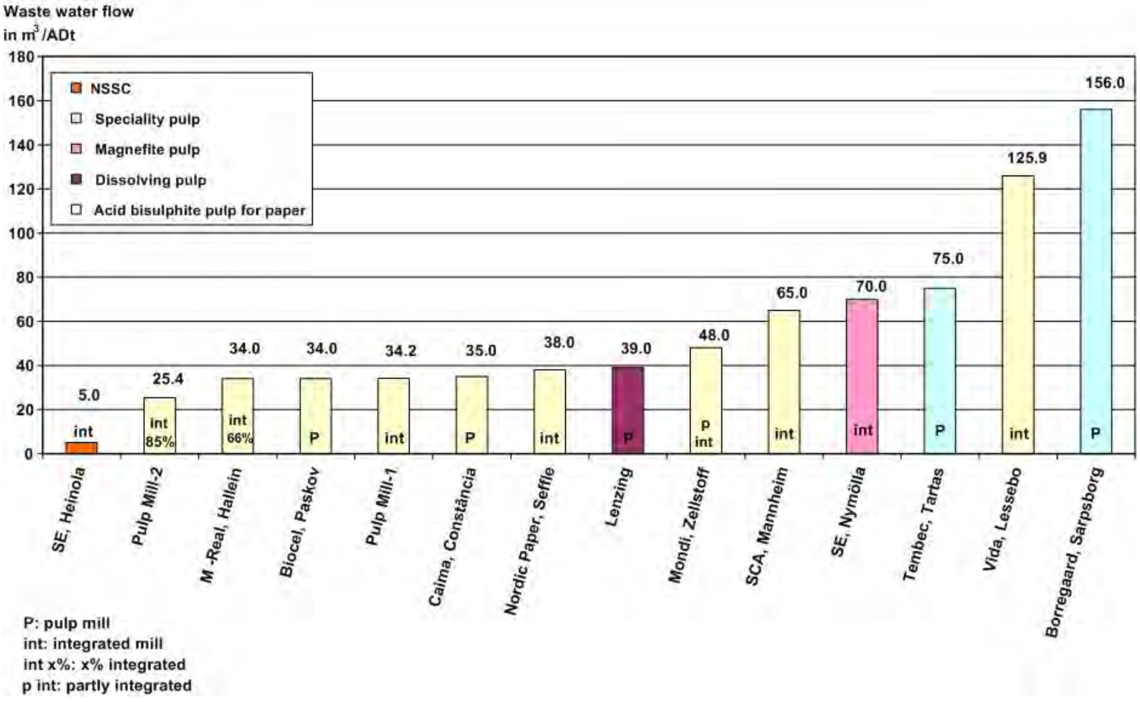
Figure 4.13 gives an overview of the main processes involved in sulphite pulping and the major sources of emissions to water. The emissions to water originate from different processes, mainly washing losses, effluents from the bleach plant and condensates from the evaporation plant. They also include accidental spills. However, in well-managed sulphite mills there are nearly no spillages that are not recovered.



NB:
(*) Applies only to a few mills that separate lignosulphates from the spent sulphite liquor.
(**) Applies to NSSC mills only.
(***) Applies mainly to hardwood (beech) with intensive cooking (viscose pulp). The high concentration of acetic acid, furfural and xylose are transferred into the condensate of the evaporation plant and can be extracted and sold.

Figure 4.13: Major sources of emissions to water from sulphite pulping

An overview of the amount of waste water discharged (yearly averages) from different sulphite pulp mills is given in Figure 4.14. Reported values range from 25 m^3/ADt up to 156 m^3/ADt of pulp.



Source: data collection/questionnaires

Figure 4.14: Waste water discharged (yearly averages) from different sulphite pulp mills

The current emission levels of the different types of sulphite pulp mills shown in Table 4.9 reflect the range of emissions found in Europe. Most of the mills operate biological treatment plants.

Table 4.9: Reported ranges of annual average effluent discharges in 2008 from different types of European sulphite pulp mills after waste water treatment

Pulping technology and products manufactured	Flow m^3/ADt	BOD$_{5/7}$ kg/ADt	COD kg/ADt	AOX kg/ADt	Tot-P kg/ADt	Tot-N kg/ADt	TSS kg/ADt
Pulp for papermaking	35 – 65 [25 - 126] (2)	0.25 – 1.2	10 – 42 [10-120] (2)	<0.001 - 0.03	0.02 – 0.10 [0.01 – 0.17] (2)	0.17 – 0.2	0.62 – 3.7 [16]
Pulp for papermaking, magnefite (1)	45 – 70	0.7 – 2.0	30 – 40	0	0.03 – 0.15	0.17 – 0.25	1.0 – 4.0
Dissolving pulp for textile production (4)	40	not detectable	4	<0.002	<0.01	<0.1	0.25
Speciality pulp for chemical applications (1)	40 - 75 [156] (2), (3)	4.1 – 23	58 – 145 [41, 58–62, 173] (2)	0.2 – 0.75	[0.14] 0.25	1.1 (higher for NH$_4$ base: 2.5	6.1 – 16
NSSC mills, unbleached	11 – 20	0.7 – 1	5 – 10	-	0.01 – 0.02	0.1 – 1.6	0.5 – 1

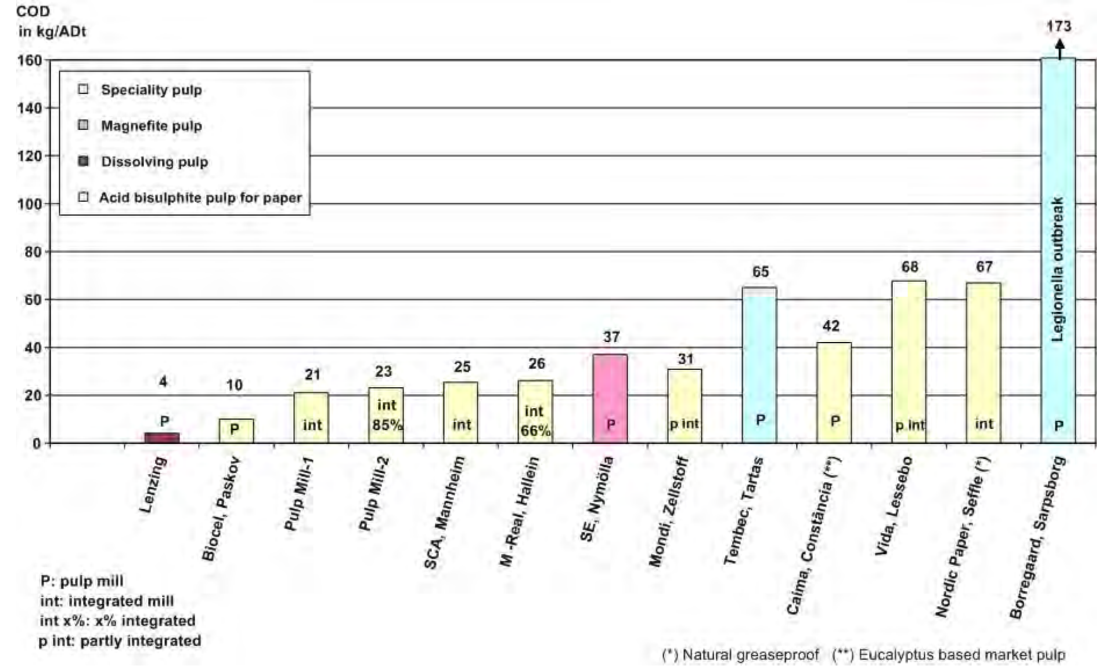
Source:
The emission levels are derived from personal communications with various mills and filled-in questionnaires.
(1) [CEPI]
(2) Figures in square brackets from data collection/questionnaires.
(3) Upper level of data collection/questionnaire: 156 m^3/ADt not included in comments.
(4) Data only from one mill.

In many cases, the flow includes process water as well as cooling water. This is because many mills use the cooling water afterwards as process water. Others discharge the uncontaminated cooling water separately.

The individual pollutants discharged are discussed in more detail below.

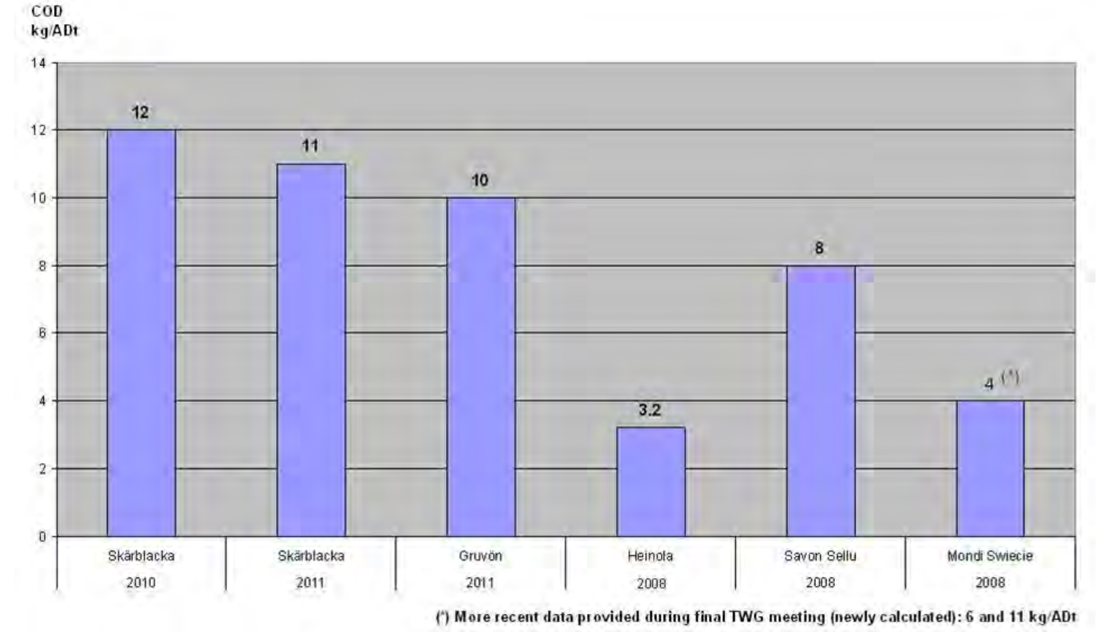
Discharge of organic substances

Discharges of organic substances after treatment in general vary between 4 kg COD/ADt and 173 kg COD/ADt (refer to Figure 4.15 and Figure 4.16 for COD data for different types of mills). The highest value refers to a pulp mill that had to shut down its aerobic waste water treatment plant due to a legionella outbreak.



Source: data collection/questionnaires

Figure 4.15: Yearly averages of specific COD loads from sulphite pulp mills (excluding NSSC)



Source: TWG input, 2013

Figure 4.16: Yearly averages of specific COD loads from NSSC pulp mills

For the acid magnesium bisulphite mills, the amount of organic substances dissolved out of the cooked wood chips in the open part of the process (namely after brown stock washing), i.e. in the bleach plant, usually amounts to 40 – 70 kg COD/ADt. However, one mill has brought specific COD emissions from the bleach plant down to 23 kg/ADt (Biocel Paskov, CZ). The specific waste water volume of well designed and operated paper pulp bleach plants is in the range of 15 – 25 m^3/ADt. One mill reported a water flow of 5 m^3/ADt from the bleach plant.

The organic load discharged with the effluents from the bleach plant is somewhat different between softwood and hardwood in the sense that although softwood bleach plant effluent contains less COD, it is much harder to degrade in biological treatment because of its composition. Also, for mills producing speciality pulp, emissions might be higher compared to paper pulp production, especially for TCF, due to ECF bleaching with ClO_2 as D1 which is absolutely necessary and an extraction stage to remove hemicelluloses that has to be performed. Streams resulting from these two stages have high loads of organic compounds (partially non-biodegradable for D1).

The COD load in condensates is normally much higher at sulphite pulp mills than at kraft mills owing to the content of acetic acid and furfural and because stripping of the most contaminated concentrated condensates is not a normal practice in sulphite pulp mills. Stripping of SO_2 to recover the sulphur dioxide and to avoid disturbances of the biological waste water treatment and subsequent anaerobic treatment of the condensates are important. COD from condensates are then degraded in a biological treatment plant. In the case of the Nymölla mill, SE, magnesium hydroxide is added before evaporation to lower the amount of COD in the condensates. The total load in condensates before treatment is up to 60 – 70 kg of COD/ADt. A single mil reported a specific load in condensates before treatment of 33 kg COD/ADt. In sulphite spent liquors a high amount of the acetic acid is in the volatile, free acid form. Furfural is produced from xylanes under acid conditions in the sulphite cook. The differences in terms of the COD load of the condensate between softwood and hardwood are quite small.

Apart from the bleach plant and the condensates, a minor amount of organic load comes from various smaller sources such as the wood yard, various washing losses, rinsing water, leakages or spillages (the latter are recovered in most cases). Normally these smaller sources contribute less than 10 % of the total organic load of the effluents.

An example for specific COD emissions from a magnefite pulp mill is the Stora Enso Nymölla mill, SE (*source:* Nymölla, 2010): the initial load of organic substances is approximately 180 kg COD/ADt, about 20 kg of which are washing losses from the cooking plant. 100 kg are released in the oxygen stage and 30 kg COD/ADt are released in the peroxide stage. There are minor differences between hardwood and softwood. Before biological treatment, the oxygen stage effluents are treated by ultrafiltration where 30 – 35 kg non-biodegradable COD are removed. After biological treatment the specific COD emissions are 43 kg COD/ADt.

In sulphite mills that use calcium as a base, the discharge loads to water tend to be higher than those that use magnesium as a base, even if comparable measures are applied. Of the three calcium-based mills in Europe, one produces paper pulp, one dissolving pulp and one speciality pulp for chemical applications. These mills do not operate a boiler to recover cooking chemicals and energy from the spent sulphite liquor (SSL). However, the major pollutant load is not only due to the absence of a recovery boiler. The organic load also comes from the evaporation stage of the SSL that is similar in both processes (calcium base and magnesium base). The auxiliary processes converting SSL to products such as the yeast, acetic acid or furfural, reduce the organic load of the condensates, and thus of the effluent. No data could be obtained about the actual level of emissions from the plants that produce paper pulp and dissolving pulp and the techniques they apply to reduce emissions. When dissolving pulp is produced, condensates have a higher organic load because more hemicelluloses are hydrolysed during cooking. The spent sulphite liquor of calcium-based mills can be partly or entirely converted into products, and in that case may leave a similar organic load to magnesium bisulphite pulp mills (*Source*:

experience from Spain). The situation of the calcium-based pulp mill that produces paper pulp is unknown because emissions data were impossible to obtain.

A dissolving sulphite pulp mill (Lenzing AG, AT) that manufactures dissolving pulp for viscose fibres (the pollution load before and after treatment) is shown in Table 4.10.

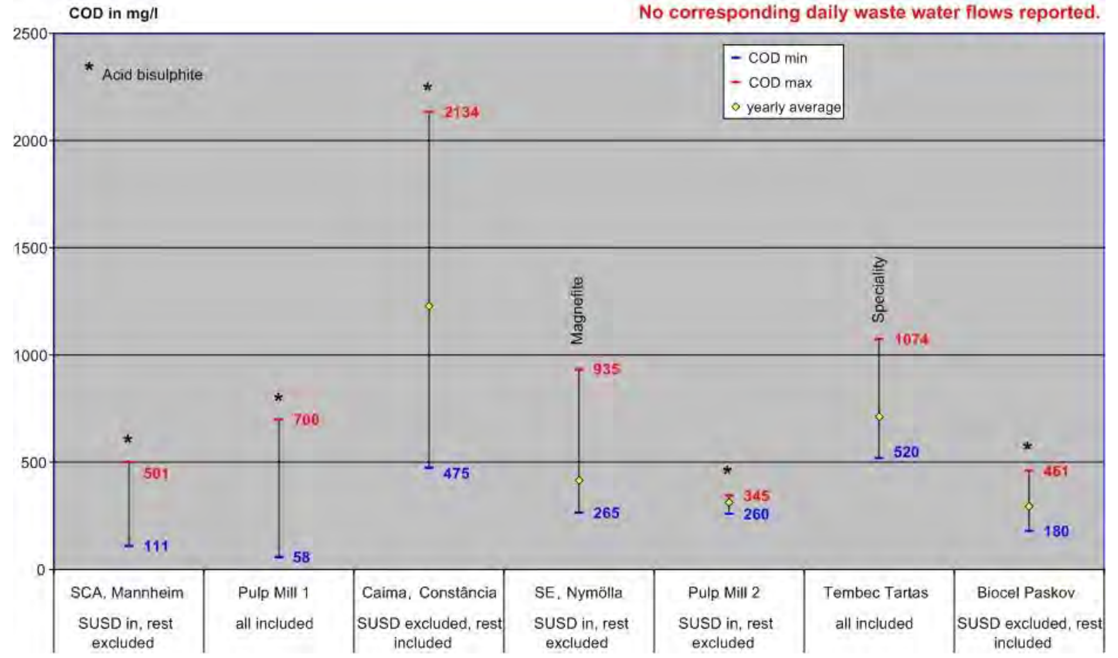
Table 4.10: Specific emissions to water of an integrated dissolving sulphite pulp mill before and after biological treatment

COD load before waste water treatment plant	Emissions to water after biological treatment
Wood yard: not separately measured	COD: 4.2 kg/t
Bleaching (1st & 2nd stage): ~ 14.2 kg/t	BOD_5: not detectable
Evaporator condensate: <39 kg/t	TSS: 0.22 kg/t
Total load: 44.9 kg/t	AOX: <0.002 kg/t
Total flow: 38.3 m^3/t	Total P: 0.005 kg/t
	Total N: <0.1 kg/t

NB:
Emissions are reported as yearly average values for 2008. The example represents a mill that has carried out possible process-integrated measures as described in Sections 4.1.1.3 and 1.1 in order to reduce releases to water. The waste water from the EOP stage is evaporated and incinerated, acetic acid and furfural are extracted from the evaporator condensates. The remaining waste water is treated in an activated sludge plant followed by a filtration step in order to reduce suspended solids, P and N.

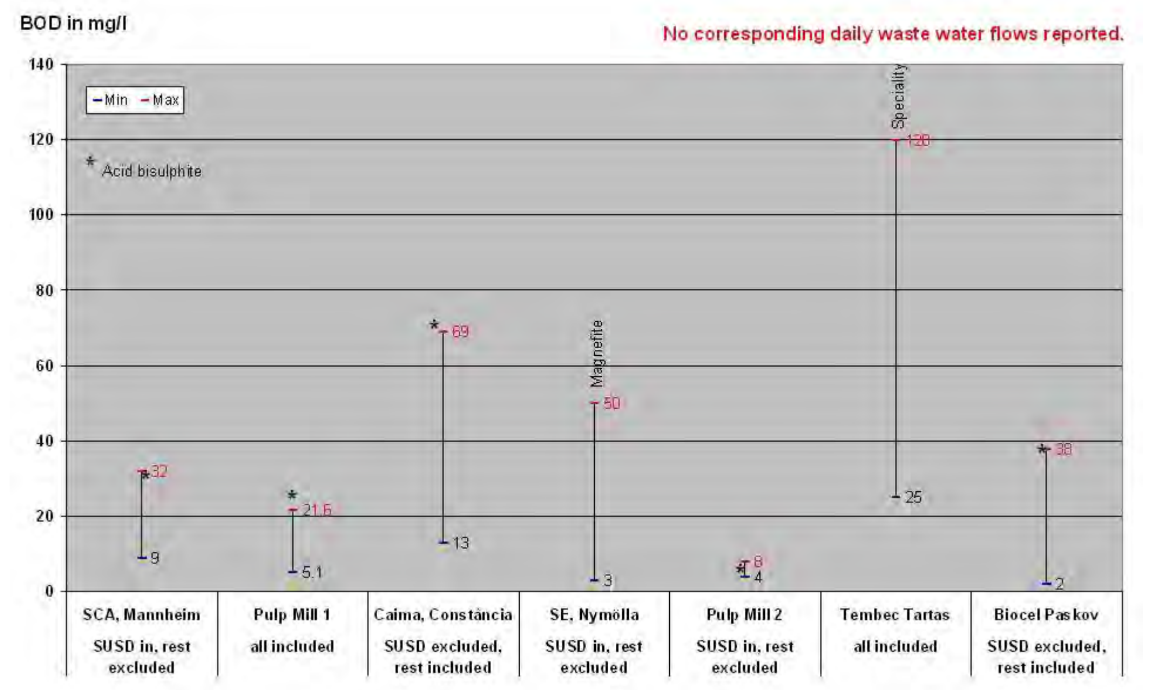
Source: [220, Kroiß 2009]

The short-term values reported for COD and BOD emissions are shown in Figure 4.17 and Figure 4.18.



Source: EIPPCB questionnaires from 2007/2009

Figure 4.17: Short-term averages of COD emissions from sulphite pulp mills



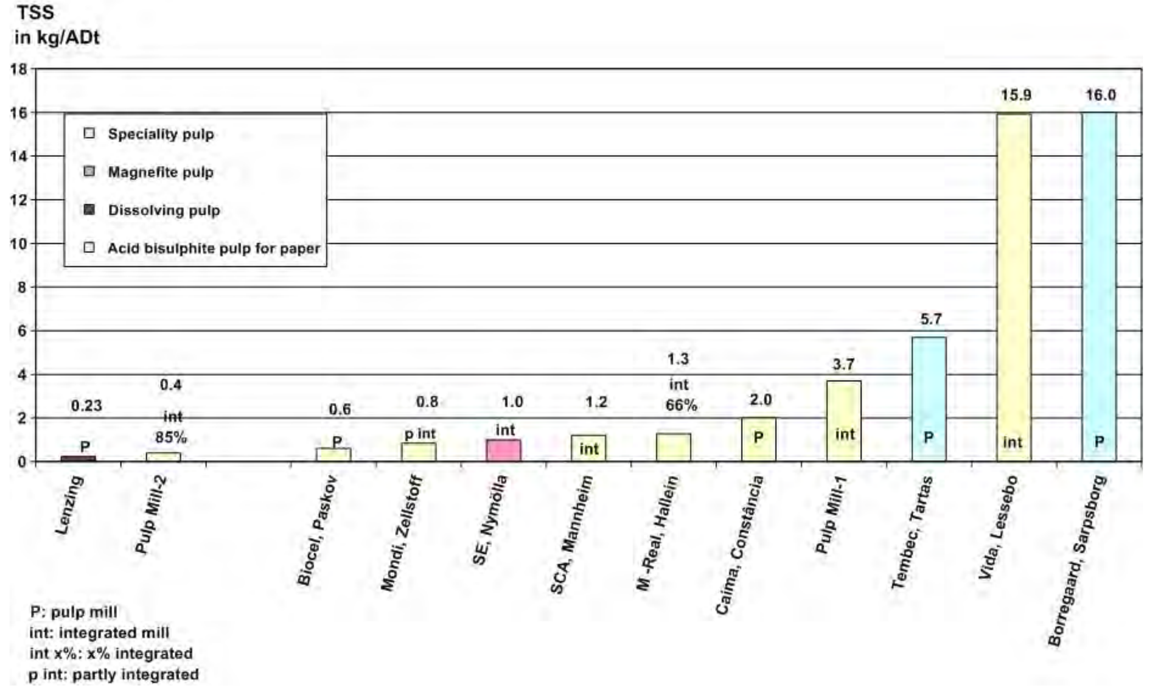
Source: EIPPCB questionnaires from 2007/2009

Figure 4.18: Short-term averages of BOD emissions from sulphite pulp mills

Discharge of total suspended solids (TSS)

After biological treatment, most of the suspended solids consist of biomass which should be retained in the treatment system as completely as possible. The lost flakes of activated sludge contain around 50 % carbon, which contributes to the discharged organic substances, measured as COD (homogenised sample), 10 % nitrogen and around 1 % phosphorus. The suspended solids are normally reduced by sedimentation and in a few cases by sand- or micro-filtration. A well operated activated sludge plant with sedimentation tanks normally achieves TSS values between 10 mg/l and 30 mg/l, although peak values of 96 mg/l have also been reported during the data collection. Higher values indicate that the settleability of the biosludge is reduced or bulking sludge occurs which may result in an unwanted loss of biomass and an increase of COD emissions. Values of 150 - 250 mg TSS/l have been reported which indicate disturbances of the biological system or hydraulic overload. In integrated pulp and paper mills there are also suspended solids which are not measured by the parameter COD such as fillers or the inorganic part of coating colours.

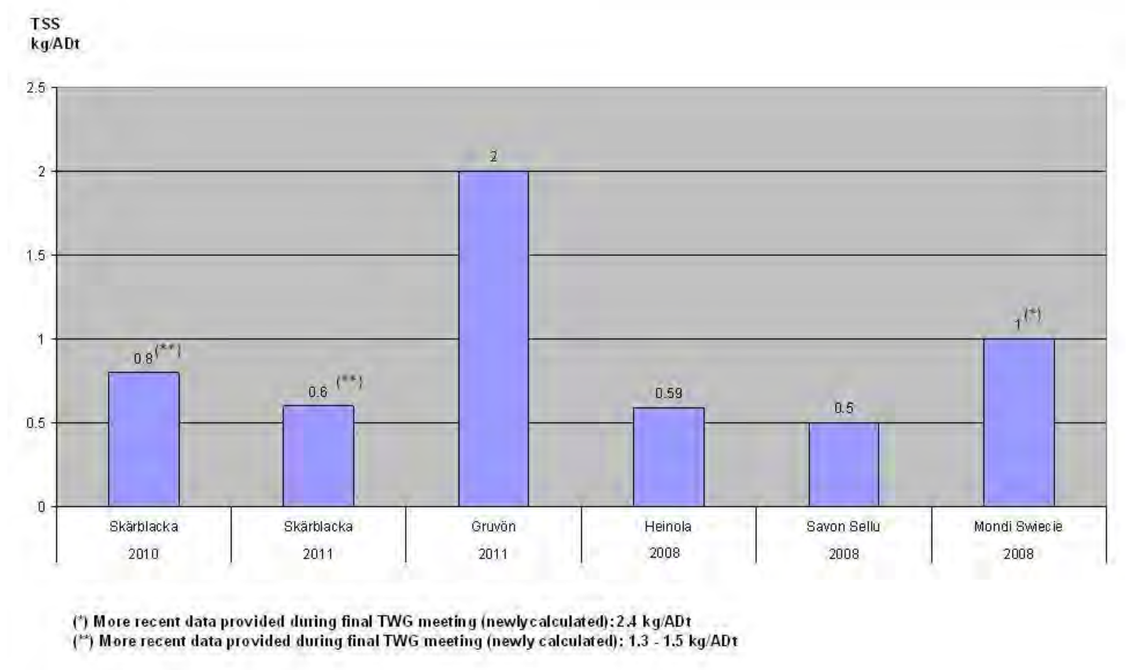
An overview of specific TSS loads for individual plants is given in Figure 4.19 and Figure 4.20 Reported loads vary from 0.2 kg/ADt to 16 kg/ADt.



P: pulp mill
int: integrated mill
int x%: x% integrated
p int: partly integrated

Source: data collection/questionnaires

Figure 4.19: Yearly averages of specific TSS loads from sulphite pulp mills (excluding NSSC)

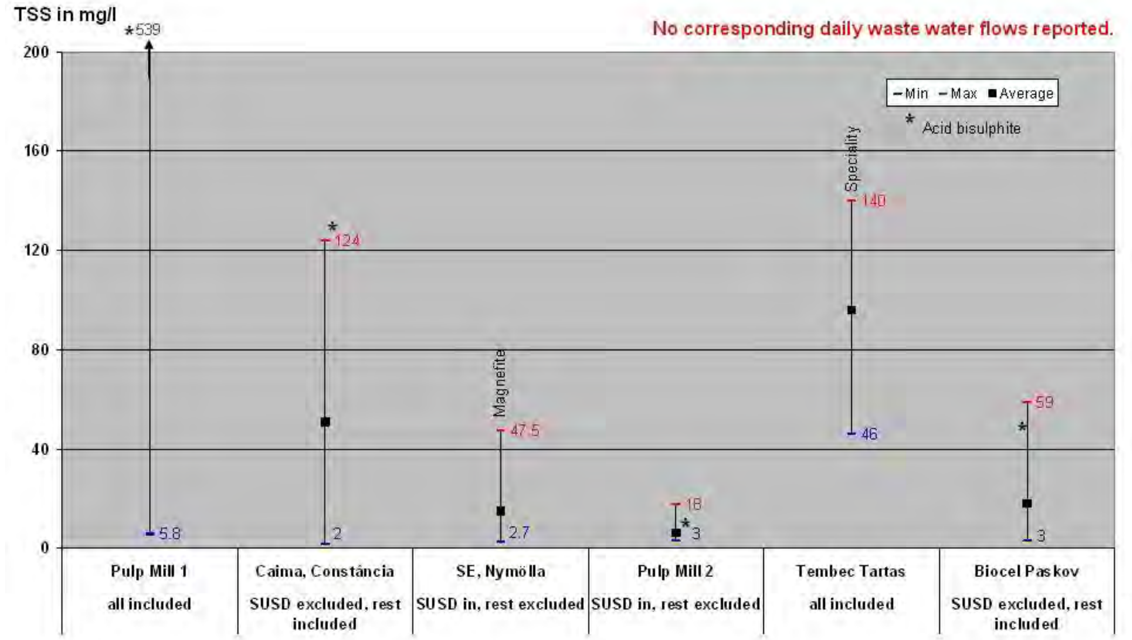


(*) More recent data provided during final TWG meeting (newly calculated): 2.4 kg/ADt
(**) More recent data provided during final TWG meeting (newly calculated): 1.3 - 1.5 kg/ADt

Source: TWG input, 2013

Figure 4.20: Yearly averages of TSS emissions from NSSC pulp mills

The short-term values reported for TSS emissions are shown in Figure 4.21.



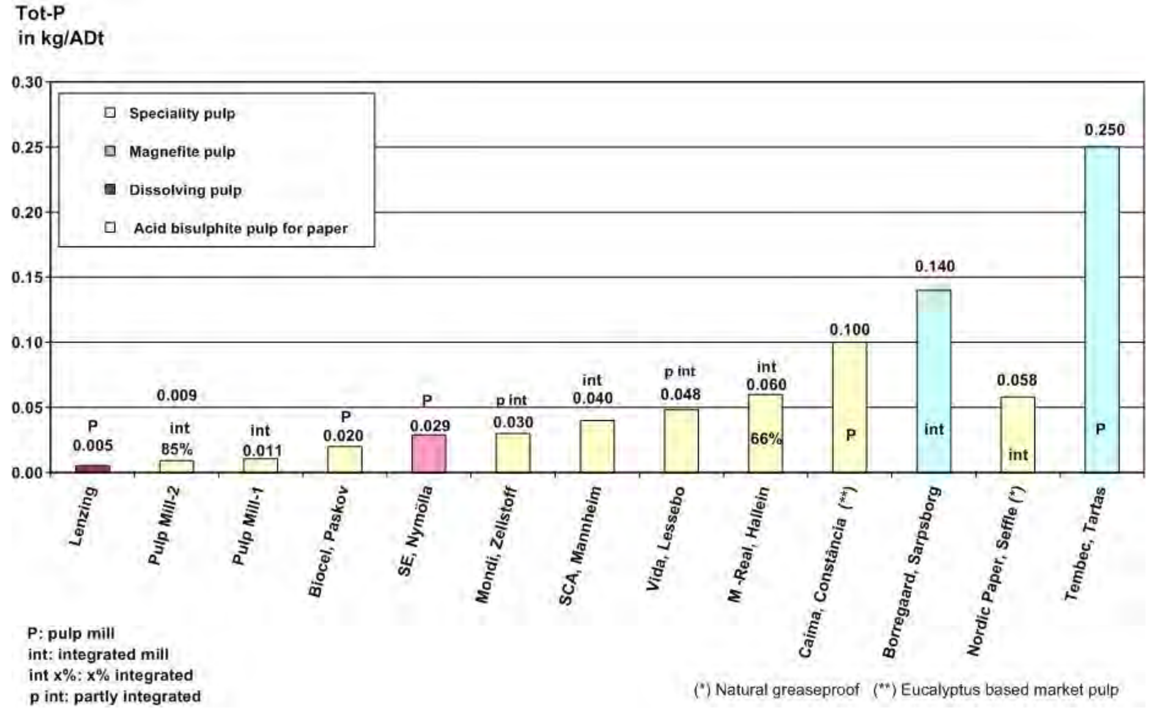
Source: EIPPCB questionnaires from 2007/2009

Figure 4.21: Short-term averages of TSS emissions from sulphite pulp mills

Discharge of nutrients

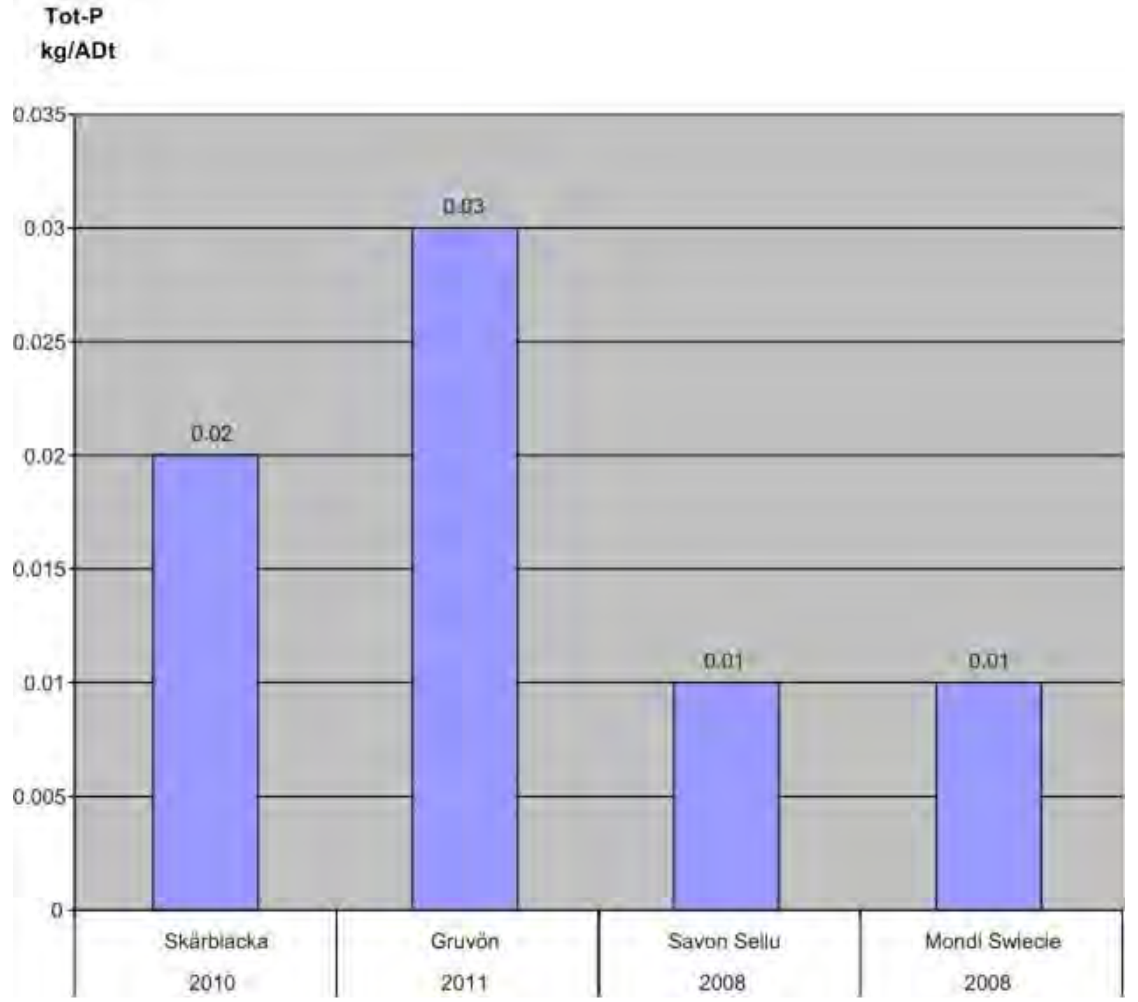
Mineral nutrients are usually added to the biological treatment plant to keep the balance C:P:N which is of crucial importance for the growth of active biomass. It is necessary to find and keep a balance between incoming N compounds and P compounds contained in the wood and the amount of nutrients added which requires a certain fine-tuning of the nutrient feed of the biological waste water treatment. Some pulp mills do not need to add phosphorus to their waste water treatment plant (e.g. a Portuguese sulphite pulp mill where TCF bleached pulp is produced using eucalyptus does not add any phosphorus to the aerobic treatment plant and still measured tot-P concentrations of 0.7 – 5.2 mg P/l [204, Portugal 2007]). In contrast, the addition of nitrogen (usually as urea) is essential for the functioning of the biological treatment. When the system is optimised, phosphorus discharges of below 1 mg tot-P/l and 5 – 10 mg tot-N/l as a yearly average are measured. Part of the total nitrogen is contributed by the poorly biodegradable N-containing complexing agents EDTA or DTPA that are released (see the paragraph on chelating agents in this section).

Overviews of specific phosphorus and nitrogen emissions for individual plants are given in Figure 4.22, Figure 4.23, Figure 4.25 and Figure 4.26. Emissions vary from 0.011 kg/ADt to 0.25 kg/ADt for total phosphorus and from 0.006 kg/ADt to 2.5 kg/ADt for total nitrogen.



Source: data collection/questionnaires

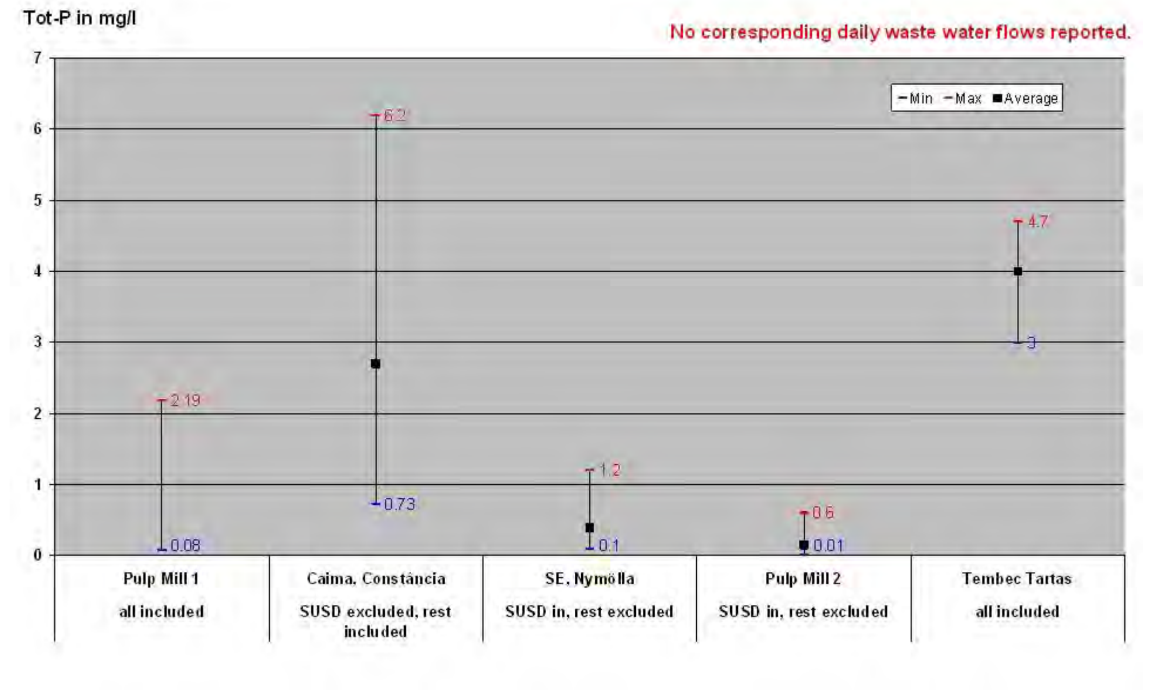
Figure 4.22: Yearly averages of tot-P emissions from sulphite pulp mills (excluding NSSC)



Source: TWG input, 2013

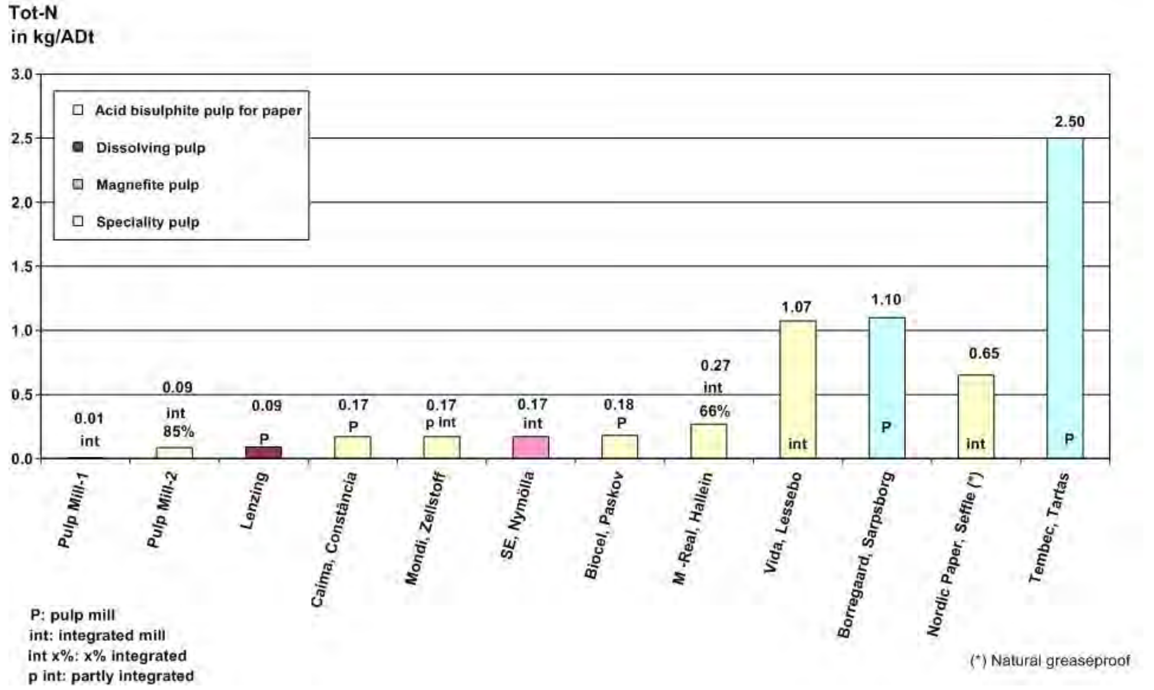
Figure 4.23: Yearly averages of tot-P emissions from NSSC pulp mills

The short-term values reported for tot-P emissions are shown in Figure 4.24.



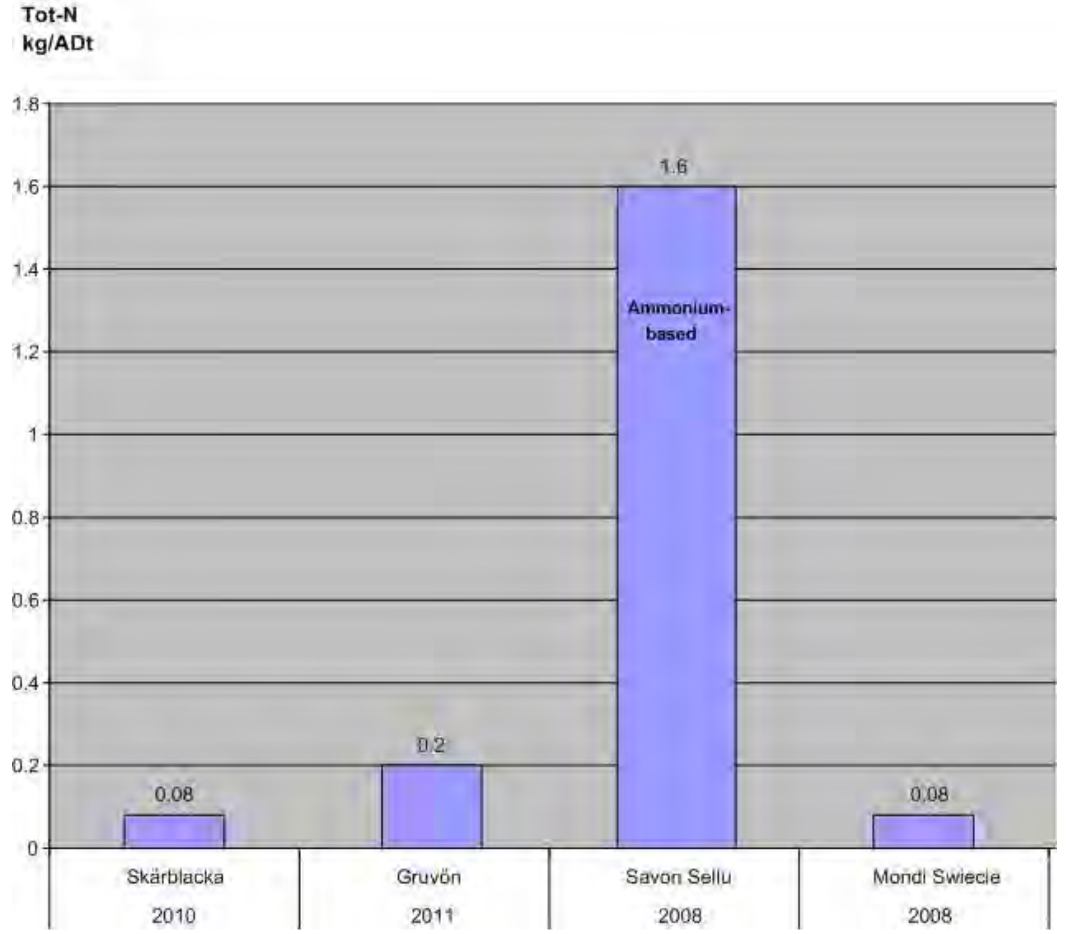
Source: EIPPCB questionnaires from 2007/2009

Figure 4.24: Short-term averages of tot-P emissions from sulphite pulp mills



Source: data collection/questionnaires

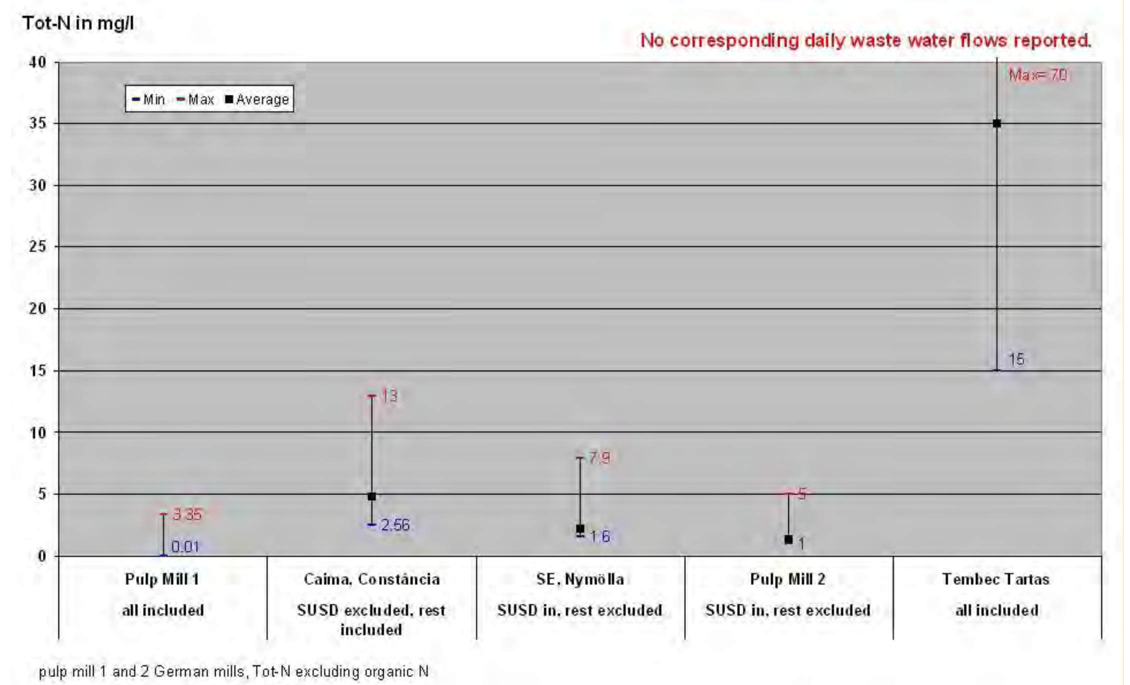
Figure 4.25: Yearly averages of tot-N emissions from sulphite pulp mills (excluding NSSC)



Source: TWG input, 2013

Figure 4.26: Yearly averages of tot-N emissions from NSSC pulp mills

The short-term values reported for tot-N emissions are shown in Figure 4.27.



Source: EIPPCB questionnaires from 2007/2009

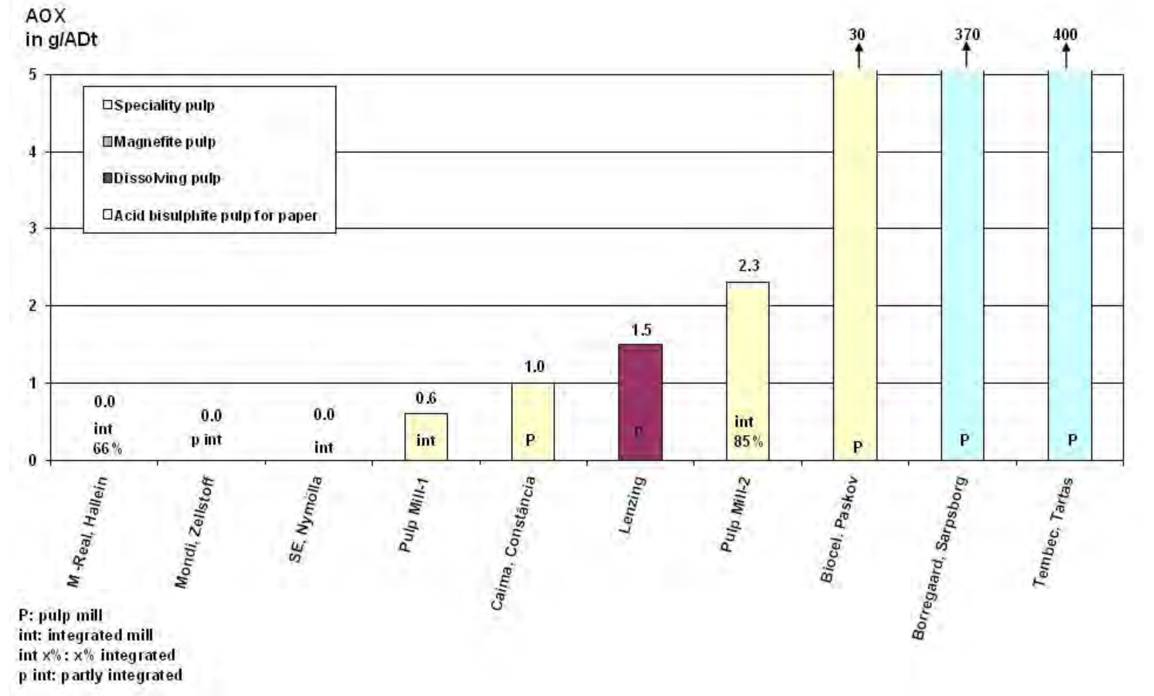
Figure 4.27: Short-term averages of tot-N emissions from sulphite pulp mills

Discharge of chelating agents
Most of the chelating agents used in the acid chelating stage are washed out of the pulp and are discharged to waste water treatment plants. Because the currently used chelating agents are not readily biodegradable, a high percentage of these chemicals will end up in the recipient. In most mills the output of acid Q stages are led to waste water treatment. The use of EDTA or DTPA is in the range of 0 – 3 kg chelating agent/ADt. Complexing agents are normally not measured in the effluents of sulphite pulp mills in Europe. Therefore, no measured emissions data are given here. However, at least one mill in Germany (SCA Mannheim) has been permitted with an emission limit value for DTPA emissions of 60 kg /day.

There are at least two sulphite pulp mills that do not use chelating agents although they manufacture high brightness pulp for papermaking (87 % ISO).

Discharge of chlorinated organic compounds (AOX) and chlorates
Totally chlorine free (TCF) mills discharge virtually no chlorinated organics (they are not formed in bleaching). The mills that manufacture ECF sulphite pulp measure AOX emissions depending on the process layout (number of stages where ClO_2 is applied; dosage of ClO_2) and the pulp quality manufactured.

An overview of specific AOX loads for individual plants is given in Figure 4.28. Loads vary from (undetectable) 0.06 g/ADt to 400 g/ADt, while concentration values between 0.02 mg/l and 0.91 mg/l were reported. The three mills with the highest values (30 – 400 g/AD/t) are ECF mills.



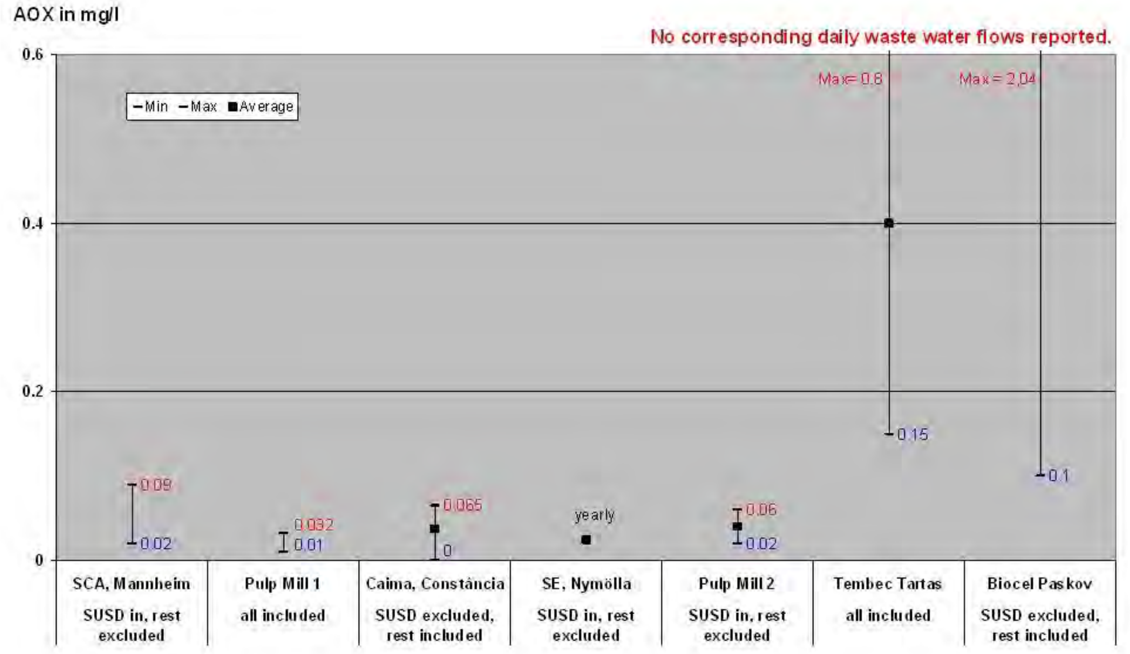
Source: data collection/questionnaires

Figure 4.28: Yearly averages of AOX loads from sulphite pulp mills (excluding NSSC)

Tembec Tartas (FR), a mill that produces pulp for speciality grades, of which 10 – 20 % is fluff pulp for hygiene products (bleaching sequence: D-E/O-D), reported AOX values between 1.5 mg/l to 8 mg/l representing 0.2 kg/ADt to 0.75 kg/ADt depending on the pulp quality produced (low viscosity to high viscosity). The yearly average load was reported to be 0.4 kg/ADt. This variability is due to the different grades of speciality pulps manufactured.

Biocel Paskov (CZ), a mill that manufactures paper pulp with the bleaching sequence O – EOP – D – PO(P) – P, reported: if a pulp bleached with only small portions of ClO_2 is produced, the AOX emissions are between 0.6 mg/l and 0.8 mg/l; in the case of ECF pulp production 1.2 – 1.8 mg AOX/l are discharged.

The short-term values reported for AOX emissions are shown in Figure 4.29.



Source: EIPPCB questionnaires from 2007/2009

Figure 4.29: Short-term averages of AOX emissions from sulphite pulp mills

Chlorate emissions are released by two sulphite pulp mills manufacturing speciality cellulose only: Tembec Tartas (FR) and Borregaard (NO). Usage of ClO_2 to bleach pulp leads to emissions of chlorates due to oxidation of ClO_2. Emissions could not be quantified by the mills.

Discharge of metals

Table 4.11 shows the discharge of metals from a Swedish partly integrated pulp mill to the receiving water body. The results are based on sampling (random sampling once a day) during a five-day period in September 1996. The random samples were mixed in proportion to the flows to give a combined sample which was analysed with regard to cadmium, chromium, copper, nickel, lead and zinc. The analysis of the metals was done using inductively coupled plasma-mass spectrometry (ICP-MS). These emissions are difficult to avoid as the major source for the emissions of these metals is the wood used for pulping.

Table 4.11: Discharge of metals to the receiving water body from a Swedish partly integrated sulphite pulp mill in 1996

Metal	Concentration [mg/m^3]	Specific load [g/t]
Cadmium	1.37	1
Chromium	5.5	4.4
Copper	9.3	7.4
Nickel	12	9.6
Lead	9.4	7.5
Zinc	144	115.2
NB: Water flow around 80 m^3/ADt		

In summer 2008, the Finnish NSSC mill SE Heinola Fluting measured metals in random samples of the discharge to the receiving water body. The analysis was done using ICP-MS. The results obtained were similar to those from the random sampling of the Swedish mill analysed 12 years earlier. According to the test results, the only metal detected in the sampling was zinc (the others were below the detection limit).

4.2.2.5 Emissions to air

The major point sources for emissions to air are the recovery boiler, the bark or biomass boiler and other steam blocks for steam production, but potential releases of emissions to air from a number of processes are also to be taken into account.

Sulphur emission levels from sulphite mills and the potential for further reductions are highly dependent on the type of mill. Due to differences between different sulphite processes, the emission levels might show higher variations than in kraft pulp mills. Figure 4.30 shows by use of an example (an acid magnesium bisulphite pulp mill for papermaking) the collection of the concentrated and less concentrated sulphur dioxide-containing and odorous gases and their treatment. The abatement of emissions from the recovery boiler and the recirculation of the recovered chemicals are included. The integration of the SO_2 cycle into the abatement system for the emission to air can be seen.

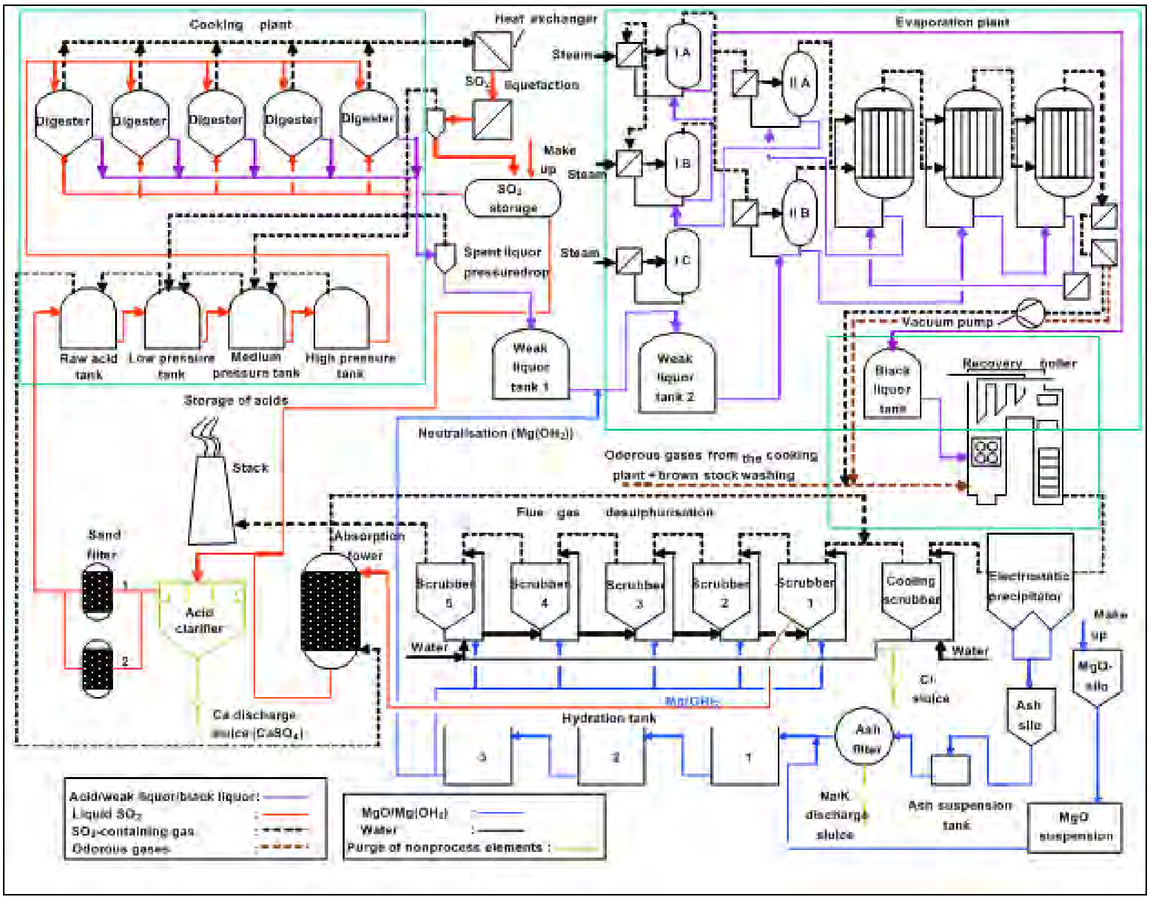


Figure 4.30: Example of the collection of sulphur dioxide-containing and odorous gases and their treatment

Figure 4.30 gives an overview of important flows of the spent liquor, the acid cooking chemical SO_2 and the corresponding base, in this case MgO. Gases are collected at different points of the process and the air abatement techniques implemented the recovery boiler are illustrated (ESP, scrubbers). The steps to regenerate the cooking liquor are also indicated.

The emissions released to the atmosphere depend to a large extent on the collection and abatement system used for treatment of gaseous emissions. The following devices and systems can be found in sulphite pulp mills for collecting and purifying emissions to air.

- Cyclone for chip blowing.
- The gases from the continuous pressure control relief of the digesters are led to combustion in the recovery boiler or to the primary recovery system where acid from secondary recovery is fortified. In the primary recovery system, the cooking acid is fortified by SO_2 from the relief gases of the digesters and also by SO_2 from the evaporation plant (for increasing total and free SO_2).
- Collecting system for aerating gases from digesters, blow tanks, knot screens, washing filters, all weak and thick liquor tanks and fibre filters. In most cases, these gases are led to combustion in the recovery boiler. In a few cases, these gases are led to wet scrubbers that use NaOH or H_2O_2 as absorption liquid (abatement of SO_2 and also of odour).
- Scrubbers for the absorption of sulphur dioxide in aerating gases from the bleach plant.
- Non-condensable gases from the evaporation are led to combustion in the recovery boiler or to the primary recovery system for acid fortification.
- Absorption of SO_2 in the flue-gases leaving the recovery boilers in the acid preparation plant (venturi scrubber system).
- Collection system for ventilation gases from the liquor and condensate tanks of the boiler house, from the weak liquor filter and the mix tank. The gases are led to combustion in the recovery boiler.
- Dust separation from flue-gases from the auxiliary boiler (burning bark, oil or other fuels) with an electrostatic precipitator (ESP) and wet scrubber.
- NO_X reduction in the bark boiler by injection of urea or ammonia (SNCR), and by recirculation of flue-gases.
- Water seals can also be applied as a method to decrease fugitive emissions from the digester.

Emissions to air from the recovery boiler

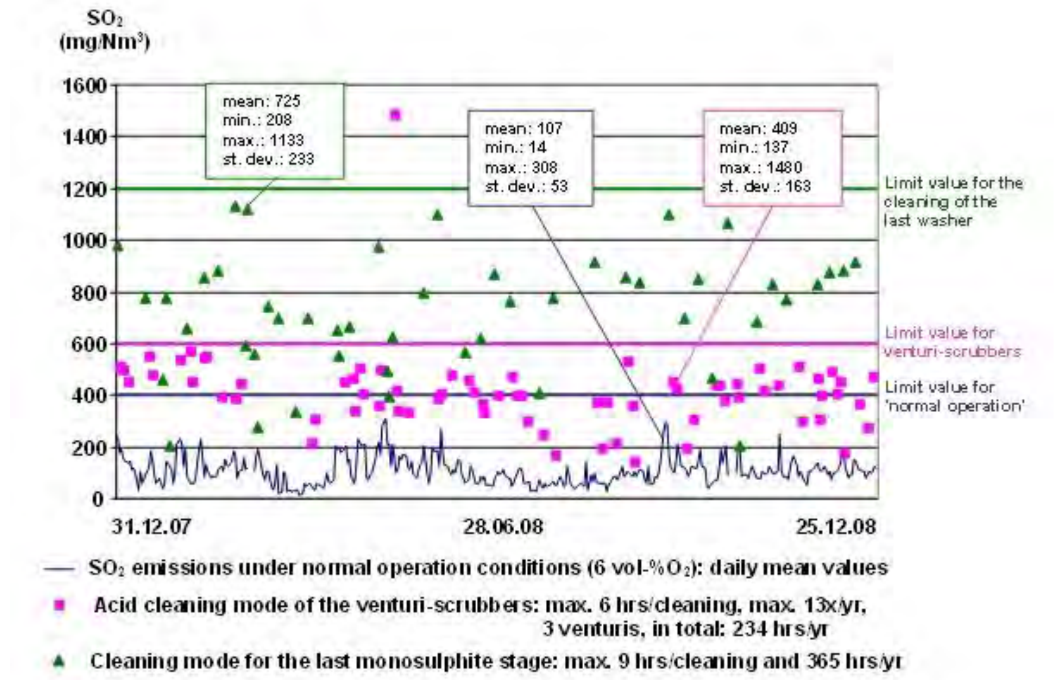
In a magnesium sulphite mill the main source of sulphur oxide emissions is the recovery boiler. Other relevant emissions are sulphur dioxide, nitrogen oxides, emissions of particulates or dust and carbon monoxide.

After the evaporation plant, the black liquor has a dry solids content of about 58 – 60 % which corresponds to a lower calorific value (LCV) of around 7 000 kJ/kg. The recovery boiler is fed with the concentrated spent liquor that leaves the evaporation plant. In most recovery boilers oil or gas is also used as additional fuel.

The dust leaving the recovery boiler, which in the case of magnesium sulphite mills is mainly magnesium oxide ash, is collected from the flue-gas in electrostatic precipitators or multicyclones and washed with water to form magnesium hydroxide. This liquid is used in venturi scrubbers or counter-current washers to absorb SO_2 and SO_3 from the flue-gas of the recovery boiler (and in a few mills also from the digesters, washers and evaporators). The absorption system is made up of a number of venturi scrubbers or washers, normally three, four, five or six. Emissions are about 0.5 – 2.7 kg SO_2/ADt per tonne of pulp.

SO_2 emissions

With regard to the SO_2 emissions from recovery boilers of sulphite pulp mills, in most mills, two different operating conditions have to be distinguished between: 'normal operating conditions' and periods of 'acid operation' (flushing and cleaning of the incrustation in the scrubbers and washers). The latter refer to an operational mode where the scrubbers are cleaned to prevent incrustations of magnesium monosulphite ($MgSO_3$). During the cleaning cycles of the scrubber, the emissions increase as one of the scrubbers or the final washer is not operating and must be compensated for by the residual scrubbers. Figure 4.31 shows the emissions of a mill that has installed four-stage venturi scrubbers and one final washer (sulphite stage). The emission profile for 'normal operation' in Figure 4.31 (blue line) does not include the emissions during the cleaning cycles. The yearly average SO_2 concentration in this example is 107 mg/Nm^3 (at 6 % O_2). The yearly average including the weighted operating hours in the 'acid mode' is 144 mg/Nm^3. The highest emissions occur during 15 days of the year when the final washer is cleaned as a preventive measure. The mill has to meet limit values for three different operation modes expressed as a daily average as indicated in the picture (400/600/1 200 mg SO_2/Nm^3 at 6 % O_2). In the example mill, this system leads to a specific load of 1.1 kg SO_2/ADt or 0.54 kg SO_2-S/ADt.

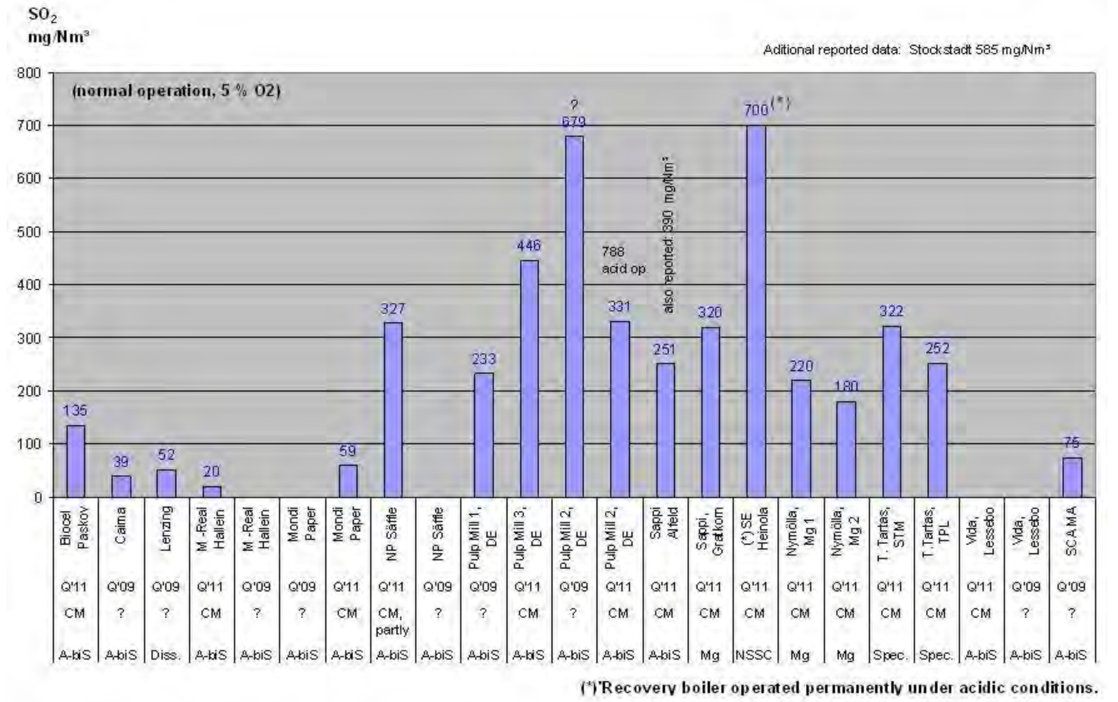


Source: [219, SCA Mannheim 2009]

Figure 4.31: **Example of SO_2 emissions from recovery boilers for 'normal operation' and 'acid operation mode'**

A similar emission profile can be observed at most sulphite pulp mill recovery boilers. There are lower SO_2 emissions during 'normal operating conditions' and higher SO_2 emissions occur during the 'cleaning mode' of the different scrubbers. The emissions during the preventive cleaning of the scrubbers show certain differences between the different desulphurisation systems depending on the number, type and mode of operation of the scrubbers and/or washers. For example, some mills only have two different operating modes (and limit values) and not three as shown in Figure 4.31.

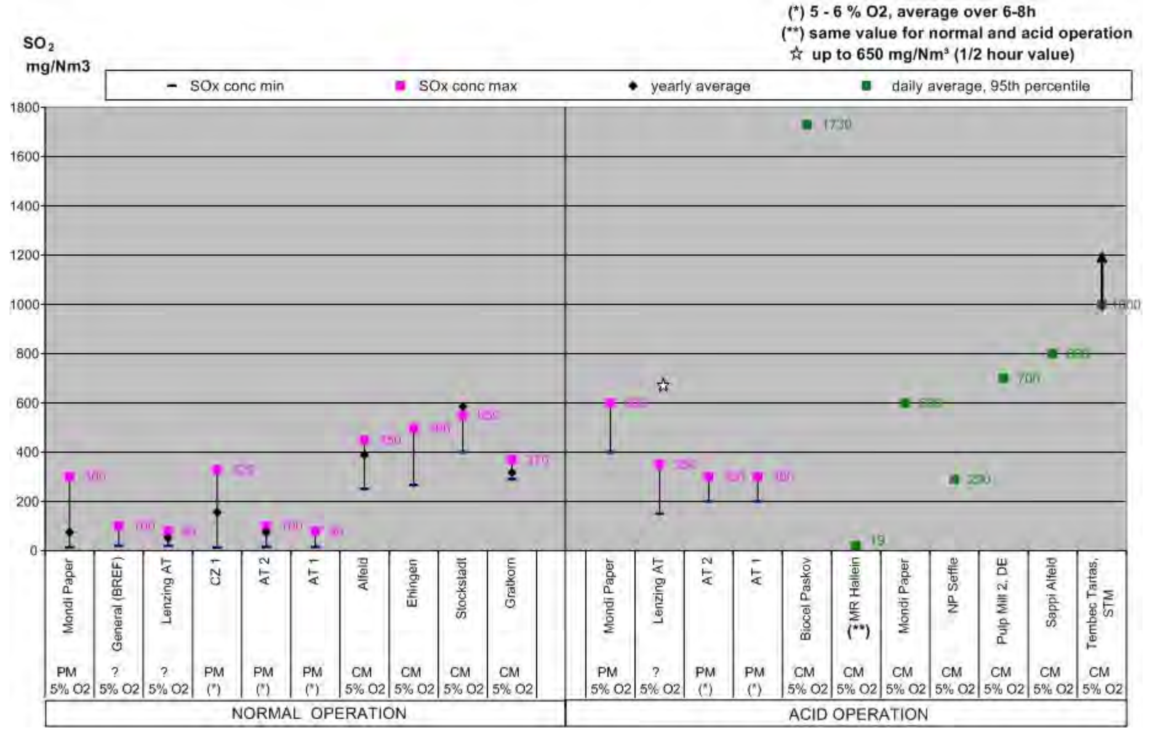
The reported SO_X emissions are shown in Figure 4.32 and Figure 4.33.



NB: CM = Continuous monitoring; PM = Periodic monitoring; ? = No information on type of monitoring

Source: EIPPCB questionnaires from 2007/2009 and other TWG input

Figure 4.32: SO_2 emissions from the recovery boiler



NB: CM = Continuous monitoring; PM = Periodic monitoring; ? = No information on type of monitoring

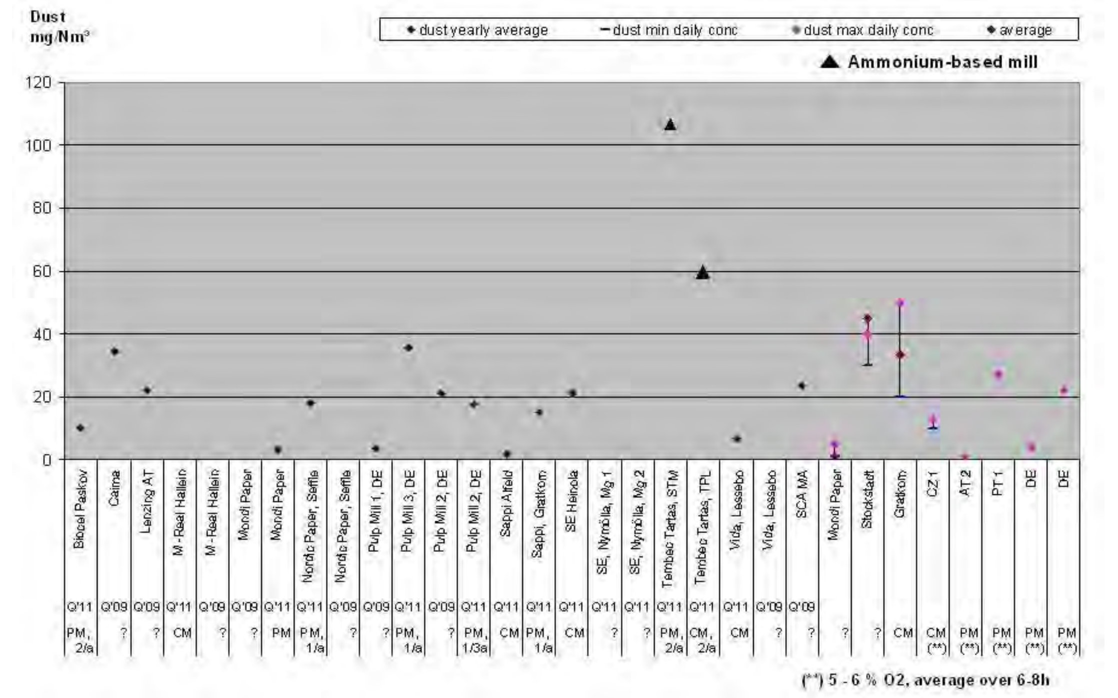
Source: EIPPCB questionnaires from 2007/2009 and other TWG input

Figure 4.33: SO_2 emissions from the recovery boiler as short-term averages

Dust emissions

In sulphite pulp mills, dust emissions are between 1 mg/Nm³ and 25 mg/Nm³ as a mean value of the sampling period (e.g. a day). Dust emissions are normally measured periodically. The higher value is observed when a higher share of hardwood (potassium-rich) is used or when the mill does not succeed in removing the aerosols in the droplet catchers after the last washing stage.

The reported dust emissions are shown in Figure 4.34.



NB: CM = Continuous monitoring; PM = Periodic monitoring; ? = No information on type of monitoring

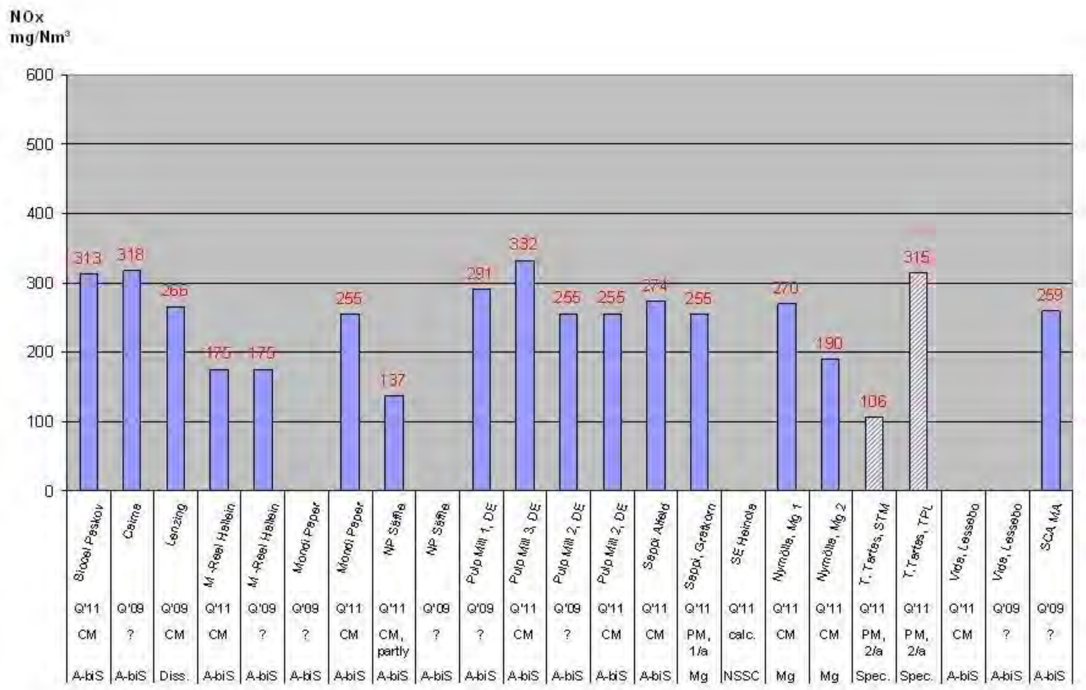
Source: EIPPCB questionnaires from 2007/2009 and other TWG input

Figure 4.34: **Dust emissions from the recovery boiler as yearly averages**

NO$_X$ emissions

Emissions of NO$_X$ from sulphite pulp mill recovery boilers are generally higher than those from kraft pulp mills because of the higher temperature in the recovery boiler. NO$_X$ emissions range normally from 175 mg/Nm^3 to 400 mg/Nm^3 or from about 0.9 to 2.6 kg/t of pulp. Table 4.12 summarises typical ranges for emissions to air from recovery boilers. The gas flow varies strongly between mills.

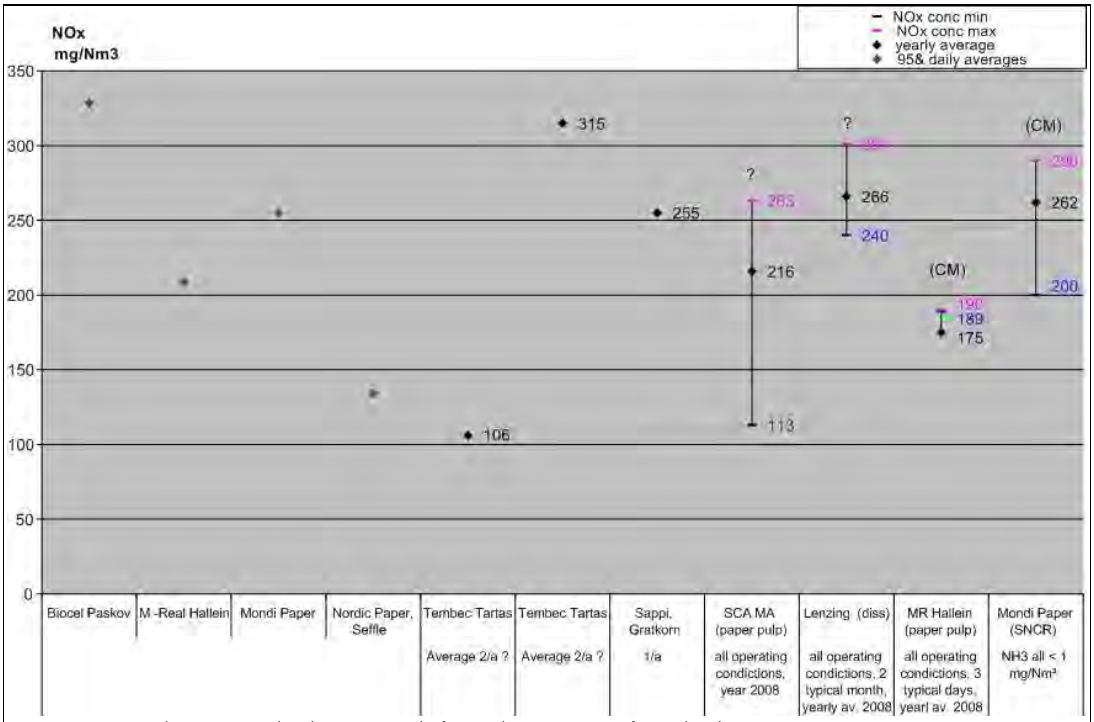
The reported NO$_X$ emissions are shown in Figure 4.35 and Figure 4.36.



NB: CM = Continuous monitoring; PM = Periodic monitoring; ? = No information on type of monitoring

Source: EIPPCB questionnaires from 2007/2009 and other TWG input

Figure 4.35: NOX emissions from the recovery boiler as yearly averages



NB: CM = Continuous monitoring;? = No information on type of monitoring

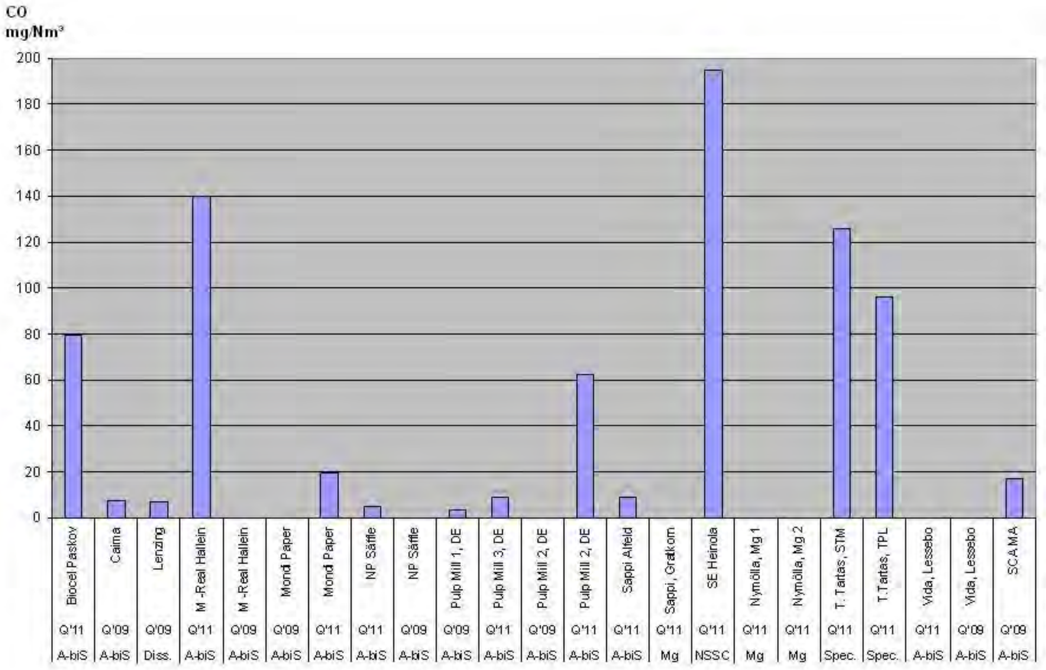
Source: EIPPCB questionnaires from 2007/2009 and other TWG input

Figure 4.36: NO_X emissions from the recovery boiler as short-term averages

CO emissions

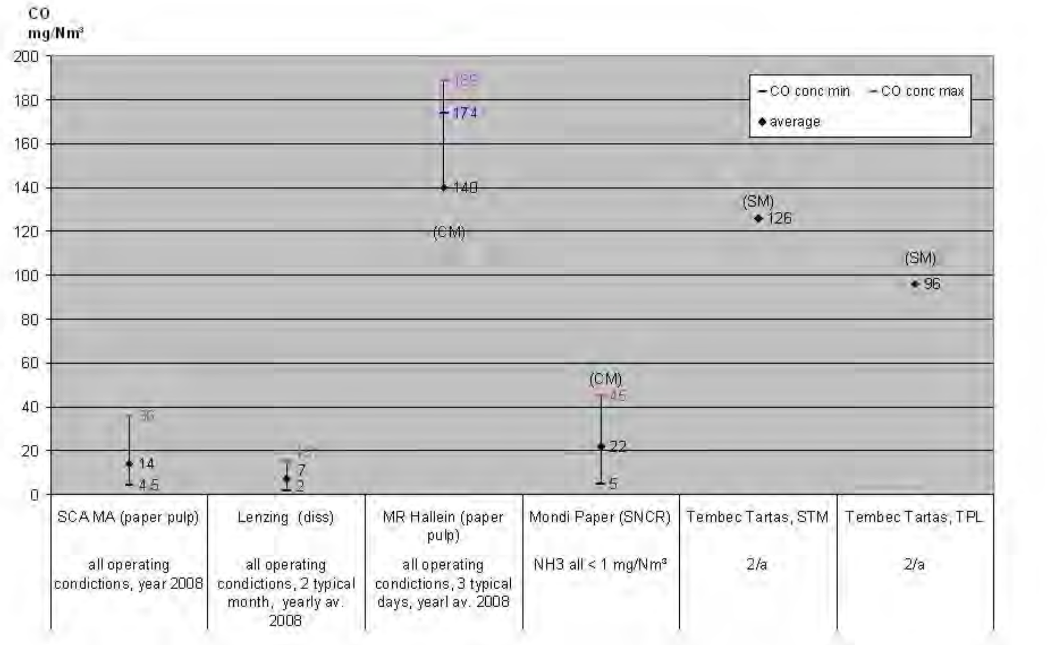
The emissions of carbon monoxide (CO) are normally caused by the organic constituents input via the concentrated spent liquor. During combustion, these are converted into CO_2 and to a minor extent into CO. The CO emissions may result from poor combustion and improper burning conditions. Such an increase in the CO emissions rate normally coincides with a decrease in the NO_X emissions. The exhaust gas concentrations of CO and organically bound carbon are a yardstick for the burnout rate of the fuels. The CO concentrations vary between 5 mg/Nm^3 and 190 mg/Nm^3 as a daily mean value. The higher CO values are observed when oxygen for combustion is kept low (e.g. 1.5 % O_2) in order to reduce the NO_X emissions. Other mills operate the recovery boiler with between 3 % and 5 % oxygen content.

The reported CO emissions are shown in Figure 4.37 and Figure 4.38.



Source: EIPPCB questionnaires from 2007/2009 and other TWG input

Figure 4.37: CO emissions from the recovery boiler as yearly averages



Source: EIPPCB questionnaires from 2007/2009 and other TWG input

Figure 4.38: CO emissions from the recovery boiler as short-term averages

Table 4.12: Emissions from example sulphite pulp recovery boilers

Sulphur dioxide (as SO_2)	**Yearly average**	**Daily average (min.-max. range) incl. explanatory remarks***
Four-stage venturi scrubber and washer	144 mg SO_2/Nm^3 1.1 kg SO_2/ADt	30 – 200 mg SO_2/Nm^3 (normal operation); 200 – 550 mg SO_2/Nm^3 (cleaning of the venturi scrubber) 500 – 1 000 SO_2/Nm^3 (cleaning of last washer); see Figure 4.31; (6 % O_2)
Electrostatic precipitator and three-stage counter-current washer	No information provided 0.62 kg SO_2/ADt	20 – 80 mg SO_2/Nm^3 (normal operation); during the cleaning of the scrubber values increase to 250 – 300 mg SO_2/Nm^3; some half-hour values reach 1 200 mg SO_2/Nm^3 (cleaning of the last washer); (5 % O_2)
Electrostatic precipitator and three venturi washers	156 mg/Nm^3 1.12 kg SO_2/ADt	Acid washing of venturi washers (8 hrs/month) are not included in the data (2.5 % O_2)
Nitrogen oxides (as NO_2)	**Yearly average**	**Daily average (min.-max. range)**
Control of the combustion: CO, O_2 and NO_X	175 – 400 mg NO_X/Nm^3 0.9 – 2.6 kg NO_X/ADt	170 – 500 mg NO_X/Nm^3
Particulates	**Yearly average**	**Daily average (min.-max. range)**
Desulphurisation plant; no specific abatement technique	Periodically measured	1 – 25 mg dust/Nm^3; in single cases up to 150 mg dust/Nm^3
Carbon monoxide	**Yearly average**	**Daily average (min.-max. range)**
Depends on the combustion conditions and set targets	4 – 150 mg CO/Nm^3	5 – 190 mg CO/Nm^3
NB: Data refer to normal operating conditions: temperature: 273.15 K, pressure: 101.3 kPa, dry gas. Where the O_2 content is not indicated, data refer to 2.5 – 6 % O_2; data source: filled-in questionnaires.		

A NSSC mill that operates a rather small recovery boiler (35 MW_{th}) reported emissions as indicated in Table 4.13. The high variations of the emissions stand out. They seem to occur because any abnormal situation in the production, chemical recovery and boiler operations can be observed in the emissions profile of the small boiler which has very little buffer capacity to compensate. Emissions in shutdowns and start-up periods are higher than in normal operations. The higher values in Table 4.13 are exceptional and normally there is usually one high value only once in a while. But higher emission levels from recovery boilers are normal for NSSC mills with chemical recovery and the type of boiler used.

For CO emissions, high values normally occur in shutdowns and start-ups. Particulates are more difficult to control because sodium-based salt may produce scaling in the segments of the electrostatic precipitator.

Table 4.13: Emissions to air and variations from a small recovery boiler of a NSSC mill

Sulphur dioxide (as SO_2)	**Yearly average**	**Daily average (min.-max. range)**
After electrostatic precipitator and single-stage scrubber, 6 % O_2	700 – 1 000 mg/Nm^3 0.7 – 0.9 kg/ADt	300 – 3 000 mg/Nm^3
Nitrogen oxides (as NO_2)	**Yearly average**	**Daily average (min.-max. range)**
No reduction techniques, only control of burning conditions, 6 % O_2	Not applied 0.3 – 0.4 kg/ADt	100 – 300 mg/Nm^3
Particulates	**Yearly average**	**Daily average (min.-max. range)**
Three segment electrostatic precipitator, 3 % O_2	30 – 90 mg/Nm^3 0.1 – 0.2 kg/ADt	20 – 150 mg/Nm^3
Carbon monoxide	**Yearly average**	**Daily average (min.-max. range)**
No reduction techniques, only control of burning conditions, 6 % O_2	200 – 600 mg/Nm^3 0.3 – 1.0 kg/ADt	100 – 5 000 mg/Nm^3
NB: Data were measured at one NSSC mill between 2004 and 2009 and refer to normal operating conditions.		

Fugitive SO_2 emissions from the process

SO_2 emissions from a sulphite pulp mill basically come from three sources: recovery boilers (see paragraphs above), bark boilers (see next paragraph below) and various processes. Fugitive, less concentrated process-related emissions of SO_2 occur in the acid cooking liquor production, digesters, the brown stock washing and the evaporation plant. Some mills measure these fugitive emissions periodically and approximate the released load by multiplying these values with measured flows or emission factors.

For example, one NSSC mill reported that their fugitive gases are measured once a year. On the basis of the results of these measurements, the mill calculates the approximate fugitive emissions. Other sources of fugitive emissions are calculated continuously on the basis of the results of measurements and some factors which are plotted by means of a reporting system. Only two sources of fugitive emissions (out of around 40 in this case) are measured three times a week and the load is then calculated.

Many sulphite pulp mills (e.g. all mills in Austria and Germany) have installed a system for the collection of the vent gases from nearly all processes that may release diffuse SO_2. The vast majority of these diffuse gases are captured by the weak gas collection system and used as combustion air in the recovery boiler. Well designed, maintained and operated gas collection systems should allow the recovery of almost all fugitive SO_2 emissions of the mill so that no significant diffuse SO_2 emissions are released to the environment.

Many sulphite mills are handling liquid sulphur dioxide. If they store and handle more than 200 tonnes of SO_2, the extended safety obligations of the Seveso II Directive apply because the use of liquid SO_2 constitutes a possible risk for health and the environment in case of accidents.

Emissions from bark and auxiliary boilers for steam and power generation

Besides the recovery boiler, there are emissions to air from other combustion processes for steam and power generation: NO_X, SO_2, CO and dust are released. Different types of fuels and boilers may be used for steam generation. Usually sulphite mills operate a bark boiler where bark, rejects, knots, fibre and biosludge are incinerated as well (see Section 2.6).

Emission of odorous gases

Emissions of odorous gases in sulphite pulping are normally limited compared to kraft pulping. However, emissions of furfural mercaptan and H_2S might cause odour and emissions of gaseous sulphur may also cause annoyances. At many mills, emissions of odorous gases are collected and burnt in the recovery boiler (all German and Austrian mills). Another option is treatment in wet scrubbers.

VOC emissions

Emissions of VOC from the process are about 0.2 kg/t of sulphite pulp. The chip heaps also contribute to emissions of VOC.

One mill uses the extracted evaporation condensates for the preparation of the cooking liquor which may lead to the emission of volatile organic compounds (organic acids) from the stack. If hardwood undergoes intensive cooking (viscose pulp) most of the hemicellulose is hydrolysed which results in high concentrations of acetic acid, furfural and xylose in the spent liquor. In the evaporation plant these volatile substances end up in the condensate. From there, they can be extracted and sold as products. The purified condensate which contains the rest of the acetic acid and furfural can be used in the scrubbers and in the MgO ash washing. Part of the volatile substances may be emitted with the flue-gas, although no measurements are available.

4.2.2.6 Solid waste generation

The production of sulphite pulp is related to the generation of different types of manufacturing-specific wastes/residues, most of which can be utilised. The wastes/residues arise from different stages of the production process such as debarking, chipping, screening, clarification of the cooking liquor (the sludge from the acid preparation serves as a calcium drain), cleaning of process equipment in the digester area (if calcium is used as a base), maintenance and sludge from treatment of raw and waste water. Table 4.14 shows data from a German sulphite pulp mill reporting the main fractions of waste including some options for further treatment. The latter usually depend strongly on local conditions.

Table 4.14: Example of waste generated in the production of sulphite pulp

EWC Code (1)	Description	Originate	Amount (2)	Possible disposal route
17 04 05	Scrap (steel tapes, part of equipment, etc.)	Packaging of logs, maintenance of installations	2.8 kg/t	Utilisation as material
03 03 01	Bark	Debarking plant	90 kg/t	Utilisation as fuel, biomass boiler
-	Sawdust	Wood handling	30 – 50 kg/t	Production of chip boards
-	Rejects from coarse screening	Screening	23 kg/t	Utilisation as fuel, biomass boiler
-	Rejects from fine screening (chips, knots, bark, fibres, sand)	Screening (0.51 % losses)	8 kg/t	Utilisation as fuel, in brickwork, biomass boiler
03 03 06	Sludge from pulp and paper production	Mechanical and biological treatment of process water, recovery of chemicals (sludge of SO_2 clarifier)	60 – 80 kg/t	Combustion on site, recultivation of landfills, brickwork
20 03 01	Mixed municipal waste	Operation of installations	0.4 kg/t	Sorting, utilisation as material or fuel
13 02 02	Oil waste	Maintenance	0.03 kg/t	Utilisation as material or fuel

NB:

(1) The EWC is a harmonised, non-exhaustive list of wastes that will be periodically reviewed and if necessary revised in accordance with the Committee procedure. However, the inclusion of a material in the EWC does not mean that the given material is a waste in all circumstances. The entry is only relevant when the definition of waste has been satisfied [IPTS, 1997].

(2) The reference (German mill, reference year: 1996) did not qualify the dry solids content. It seems that the figure above includes more than 50 % water. Normally, a value between 20 – 25 kg/ADt dry solids for primary and secondary sludge seems reasonable, when activated sludge is applied.

Aside from the information given in the table, the following types of waste/residue have to be considered: ash and cinder from energy extraction (combined burning of biofuel and fossil fuel);

wood room waste (sand, etc.); ash and cinder from the recovery boilers; sand from the fluidised bed boiler (if operated); gypsum from the calcium sulphite process; and, in case of integrated pulp mills, residues from the paper mill. Wood waste such as bark, chips, sawdust, knots, etc. is often burnt on site. Ashes from the recovery boiler and bark boilers are partly used for other purposes. Furthermore, sludge from clarification of the cooking liquors and base tanks is generated.

A German sulphite mill using surface water reported significant quantities of sludge from raw water treatment (flocculation), amounting to 50 kg/ADt.

The amount of waste sent from sulphite pulping to landfill in Europe ranges from about 2.5 kg to 50 kg. Organic waste consists of wood residues, bark, pulping rejects, fibre sludge and waste water sludge. If the organic waste is incinerated in dedicated incinerators, there is virtually no organic waste to be landfilled. According to the European Landfill Directive [265, Directive 1999/31/EC 1999], the time taken for the deposit of non-inert waste such as waste water treatment sludge or waste with a high amount of organic matter is limited. The Directive sets targets and limits on the amount of biodegradable waste that is allowed to be disposed of in landfills, so sulphite mills have to look for strategies to avoid landfilling their organic waste without pretreatment. In an integrated sulphite pulp mill that incinerates all organic residues on site (bark, wood waste, fibre sludge, sludge from biological treatment), the amount of waste reported is 1.3 kg dry solids (DS)/ADt (100 % DS) from pulp production and 0.9 kg DS/ADt from papermaking. The ash from the incineration process can be utilised in different ways, e.g. in the cement industry.

4.2.2.7 Noise

Noise emissions occur throughout the pulp manufacturing process from the transport of the logs or sawmill residues to the wood yard, to the debarking drums and chippers, to many other noise-generating processes.

The wood yard noise emissions are measured at different positions close to the wood yard. The noise sources are mainly:

- transporting and handling of logs (e.g. wood conveyor, feed table for food handling),
- unloading of bulk chemicals and fuels,
- debarking devices,
- cutter to transform wood into chips,
- high-speed fans on the roof (reduced by silencers which are installed around the fans),
- vacuum pumps,
- grinding devices,
- safety valves,
- chimney outlets,
- blowers,
- motors,
- logistics operations.

Sulphite pulp mills are often required to meet reduction standards in compliance with national legislation, and noise surveys are conducted and evaluated. Natural noise barriers, such as office buildings, walls, trees or bushes, are also used in pulp mills to reduce noise emissions. Where residential areas are located close to a plant, investments in process changes or an increase in capacity are connected with a necessity to reduce noise emissions.

4.3 Techniques to consider in the determination of BAT

This section describes techniques (or combinations thereof), and associated monitoring, considered to have the potential for achieving a high level of environmental protection in the activities within the scope of this document. The techniques described will include both the technology used and the way in which the installations are designed, built, maintained, operated and decommissioned.

It covers environmental management systems, process-integrated techniques and end-of-pipe measures. Waste prevention and management, including waste minimisation and recycling procedures are also considered, as well as techniques that reduce the consumption of raw materials, water and energy by optimising use and reuse. The techniques described also cover measures used to prevent or to limit the environmental consequences of accidents and incidents, as well as site remediation measures. They also cover measures taken to prevent or reduce emissions under other than normal operating conditions (such as start-up and shutdown operations, leaks, malfunctions, momentary stoppages and the definitive cessation of operations).

Annex III to the Directive lists a number of criteria for determining BAT, and the information within this chapter will address these considerations. As far as possible, the standard structure in Table 4.15 is used to outline the information on each technique, to enable a comparison of techniques and the assessment against the definition of BAT in the Industrial Emissions Directive.

This section does not necessarily provide an exhaustive list of techniques which could be applied in the sector. Other techniques may exist, or may be developed, which could be considered in the determination of BAT for an individual installation.

Table 4.15: Information for each technique described in this chapter

Headings within the sections
Description
Technical description
Achieved environmental benefits
Environmental performance and operational data
Cross-media effects
Technical considerations relevant to applicability
Economics
Driving force for implementation
Example plants
Reference literature

Some of the techniques for prevention and reduction of emissions from kraft pulp mills are similar to the measures that can be applied in sulphite pulp mills. Therefore, for sulphite pulp mills, the presentation of the techniques to consider in the determination of BAT can be divided into four different groups of techniques in order to avoid repetition.

Group 1: Because of the similarities between sulphite and kraft pulping, a number of the measures for kraft pulping are valid in most respects for sulphite pulping too. This is considered to be the case for the techniques listed below and the reader is referred to the respective sections in Chapter 3 on kraft pulping (and to sections of Chapter 2, respectively, where techniques common to all mills are discussed):

- Dry debarking (see Section 2.9.2.2).
- Closed screening, i.e. the water system in the brown stock screening plant is completely closed (see Section 3.3.4).
- Collection of spillages, i.e. collection of diverted or spilled liquor at the highest possible liquor solids concentration and return of collected strong or weak liquor and fibre to the process at appropriate locations. If the spillage cannot be completely reused peak loads of concentrated streams should be prevented from entering the effluent treatment (see Section 3.3.9).
- Efficient washing. Efficient washer systems achieve a carry-over, often denoted as 'washing losses', of around 5 – 10 kg COD/ADt (see Section 3.3.10)
- Installation of low-NO_X technology in auxiliary boilers (bark, coal, oil) (see Section 2.9.7.2.1) and SNCR in bark boilers (see Section 2.9.7.2.2).
- Electrostatic precipitator or bag filter for dust reduction in bark boilers (see Section 2.9.7.1).
- Use of sufficiently large buffer tanks for the storage of concentrated or hot liquids from the process in order to prevent short-lived peak flows from entering the biological effluent treatment and causing pH shocks and probably upsetting the treatment system due to accidental discharges. The available storage capacity (volume) to control these spillages of weak and strong liquors from sulphite production especially in start-up, shutdown or abnormal conditions is crucial. Extra volume is required (greater than that of normal operation) for containing peak flows lasting a few hours, which are due to operational disturbances (see Section 3.3.12).
- Tertiary treatment such as chemical precipitation after biological treatment to reduce phosphorus and/or suspended solids (see Section 3.3.14).

Group 2: There are particular differences between kraft and sulphite technologies concerning the following techniques:

- extended modified cooking to a low kappa number (batch or continuous) (see Section 3.3.3);
- oxygen delignification (see Section 3.3.5);
- TCF bleaching (see Section 3.3.7);
- ECF bleaching (see Section 3.3.6);
- partial closure of the bleach plant combined with increased evaporation (see Section 3.3.8);
- closed-loop bleaching for sodium-based sulphite mills;
- pretreatment of waste water from the oxygen stages in an ultrafiltration plant;
- use of an emission-optimised recovery boiler by controlling the firing conditions;
- aerobic biological treatment of the effluents (see Section 3.3.13);
- installation of ESPs and multistage scrubbers in the recovery boiler (see Section 3.3.17.2);
- collection of ground-level odorous and diffuse process SO_2 gases and combustion in the recovery boiler or washing in scrubbers (see Section 3.3.16.1);
- SNCR (ammonia injection) in the recovery boiler;
- measures to prevent uncontrolled operational conditions and to reduce the consequences of accidents.

With regard to these techniques there are significant differences between kraft and sulphite pulp mills although the principles of the techniques are very similar. The differences mainly concern detailed technical solutions, achievable kappa numbers reflecting residual lignin content, bleaching sequences, bleachability and pulp brightness, volatile organic compounds in contaminated condensates, etc. Techniques from group 2 above are discussed in this section.

Group 3: Some techniques of kraft pulping are not valid at all for sulphite pulp mills such as:

- increasing the dry solids content of black liquor (see Section 3.3.17.1);

- stripping of most concentrated contaminated condensates and reusing most condensates in the process (see Section 3.3.11);
- collection and incineration of odorous gases in the lime kiln (see Section 3.3.16.2);
- installation of improved washing of lime mud in recausticising (see Section 3.3.20.2);
- electrostatic precipitator for dust reduction in the lime kiln (see Section 3.3.22);
- incineration of odorous gases in a separate furnace including a scrubber (see Section 3.3.16.3).

Group 4: Finally there are a few additional techniques to be mentioned which are only applicable to sulphite pulp mills and which are not valid at all for kraft mills. They are also discussed in this section and include the following:

- neutralising of weak liquor before/inside the evaporation plant;
- anaerobic pretreatment of the condensates;
- reduction of dust and SO_2 emissions from the recovery boiler by installing multicyclones/electrostatic precipitators and multistage scrubbers.

In Sections 4.3.2 to 4.3.25, the techniques of groups 2 and 4 are described and discussed. Furthermore, there are techniques common to most pulp and paper mills. Regarding these common techniques, the reader is referred to Section 2.9.

4.3.1 Dry debarking

See Section 2.9.2.2.

4.3.2 Extended modified cooking before bleaching

Description

The degree to which the lignin is extracted from the wood in the cooking stage determines the amount of lignin to be taken away in the subsequent bleaching stages. Longer cooking periods under optimised conditions allow a maximum amount of lignin to be extracted before the bleaching: lower kappa numbers mean less residual lignin to be removed during bleaching. The cooking kappa number is also one of the parameters that determines the conditions for the final pulp quality needed for the specific paper end use. The residual lignin content (kappa number) depends on a number of factors that need to be balanced.

Achieved environmental benefits

The kappa number after cooking determines the discharges of organic substances to the waste water treatment plant. At lower kappa numbers, less residual lignin is removed in the bleach plant and leads to less organic load to be treated in the waste water treatment plant. The consequence is lower emissions to the water bodies.

Environmental performance and operational data

In acid sulphite cooking, common kappa numbers are between 14 and 22 for softwood and 10 and 20 for hardwood. In comparison, kappa numbers of 14 to 16 are normally reached with the acid sulphite process in integrated production where the pulp is never dried (e.g. Hallein and Neusiedler, AT; Alfeld, Stockstadt and Ehingen, DE). For example, two integrated sulphite pulp and paper mills operating with the acid bisulphite magnesium method (around 50 % beech and 50 % spruce) cook down to a kappa number of 14 – 15. After two-stage peroxide bleaching, the pulp has 86 – 88 % ISO brightness and is used for the production of printing paper. On the other hand, a mill that produces market pulp from hardwood (Caima, PT) cooks at a kappa number of 20 – 22 to meet the required strength properties and compensate the strength losses during the drying of the pulp.

In the magnefite process (see Section 4.1.1.2), the delignification of softwood (spruce) can be brought down to a kappa number of 21 – 23 in order to maintain acceptable pulp strength properties.

Hydrolytic attacks on the cellulose molecules, occurring particularly and more intensely during the end of the cook, limit the possibilities of dramatically decreasing the kappa number. By optimising the process a minor decrease could be possible.

The kappa number can be further decreased before bleaching by an oxygen stage (see Section 4.3.3).

A few mills in Europe cook to higher kappa numbers due to special product quality requirements or because they are producing market sulphite pulp. These mills may need to take more action to compensate for the higher organic loads created in subsequent bleaching steps.

Cooking is extended further to produce dissolving pulp but at the expense of the yield. The same applies to the manufacturing of speciality pulp for chemical applications.

Cross-media effects
Extended cooking to low kappa numbers may have negative effects on strength and brightness. However, this can be avoided to a large extent by optimising and fine-tuning the processes.

Technical considerations relevant to applicability
Extended cooking to lower kappa numbers can be applied to new and existing mills, except for calcium-based sulphite mills as this will lead to an increased degree of scaling. If the capacity of the digesters is the bottleneck of the mill, extended cooking is not an option. In this case, shorter cooking sequences may be applied which results in higher kappa numbers.

Economics
Lignin extracted during cooking allows for sending dissolved lignins to the evaporation plant and then to the energy recovery boiler. Oxidising the residual lignin released in the effluents of the bleach plant in a waste water treatment plant all in all is a more expensive option.

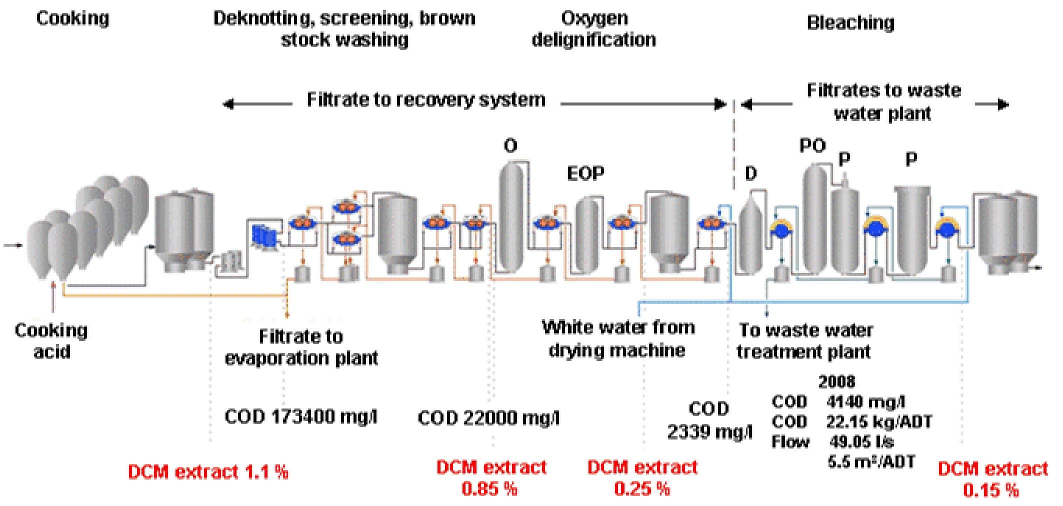
Driving force for implementation
Gentle cooking down to low kappa numbers while still allowing high quality requirements to be met are often driven by national water legislation and the need to reduce the load of organic material to the water bodies. It is also a cost efficient measure.

Example plants
At least six plants in Germany and Austria.

4.3.3 Oxygen delignification before bleaching

Description

Oxygen delignification (shorthand 'O' and 'EOP' stage) can be seen as a bridging step between cooking and bleaching. It uses elevated temperatures (85 – 95 °C), pressure (2.5 bar), oxygen and a base to increase pH up to alkaline conditions. Oxygen delignification removes a substantial fraction of the lignin remaining after cooking and before the first bleaching step. Measured as COD, the reduction of the discharges of organic substances from the oxygen stage is about 50 % compared to the situation without O_2 delignification. O_2 delignification contributes to the deresination by saponification (alkaline medium) which can be measured by use of the dichloromethane (DCM) extract value. The DCM extract figures show how the amount of resins decreases during oxygen delignification (see figures before and after oxygen stages). O_2 delignification also has a positive influence with regard to impurities in the bleached pulp. Figure 4.39 shows an example of a fibre line with O_2 delignification including the COD and DCM extract values before and after O_2 delignification. The impact of the oxygen stages on the COD load before and after the oxygen reactors can be seen. The bleaching stages are nominated using symbolic shorthand according to the bleaching agent that is applied: oxygen (O), hydrogen peroxide (P) or combinations (OP) and chlorine dioxide (D).



Source: Biocel Paskov, CZ

Figure 4.39: Example of a fibre line with O_2 delignification including the COD and DCM extract values before and after O_2 delignification

Oxygen delignification is potentially suitable for closed water systems because their effluents are normally used as wash media in brown stock washing, from where they are sent to the chemical recovery process. However, the base used for increasing the pH in O_2 delignification is important for reaching the right buffering effect. There is some experience of the use of MgOH in the O_2 stage not being cost efficient. Two mills that use magnesium as a base in cooking but sodium for increasing the pH in the O_2 stage have found a solution for this difficulty:

(a) One sulphite mill (market pulp) with a two-stage O_2 delignification process (Biocel Paskov, CZ) reports that it is not necessary to use the same alkali for the oxygen stage as for the cooking. In their magnesium bisulphite pulping they use the Na-alkali in the delignification and bleaching stages. As a consequence, the operation of the chemical recovery circuit has to be adapted and sodium removed from time to time. When the spent sulphite liquor with a limited amount of the sodium ions is combusted in the recovery boiler, the boiler has to be cleaned four times per year in order to remove sodium deposits. Sending larger amounts of sodium back to the recovery boiler would plug the boiler tubes and may block the boiler (see example under (b)). With the use of the O_2 stages, it is in this case possible to send those process waters which are poorly biodegradable (process water with dissolved lignin) in particular by counter-current washing to the recovery system and not to the effluent treatment.

(b) Another option is to concentrate the effluent from the oxygen stage of the bleach plant by use of ultrafiltration (see Section 4.3.12). The separated concentrate can be burnt in the bark boiler. The filtrate is led to the biological waste water treatment plant (e.g. Nymölla magnefite pulp mill, SE). After the ultrafiltration of the oxygen stage effluent, the concentrate was first added to the thin spent sulphite liquor. A dramatic increase in clogging occurred in the recovery boiler. The adding of concentrate was stopped. Since then, the concentrate is burnt in the bark boiler.

Whether O_2 delignification is applied depends on a number of factors. In the following list, experiences from some mills are given:

- Delignification is used when lignin is essentially to be removed. Bleaching is used for reactions that improve the brightness by oxidising chromophore links.
- Oxygen is less a selective delignification chemical than other bleaching agents. It attacks cellulose as much as it attacks the lignin. Therefore, strength properties and pulp yield may suffer from an oxygen stage.
- The benefit of an O_2 delignification step depends on the type of pulp and the product quality to be achieved. In most cases it is not needed.
- Recirculation of effluents from O_2 delignification is easier if there is compatibility between cooking chemicals and the delignification base, i.e. for magnesium bisulphite pulping if MgO is used as a base.
- Due to the good bleachability of sulphite pulp which allows short bleaching sequences to achieve full brightness of the pulp, in most cases there is no need for oxygen delignification. For example, German pulp mills achieve a full brightness pulp (87 – 88 % ISO) with a two-stage bleaching sequence (EP-EP$_{HC}$ und P-A-P$_{HC}$) without O_2 delignification.
- Oxygen delignification is not very suitable for producers of speciality pulp because it may have a negative influence on the desired very high viscosity and alpha pulp level. It also has a limited additional effect on the lignin removal because a hot alkali extraction stage is already used in order to increase the alpha-cellulose content of the speciality pulp.

Sulphite pulp mills that apply O_2 delignification aim at an optimum point that allows the delivery of pulp from the lowest kappa number to the bleach plant while maintaining the required pulp strength and avoiding the sharply dropping ranges of the pulp yield curve.

Achieved environmental benefits
O_2 delignification removes a substantial fraction of the remaining lignin after cooking. Without O_2 delignification this COD load would be transferred to the bleach plant and subsequently to the waste water treatment plant. In the example shown in Figure 4.39, the filtrates of the oxygen stage are sent back to the recovery units.

Environmental performance and operational data
See Figure 4.39.

Cross-media effects
The degree to which O_2 delignification is applied involves a comprehensive optimisation of the fibre line process considering total cost, pulp quality, and environmental impact. No best sequence therefore exists in a sulphite pulp mill.

Technical considerations relevant to applicability
Oxygen delignification can be applied to new and existing mills. Possible restrictions need to be assessed case by case taking into account aspects such as: (a) strength properties and pulp yield may suffer from an oxygen stage; (b) the compatibility between the base used in cooking and

the delignification base; (c) the real environmental benefit of O_2 delignification; and (d) the suitability of O_2 delignification for the specific type of pulp manufactured.

Economics

In the example of Figure 4.39, the operating costs for the oxygen stage (O) and the extraction stage using NaOH with subsequent addition of oxygen and hydrogen peroxide as a reinforcing agent (EOP stage) were EUR 19.6/ADt in 2008. Yield losses in the O and EOP stage are calculated as around 3 % altogether.

Driving force for implementation

Oxygen delignification removes a substantial fraction of the lignin measured as COD and contributes to the removal of resins which can be measured by use of the DCM extract value. It also has a positive influence with regard to impurities in the bleached pulp. O_2 delignification makes it possible to send the filtrates back to the recovery units and avoid transferring them to the bleach plant or the waste water treatment plant. It thus leads to reduced emissions of organic substances to water.

Example plants

Sappi Gratkorn, AT; Biocel Paskov, CZ; Stora Enso Nymölla, SE.

Reference literature

[266, Ragnar, Kvaerner 2002].

4.3.4 Closed brown stock screening

See Section 3.3.4.

4.3.5 Efficient brown stock washing

See Section 3.3.10.

4.3.6 Effective spill monitoring and containment, also with chemical and energy recovery system

See Section 3.3.9.

4.3.7 Totally chlorine free (TCF) bleaching

Description

Since the beginning of the 1990s, TCF bleaching has become the predominantly used bleaching method in European sulphite pulp mills.

A TCF bleaching sequence is characterised by the absence of chlorine-containing substances. Only oxygen-containing substances are used, avoiding the generation of organically bound chlorine in the pulp and in the waste water stream. In Europe, no sulphite pulp mills apply chlorine as a bleaching agent and most elemental chlorine free (ECF) pulp production has been replaced by TCF bleaching sequences. Existing bleaching plants were converted by reorganising and upgrading equipment. Bleaching sequences with chlorine application, e.g. C-E-H-H and C/D-E-D(E-D) were converted stepwise to TCF sequences. First molecular chlorine bleaching steps were dropped and ECF pulp was produced. Then the processes were converted to TCF bleaching (e.g. EOP-Q-EOP(-EP)) by further developing the process. The use of complexing agents in peroxide stages and the increase in consistency in the bleaching tower made it possible to manufacture high-quality TCF paper pulp. Further prerequisites for TCF bleaching such as extended and even cooking, high efficiency washing processes and increased evaporation capacities were implemented.

One of the drawbacks of the early TCF bleaching operations was a loss of strength of the produced pulp, because of an attack of the cellulose backbone by various radicals formed during peroxide bleaching. By introducing a better process control to avoid the peroxide deterioration, as well as adjusting the temperature and pH profile, and by introducing complexing agents, these problems have been solved. TCF sulphite pulp producers have learnt to adjust the process to the required brightness and strength levels by optimising the whole system from an environmental, performance and cost level point of view. This view covers the integrated paper pulp producing units. A sulphite market pulp producer with a much wider customer base may need to operate a mild chlorine dioxide stage (D stage) to achieve the pulp quality demand of the customers.

The introduction of magnesium hydroxide as an alkali source (only for those sulphite mills with a magnesium base in the digester), in the first bleaching stage after the digester, made it possible to further close the water cycle and promote the utilisation and integration of these volumes in the thermal recovery cycle (see Section 4.3.8). Some mills however found that magnesium hydroxide used as an alkali is not compatible with pulp with high brightness requirements (above 87 % ISO). After replacement, the degree of delignification will be reduced from 40 – 60 % to 25 – 35 %. About 50 – 60 % of the liquor from the oxygen stage will be sent to evaporation and 40 – 50 % will be sent for biological treatment.

A reduction in fresh water consumption, an optimised steam demand, and the management of undesired substances needed to be implemented before fully utilising this technical option. The control of the deterioration of the hydrogen peroxide, which is the main cost driver in this process, by means of introducing complexing agents (DTPA) as well as stabilisers like sodium silicate was a must to control the process. The control of the MgO transfer into the subsequent bleaching stage during the acid washing stage is crucial and should be monitored very closely.

An example of the process conditions of a typical TCF bleaching sequence for sulphite pulp is shown in Table 4.16.

Table 4.16: Example of the process conditions of a bleaching sequence for TCF sulphite pulping

Parameter	O or EOP stage	Acid washing	EP or EOP stage(s)
Temperature	65 – 75 °C	50 – 70 °C	65 – 80 °C
Pressure	1 – 4 bar	-	1 – 2.5 bar
Consistency	10 – 14	3 - 5	14 – 40
Kappa number	21 – 24 → 11 – 13	-	→ 3 – 5
NaOH	15 – 25	-	5 – 15
O_2	5 – 15	-	0 –7
H_2O_2	2 – 10	-	10 – 25
EDTA/DTPA	-	0.5 – 1.5	

Achieved environmental benefits
No formation of adsorbable organically bound halogens (measured as AOX) in bleaching. Releases of purgeable or volatile organically bound halogens (POX) to air are reduced down to zero. The TCF bleached pulp produced does not contain organically bound chlorine that might be released when the pulp is repulped in paper mills.

In general, TCF bleaching leads to lower emissions of coloured substances with waste water and the degradability of the waste water in the biological treatment plant is enhanced. Moreover, energy savings are achieved by TCF bleaching. The steam demand in the bleach plant can be reduced from 0.5 – 1 tonnes of steam/ADt down to below 0.5 tonnes of steam/ADt. The power demand can be reduced by 10 – 20 %. These data depend on the capability of process water recycling and closure of the water circuits. Pulp quality aspects also have to be considered here. A higher degree of water closure increases the risk of unwanted peroxide deterioration, as the amount of undesired substances (whether organics or metals) may increase in closely operated water circuits.

In TCF bleaching, there are obviously none of the risks associated with the storage of chlorine and the preparation of chlorine dioxide.

Environmental performance and operational data

Today, for all qualities of TCF bleached sulphite pulp, sufficient experience has been gained. There are no operational problems reported as long as very straightforward metal management and anti-scaling and cleaning procedures for process equipment are maintained. The strict control of the pH in all process steps is crucial for avoiding scaling effects. To maintain operability, careful cleaning procedures of scaled material and equipment have to be followed either during the regular shutdown or during periods where the equipment can be taken out of operation. The waste water resulting from this cleaning operation is sent to the effluent treatment plant.

For sulphite pulp mills that manufacture market paper pulp only, one mild D stage may be necessary to achieve the market demands for the pulp quality. However, this pulp can be produced at a relatively low ClO_2 dosage. The only European sulphite pulp mill that manufactures solely market paper pulp with one ClO_2 bleaching stage reported AOX emission levels below 0.1 kg/ADt. If pulp bleached with only small portions of ClO_2 is produced, AOX emissions in the treated effluents are between 0.6 mg/l and 0.8 mg/l; in the case of pure ECF pulp production 1.2 – 1.8 mg AOX/l are measured in the effluents at an average flow of around 34 m^3/ADt.

Section 3.1.7 summarises the results of the discussion about ECF versus TCF bleaching.

Cross-media effects

The numerous positive effects of this technique are mentioned in the paragraph above (achieved environmental benefits). As drawbacks, the following aspects can be noted: releases of complexing agents such as DTPA/EDTA (0.2 – 2 kg/ADt) if they are applied in bleaching stages that discharge the washing liquids via waste water treatment plants. However, by optimising the dosage of complexing agents, the amount of DTPA/EDTA can be reduced. There are experiences that the sedimentability of the biosludge in the sedimentation tank can deteriorate to a certain extent. In other mills this effect does not occur. Because of possible risks, peroxide should be handled with care.

Technical considerations relevant to applicability

This technique is applicable to both new and existing mills (conversion). Also, dissolving pulp can be produced with a TCF bleaching sequence. For market pulp mills, one mild chlorine dioxide stage with a low ClO_2 charge may be necessary to produce high brightness pulp. For mills that manufacture speciality pulp for chemical applications, chlorine dioxide or hypochlorite is usually still needed as a bleaching chemical.

Economics

The investment cost for conversion to TCF bleaching and the upgrade of the existing bleach plant amounts to about EUR 20 – 50 million for a sulphite pulp mill with a daily production capacity of 700 ADt/day. However, these figures depend to a certain extent on the pulp qualities to be achieved. The total savings depend on the overall process design, the equipment used, the price of chemicals and energy in the given country, as well as of the amount of closure of the water cycle. Closed water cycles are generally associated with higher costs as measures have to be taken to control the process and to evaporate the additional water. For example, introducing MgO as an alkali in the first bleaching stage leads to generally higher peroxide consumption and results in the need for higher amounts of neutralisation chemicals like sulphuric acid to reduce the carry-over of MgO to the subsequent bleaching stages. This is not compensated for by increased energy output from the combustion of the organics which are recovered and thermally utilised.

Driving force for implementation

Requirements from regulators and competent authorities concerning the protection of the environment (reduction of discharges of chlorinated organic matter and other toxic and less biodegradable substances), public awareness about environmental and health risks of persistent organically bound chlorine compounds, occupational safety aspects and market demands of environmentally aware customers were important drivers for the conversion process. Especially for tissue applications, there is a clear demand from clients that ask explicitly for TCF sulphite pulp.

Concerning operating costs, TCF bleaching results in slightly higher total costs. Delignification in the digester has to be developed to a lower level of the kappa number. As a consequence, the yield of the pulp manufacturing decreases slightly. The costs and the amount of chemicals consumed for TCF bleaching are higher than for ECF bleaching. The demand of environmentally aware customers is not connected with a premium price for TCF pulp.

Example plants

Most sulphite pulp mills in Europe use TCF bleaching. Three mills in Europe have ECF bleaching sequences (one paper grade market pulp and two speciality pulp manufacturers).

Reference literature

[237, Bajpai 2005]

4.3.8 MgO-based pre-bleaching and recirculation of washing liquids from pre-bleaching to brown stock washing

Description

There are a few pulp mills (using the acidic magnesium bisulphite method) that achieve partial recirculation of the washing liquids of the first MgO-based bleaching step back to the brown stock washing. Operating some parts of the bleach plant with magnesium as a base is however more difficult than with the use of sodium (chemical wear of the pumps, higher consumption of hydrogen peroxide). On the other hand, the use of MgO in the first bleaching step opens up the possibility to send the effluents from the first bleaching step back to the chemical recovery units and thus generate less organic load to be treated in the effluent treatment plant. The example mills circulate 35 – 50 kg COD/ADt back to the evaporation plant, thus avoiding their discharge.

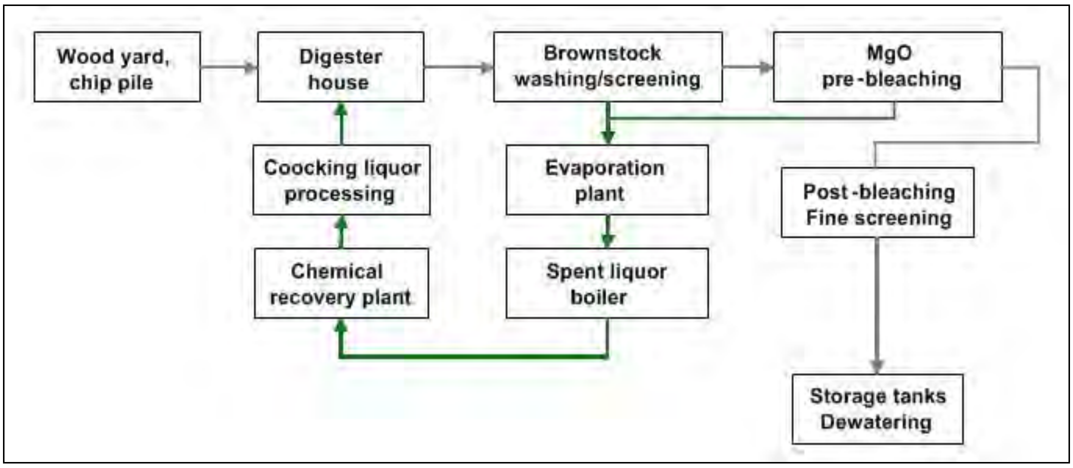


Figure 4.40: **Closed-loop pre-bleaching with MgO as a base (M-real Hallein, AT)**

Achieved environmental benefits

The partial closure of the bleaching plant prevents the effluents being sent to the effluent treatment plant. The released COD load is reduced compared to the conventional process and the waste water treatment plant can be designed for a smaller COD load.

Environmental performance and operational data

The two mills that apply this technique produce pulp for tissue and pulp for printing paper, both in an integrated mill. Consumption of chemicals in the bleach plant has been reported from one of the mills that applies closed-loop pre-bleaching as shown in Table 4.17 (data from 2008).

Table 4.17: **Consumption of chemicals in a mill operating closed-loop pre-bleaching**

Consumption of chemicals	Amount (kg/ADt)
H_2O_2 (50 %)	50 – 60
MgO	20 – 25
Sulphuric acid (94 %)	50 – 60
NaOH (100 %)	8 – 12
Dispersing agent for resins	Required but not specified

Cross-media effects

Closed-loop pre-bleaching requires higher amounts of hydrogen peroxide. The base from the pre-bleaching is recovered in the recovery units of the mill.

Technical considerations relevant to applicability

Magnesium-based pre-bleaching with chemical recovery is an option for sulphite pulp mills to reduce the waste water discharge. Prerequisites for the use of this technique are: (a) kappa number after cooking has to be suitable for the MgO pre-bleaching (low kappa number); (b) sufficient hydraulic capacity of the installations to assimilate the additional flows; (c) possibility to clean and wash the washing equipment used; (d) sufficient capacity of the recovery boiler(s) to burn additional liquor; and (e) an appropriate brightness level. The example mills produce pulp and paper at the same site (integrated production) and achieve 87 % ISO under economically viable conditions; market pulp producers often have to reach brightness levels above 87 % ISO which is difficult to achieve with MgO pre-bleaching because it may lead to the loss of some brightness points.

Economics

The consumption of chemicals of a bleach plant that uses MgO in the first bleaching stage is around 20 – 30 % higher than a plant that does not (higher purity of MgO for recirculated MgO is needed). However, the waste water treatment plant can be sized significantly smaller, which leads to reduced investment and operational costs.

Driving force for implementation
Closed-loop pre-bleaching in magnesium-based acid bisulphite mills can be motivated by higher requirements for the effluents (COD). Quality aspects can be another reason, as pulp bleached with magnesium as a base may achieve higher pulp strength under certain conditions.

Example plants
M-real Hallein (AT), SCA Mannheim (DE).

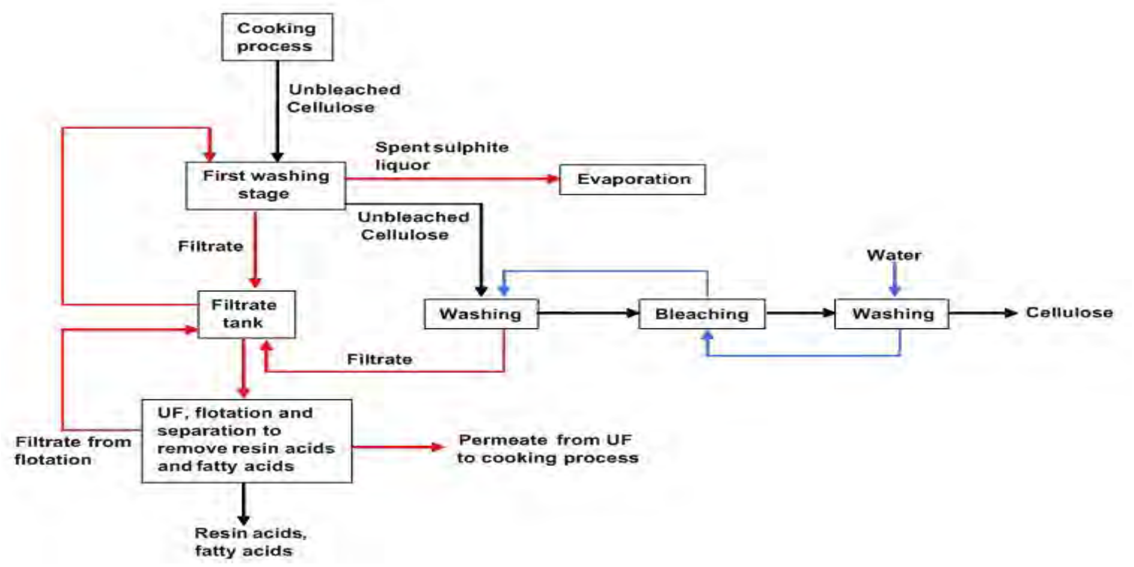
Reference literature
[276, Sixta 2006].

4.3.9 Closed-loop bleaching (in a sodium-based sulphite mill using ultrafiltration, flotation and separation)

Description
In an acidic sulphite pulp mill manufacturing dissolving cellulose using sodium as a cooking base, the bleach plant effluent is treated by ultrafiltration (UF), flotation and separation to enable closed-loop bleaching. No effluent from the washing or bleach plant exits as waste water. Instead, the filtrate from the bleaching and washing is used in the first washing stage after cooking.

The dissolving pulp mill uses the same base for cooking and pH adjustment in the bleaching process, which is one of the criteria to enable the closed-loop bleach plant (CLB) to function. The purpose of the UF and the other separation techniques used is to remove resin acids and fatty acids from the filtrate in the closed-loop system. This process is similar to a kidney because, without the treatment, process foreign substances would accumulate in the system making the CLP impossible considering the quality of the cellulose. Unwanted substances have to be purged from the system.

The treatment of the filtrate is carried out in several process stages starting with the UF, where resin acids and fatty acids are separated out (see Figure 4.41). The resulting permeate is reused in the cooking process, whereas the concentrate is further treated by means of flotation and separation to separate out even more of the resin and fatty acids from the water phase. The treated filtrate from the flotation is pumped back and used in the first washing stage.



Source: [230, Selling 2009]

Figure 4.41: Ultrafiltration system in a dissolving pulp mill, Domsjö Fabriker AB, SE

Achieved environmental benefits

No waste water is released from the bleach plant. The COD load which would normally be sent to the waste water treatment plant is held back in the system. Also, the water consumption is lower.

Environmental performance and operational data

The ultrafiltration unit is installed to treat process water after brown pulp washing. The resulting permeate is pumped back and reused in the cooking process.

Cross-media effects

No data on energy consumption for the operation of the separation units were provided. Concentrates are evaporated and burnt.

Technical considerations relevant to applicability

This technique can be installed in both new and existing mills. Before being installed, ultrafiltration tests need to be performed in a pilot plant. In this pilot, design and layout parameters are usually determined and operation conditions optimised to the specific effluents to be treated. Normally, in the first phase of membrane applications, there are certain setbacks that can be overcome by adjusting the pH, the flow or introducing some kind of appropriate pretreatment. In this case after-treatment is also applied.

The application of the closed-loop bleach plant is still limited to sulphite pulp mills using sodium as a base (the same base that is used to adjust the pH in the peroxide bleaching stages). Also, the pH of the filtrate is of importance because it affects the possibility to separate resin acids and fatty acids.

Economics

No data on investment and operational costs were provided.

Driving force for implementation

Environmental legislation for sulphite pulp mills regarding releases of organic substances to water bodies is the driving force for implementation. The mill operators regard the measure as an important method to reduce the COD passed on to the receiving water body.

Example plants
Domsjö pulp mill (SE). There are no other sulphite mills using this application but membranes are used in other applications in sulphite mills, e.g. in the Nymölla mill (see Section 4.3.12).

Reference literature
[230, Selling 2009].

4.3.10 Reduction of emissions by the use of chelating agents in the peroxide stages of the bleach plant

See Section 2.9.9.

4.3.11 pH adjustment of weak liquor before/inside the evaporation plant

Description
It is important to neutralise the spent sulphite liquor after the first stage of evaporation or before evaporation. Otherwise acetic acid and other short-chain organic acids will be evaporated and turn up in the condensates instead of being led together with the concentrated spent liquor to the recovery boiler. The COD load in the condensates is normally much higher at sulphite pulp mills compared to kraft mills. The total load in condensates before treatment is normally up to 60 – 70 kg of COD/ADt.

Achieved environmental benefits
A significant part of the organic load (COD) of the condensate, especially short-chain organic acids, is transferred back to the spent liquor and remains in the recovery circuits. The effect of this technique is that less organic loaded effluent is sent to the waste water treatment and less COD is released to water bodies.

Environmental performance and operational data
This measure is a proven technique in most mills. In acid magnesium sulphite mills, fresh MgO from the MgO silo and recovered dust from the electrostatic precipitators are used for neutralisation. In a first step before the concentration of the spent liquor by evaporation, SO_2 is stripped and recovered for reuse in the cooking plant. Higher SO_2 concentrations could have a negative impact on the operation of the waste water treatment plant. After SO_2 stripping, the pH value remains acidic. The spent sulphite liquor is then neutralised to around pH 6.5 before entering the next evaporation steps.

A calcium-based sulphite pulp mill (IT) strips the condensates from evaporation, trying to reduce both smaller organic molecules and SO_2. The stripped remaining substance is sent to burners where the organic material is oxidised while SO_2 is recovered in the process.

Cross-media effects
There are no relevant negative effects associated with this technique. The neutralisation chemicals are the same as those used as a base in cooking. Therefore, few additional chemicals are needed.

Technical considerations relevant to applicability
This technique is applicable to all magnesium-based plants. This technique needs some extra capacity in the recovery boiler and in an ash circuit.

Economics
No information provided.

Driving force for implementation

Optimisation of the energy recovery cycle and reduction of the organic pollution load from the processes are the driving forces for the implementation of this technique.

Example plants

The technique is operated in most sulphite pulp mills and also NSSC mills with chemical recovery in Europe.

4.3.12 Pretreatment of waste water from the oxygen stages of the bleach plant in an ultrafiltration plant followed by aerobic treatment of the total effluent

Description

Magnefite pulp mills and acid bisulphite pulp mills that cook to a high kappa number have higher amounts of non-biodegradable COD in the bleach plant effluents than other sulphite pulp mills. Effluents from the oxygen stages cannot be burnt in the recovery boilers of sulphite pulp mills without difficulties (see Section 4.3.3, examples (a) and (b)). Therefore, other methods must be used to reduce the amount of COD released to the environment. At the Stora Enso Nymölla mill (SE), effluents from the oxygen stage are treated in an ultrafiltration (UF) plant with two lines. Highly molecular non-biodegradable compounds are removed and burnt in the bark boiler. 98 % of the incoming liquor passes through the membranes. The concentrate cannot be sent back to the recovery units because the base of the oxygen stage (sodium) is different from the base in the cooking plant (magnesium). The concentrate is burnt directly in the bark boiler. Pilot trials have shown that it would be possible to remove at least 50 % of the water in the concentrate by evaporation but the measure has not yet been implemented. The permeate of the membrane treatment is sent to the activated sludge plant.

When using sodium as a base in the oxygen stage and returning the effluent to the cooking cycle, the boiler tubes can be seriously clogged by ash which contains sodium. The clogging ash is difficult to remove from the boiler tubes.

Figure 4.42 shows the insertion of the UF plant into the bleach plant together with the major flows. The flowsheet shows which flows are treated by the UF unit. 90 % of the organics from the oxygen stage and 65 % of the organics from the peroxide stage are treated by UF. The recirculation of peroxide effluents to dilute pulp streams saves fresh water. Additionally, large molecules from the peroxide stage are removed from the effluent before treatment in the activated sludge plant.

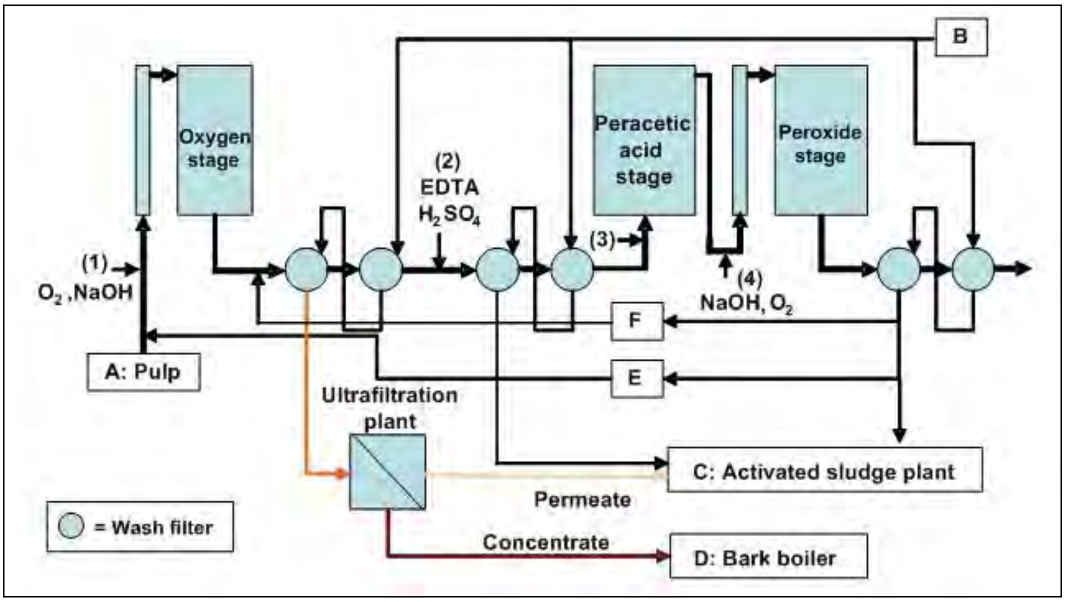


Figure 4.42: **Flowsheet of the use of the ultrafiltration plant in the Nymölla pulp mill**

Pulp enters the bleach plant after the washing of the unbleached pulp. The pulp concentration is about 30 % DS. The amount of water in the pulp is about 2.3 m^3/ADt (Stream A in the figure). The pulp is diluted with filtrates from the peroxide stages, 6.7 m^3/ADt (Stream E in the figure) to 10 % DS. Oxygen and sodium hydroxide are added to the pulp (Stream 1 in the figure). The reaction starts and proceeds in the bleach towers. The pulp is washed after the towers in two wash filters. Before washing, 1 m^3 liquor/ADt from the peroxide stage is added to the pulp (Stream F in the figure). About 9 m^3 washing liquor/ADt (from B) is added to the second filter. The filtrate from the first filter is sent to the UF plant.

Pulp is then treated with EDTA (Stream 2 in the figure) to remove ions of heavy metals like manganese and iron. In order to get a proper pH (pH 6), sulphuric acid is added. After treatment with EDTA, the pulp is washed in two serial wash filters., About 9 m^3 wash water (mostly fresh water, but also some excess water from the paper mill)/ADt is added to the second of the filters (from B). The filtrate is blended with other effluents before it is treated in the activated sludge plant (Stream C in the figure).

After EDTA treatment and washing, a mixture of peracetic acid and hydrogen peroxide is added to the pulp (Stream 3 in the figure). In the peracetic acid stage, peracetic acid and pulp react at pH 6. Hydrogen peroxide and pulp do not react at pH 6. The peracetic acid reaction proceeds in the peracetic acid tower. After the peracetic acid tower, the pH is increased by the addition of sodium hydroxide. A minor amount of oxygen is added too (Stream 4 in the figure). A hydrogen peroxide and oxygen reaction with pulp starts. The reactions continue in the peroxide towers. Afterwards, the later peroxide tower pulp is washed in two serial wash filters. About 9 m^3 washing liquor/ADt (from B) is added to the second filter. The filtrate from the last filter is split into three streams: a) 6.7 m^3/ADt is used to dilute pulp before the oxygen stage (Stream E in the figure); b) 2.3 m^3/ADt is sent to the activated sludge plant together with other effluents (Stream C in the figure) and c) 1 m^3/ADt is used to dilute pulp after the oxygen stage (Stream F in the figure).

Achieved environmental benefits

Ultrafiltration and activated sludge treatment remove different substances. Ultrafiltration removes especially non-biodegradable substances. The substances would, if not removed, be released to the environment. When UF plants stopped, the amount of COD in the inlet and outlet from the activated sludge plant increased. The inlet and outlet of the biological treatment plant showed the same increase. Removing different organic substances makes a combination of membrane and biological treatment an excellent way to reduce the COD in the water receiving body.

On average about 400 m^3 of effluent water are treated by the membrane plants every hour. The effluent of the oxygen bleach stage of the pulping process has an average COD of around 10 g/l. On a daily basis, 34 tonnes of COD are removed (37 kg COD/ADt of pulp). About 30 % of the incoming COD is removed by the membranes. The retained 30 % of the COD is concentrated by means of ultrafiltration (up to 2 % of the original volume). The concentrate is incinerated in the bark boiler (Stream D). The permeate contains 70 % of the COD from the oxygen stage effluent (86 kg COD per tonne of pulp). The permeate is sent to the activated sludge plant together with effluents from the EDTA treatment and excess water from the peroxide stage (collected in Stream C of Figure 4.42).

Under certain conditions, the effluents from the oxygen bleaching stage can also be treated by purely biological means (by means of anaerobic-aerobic treatment; see Section 4.3.15 and Section 4.3.16).

Environmental performance and operational data

The UF plant has been continuously running since 1995. The ultrafiltration plant is built as a large tubular plant with two lines (the supplier of the membranes is PCI Membranes, UK). The lines are designed for continuous production. The membranes are mounted in modules, which are arranged in groups and stacks. Every stack in the ultrafiltration line can be removed from the effluent treatment and cleaned. The other stacks continue to treat effluent. Membranes must be cleaned almost once a day.

In the example mill, severe membrane fouling problems caused stoppages of the ultrafiltration plant. The effect of UF treatment was studied by comparing UF treatment periods to periods without treatment. Today ultrafiltration is an excellent and reliable method to remove non-biodegradable COD, and to combine with biological processes.

Ultrafiltration tests need to be performed in a pilot plant to obtain design data. Results from the pilot trial will be used to select the type of membrane, the membrane capacity and the appropriate design and treatment conditions such as pH and temperature. In the first phase of membrane applications, there are often certain setbacks that need to be overcome by adjusting the pH, the flow or introducing some kind of appropriate pretreatment.

Cross-media effects

The energy consumption for running the membranes is about 2 kWh/m^3 of treated water. The consumption of fuel for burning the concentrate is around 0.6 kWh/m^3 of treated water. The energy required to remove 1 kg COD is 0.65 – 0.8 kWh.

Technical considerations relevant to applicability

Membrane treatment can be installed in both new and existing mills. Pretreatment including fibre removal, addition of chemicals and sufficient storage capacity and pilot trials on the waste water to be treated are crucial for successful applications. The treatment of the concentrates from ultrafiltration is crucial for the application of these techniques. The absence of a bark boiler for incineration of the concentrates may limit the use of ultrafiltration in other mills. Larger amounts of sodium in the filtered concentrates may cause sinterisation of the sand of fluidised bed bark boilers and lead to a stop in the boiler.

Economics

The investment cost per tonne of removed COD in 1994 was about the same as for the activated sludge plant. Specific consumption (m^3 treated water) figures and running costs in 2009 are given below:

- energy consumption: EUR 0.10 /m^3 (2 kWh/m^3);

- chemical costs: EUR 0.15 /m^3;
- energy costs in the bark boiler: EUR 0.03 /m^3;
- membrane costs and costs for the replacement of membranes: EUR 0.10 /m^3;
- personnel costs: EUR 0.03 /m^3 (0.5 worker per shift and 2.5 workers on a yearly basis).

Driving force for implementation
Environmental legislation for sulphite pulp mills regarding releases of organic substances to water bodies is the driving force for implementation. The mill operators regard the measure as an important method to reduce the COD transferred to the receiving water body.

Example plants
Nymölla mill (SE) treats bleach plant effluents by membrane treatment. A different UF application is Domsjö Fabriker AB (SE), see Section 4.3.9.

Reference literature
[278, Wickstroem 1997], [279, TNO 1999], [280, Wickstroem 2009].

4.3.13 Evaporation of effluents from the hot alkaline extraction stage and incineration of the concentrates in a soda boiler

This technique applies mainly to dissolving pulp mills and sulphite pulp mills manufacturing pulp for chemical applications. For some other mills (e.g. chemimechanical pulping), this technique could also be considered.

Description
The technique which is applied to reduce the poorly biodegradable organic compounds released from the bleach plant consists of an evaporation plant, a soda boiler equipped with a bag filter for dust removal and a smelt dissolver.

After the cooking of the wood chips, some residual lignin is unavoidable. It cannot be removed by changing the cooking conditions. More extended cooking, for instance, would lower the pulp yield and lead to an unwanted decrease in the degree of polymerisation of the cellulose. Therefore, the delignification of the residual lignin needs to be carried out by selectively effective bleaching agents. The bleaching could be understood as a continuation of the digestion mainly taking place in the cooking plant. Normally, the bleaching consists of a number of stages (see Section 4.1.3.4). Between the bleaching steps, wash filters are inserted that remove the consumed chemicals and the dissolved reaction products originating from the pulp. Only those pulp mills that manufacture viscose and speciality pulp for chemical applications operate an alkaline extraction stage to continue delignification and to extract hemicellulose. After the alkaline extraction, the remaining lignin is removed by using one or more bleaching steps.

The technique is explained by use of an example, the dissolving pulp mill Lenzing AG (AT). The mill operates the bleaching sequence E – O/P – Z – P in the first line, and E/O/P – Z – P in the second line. For the symbolic shorthand used to describe the bleaching sequences please refer to Section 3.1.7. In this context only two of them are connected to the technique discussed: 'E' which stands for 'extraction stage using sodium hydroxide (NaOH)' and 'E/O/P' which means 'extraction stage using sodium hydroxide with the subsequent addition of gaseous oxygen and hydrogen peroxide solution as a reinforcing agent'. The other shorthand symbols refer to the subsequent ozone and peroxide bleaching steps.

In both lines, the alkaline extraction enhances the delignification of the remaining lignins. For viscose pulp production, aside from the low content of residual lignin, a high proportion of alpha-cellulose is necessary (α-cellulose is that part of a cellulosic material that is insoluble in a 17.5 % solution of sodium hydroxide at 20 °C under specified conditions). In order to guarantee this specified content of α-cellulose, a hot alkaline extraction is applied (and can be combined with an oxygen and peroxide treatment). The extraction dissolves not only the lignin compounds that are dissolvable in sodium hydroxide but also low molecular hemicelluloses and resin and fatty acids that are subsequently removed in the wash filters. The hot alkali extraction constitutes an important source of the COD load from the bleaching sequence. Because of the high content of residual lignin, the waste water from the hot alkali extraction stage is not readily biodegradable in activated sludge plants. This is why these effluents are first concentrated and then incinerated in a soda boiler (see Figure 4.43).

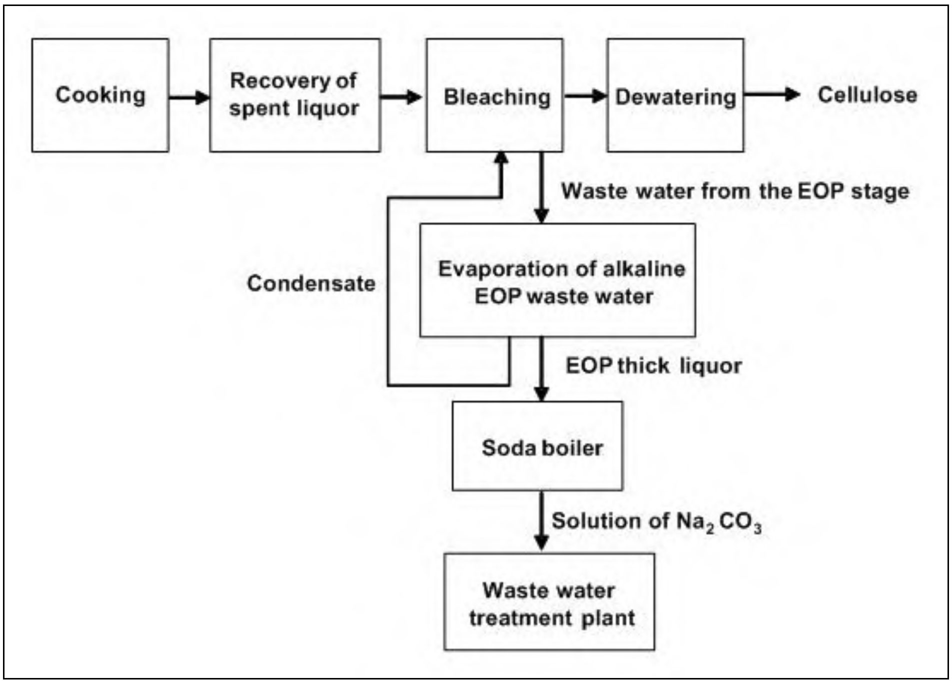


Figure 4.43: **Simplified scheme of the evaporation and incineration of the EOP effluents**

The evaporation plant concentrates the waste water of the EOP stage first to a dry solid (DS) content of around 50 % by means of a three-stage vacuum facility which is followed by a concentrator that reaches 70 % DS. The concentrate is buffered in the EOP thick liquor tank, from where it is sent to the soda boiler for combustion. The Austrian example mill has recently acquired a new evaporation plant which operates with the principle of compression of exhaust vapours. The new evaporation plant concentrates 130 tonnes per hour of weak liquor (EOP effluent) to a concentration of 4.5 % DS. Then, an amount of about 13 t/h of this liquor (of 4.5 % DS) is concentrated to about 49 % DS, and subsequently enters a concentrator which extracts another 20 % of the water. One of the concentrators is continuously operating in a flushing mode while two other units evaporate the remaining water from the liquor. All vaporisers are plate downdraught vaporisers. The final concentration of the EOP thick liquor amounts to around 70 % DS.

The organic compounds of the concentrated liquor are burnt in a soda boiler (a molten ash chamber boiler) which also converts sodium hydroxide (NaOH) to sodium carbonate (Na_2CO_3). To consistently achieve the necessary combustion temperature of about 1 000 °C which guarantees the melt flow, natural gas is added as back-up fuel. At the maximum load conditions, around 1 000 Nm^3 of natural gas per hour are needed. The hot flue-gas generates hot pressure steam of 90 bar and 480 °C in the boiler. The steam generator can also be fed with natural gas only, which then allows only 50 % of the normal steam generation. The current load of the soda boiler is 8.3 tonnes of thick liquor (oven dry) per hour (maximum capacity: 11.3 tonnes of thick liquor per hour). The heating areas in the boiler are cleaned regularly with steam-driven soot blowers. The carbon dioxide generated during the combustion is transferred into sodium carbonate. The concentrated EOP thick liquor is preheated to 120 °C before it enters the combustion chamber. Around 60 % of the sodium carbonate that is generated during combustion accumulates as melt at the floor of the furnace. From there, it is sent to the smelt dissolving tank. The remaining Na_2CO_3 is released with the flue-gas and is recovered as dust and ash at the funnels of the economisers and in the bag filter. The removed ash and dust are transferred to an ash-dissolving tank. Both the melt-dissolving tank and the ash-dissolving tank are equipped with agitators. The soda solution from the melt-dissolving tank is used for neutralising acid waste water streams from viscose production. The vapours generated in the dissolving tank area are collected and combined with the flue-gas before they enter the bag filters.

Under normal operating conditions, the measured NO_X emission levels of the soda boiler are as follows:

around 310 mg NO_X/Nm^3 (periodical measurement)	(limit value: NO_X: 350 mg/Nm^3);
around 1 mg dust/Nm^3 (continuously measured)	(limit value: dust: 15 mg/Nm^3);
around 22 mg CO/Nm^3 (continuously measured)	(limit value: CO: 125 mg/Nm^3).

All values refer to normal operating conditions and 5 % reference oxygen content. Virtually no SO_2 emissions are measured as the fuels do not contain sulphurous components. The current limit values for the soda boiler are given in brackets. Dust, CO and O_2 are measured continuously at the existing soda boiler. NO_X is measured once every three years. For the recently acquired new soda boiler, the monitoring will include the continuous measurement of NO_X. The low dust levels show very little variation. To avoid CO peaks, the burner is controlled for unwanted incrustation with slag twice a week during a short shutdown of the combustion.

Achieved environmental benefits

The purpose of the evaporation and the combustion in the soda boiler is to generate steam from organic materials originating from the pulp manufacturing process and, simultaneously, eliminate a large part of the organic load from the bleach plant effluents. The soda solution that is generated in the bottom of the soda boiler is used to neutralise the acid waste water streams before biological treatment. The released emissions to air from the soda boiler consist of CO and NO_X, as they occur in each combustion process. Dust emissions are very low as bag filters are used.

Environmental performance and operational data

The soda boiler is stopped three to four times per year in order to clean the molten ash chamber. Deposits of MgO that are more difficult to melt could negatively influence the melting process. Minor local explosions occurred during the lifetime of the example boiler but could be controlled.

Cross-media effects

The COD concentration of the EOP waste water is around 10 g/l. The energy consumption for currently running evaporation (three-stage vacuum facility) is about 7.6 kWh_e/m^3 of effluent and 130 kWh_{th}/m^3 of effluent or in total 137.6 kWh/m^3 of EOP effluent. The recently acquired evaporation plant (compression of exhaust vapours) needs about 21.8 kW_e/m^3 of effluent and 20.2 kWh_{th}/m^3 of EOP waste water or in total 42 kWh/m^3 of EOP waste water.

The consumption of fuel for 'burning' (back-up fuel) the concentrates after evaporation is around 46 kWh/m^3 of thick liquor. The generated heat from the combustion of the EOP thick liquor together with the gas back-up fuel is 113 kWh/m^3, achieving an efficiency of 90 %.

The soda produced is used for neutralisation of the waste water of the entire mill. It could also be commercialised. From the soda boiler, emissions to air, mainly NO_X, should be considered.

Technical considerations relevant to applicability

The technique can be installed at both new and existing mills. An alternative to the combustion of the concentrates from evaporation in the soda boiler can be to deliver this material to a nearby kraft pulp mill where the concentrate can be burnt as alternative raw material (biomass and make-up NaOH) in the recovery boiler. For mills producing dissolving pulp for textile, where the effluent will mainly consist of easily biodegradable hemicellulose and short molecular cellulose, an alternative technique is to treat the effluent in a multistage biological treatment plant (combined anaerobic and aerobic treatment).

Economics
It is difficult to give precise cost figures for this technique. The estimated cost for a new evaporation plant for a medium size mill is EUR 16 million and for a soda boiler around EUR 18 million, which add up to around EUR 34 million for the entire piece of technical equipment. The costs could also be 30 – 50 % higher.

Operating costs at the example mill with the current equipment (old evaporators and old boiler) are around EUR 4.35/m^3 of effluent and with old evaporators and a new boiler EUR 2.7/m^3 of effluent. The new evaporators will lower the operational costs. These cost data should be understood as a very rough approximation of the real costs which depend on the specific technical characteristics of the given mill.

Driving force for implementation
The environmental legislation for sulphite pulp mills regarding releases of organic substances to water bodies is a major driving force for the implementation of this technique. The example mill discharges to a sensitive water body. The authorised limit values for the organic load (COD/day) that is discharged to the river is relatively strict and necessitates additional measures in the existing activated sludge treatment plant. The mill operators regard this measure as an important method to reduce COD to the receiving body of water.

Example plants
Lenzing AG (AT), Tembec Tartas (FR), Borregaard (NO).

Reference literature
[217, Lenzing 2009], [218, Karlsen 2008].

4.3.14 Use of emergency and buffer tanks for concentrated liquids

See Section 3.3.12.

4.3.15 Anaerobic treatment of the condensates and the high COD load in the effluent from the bleach plant

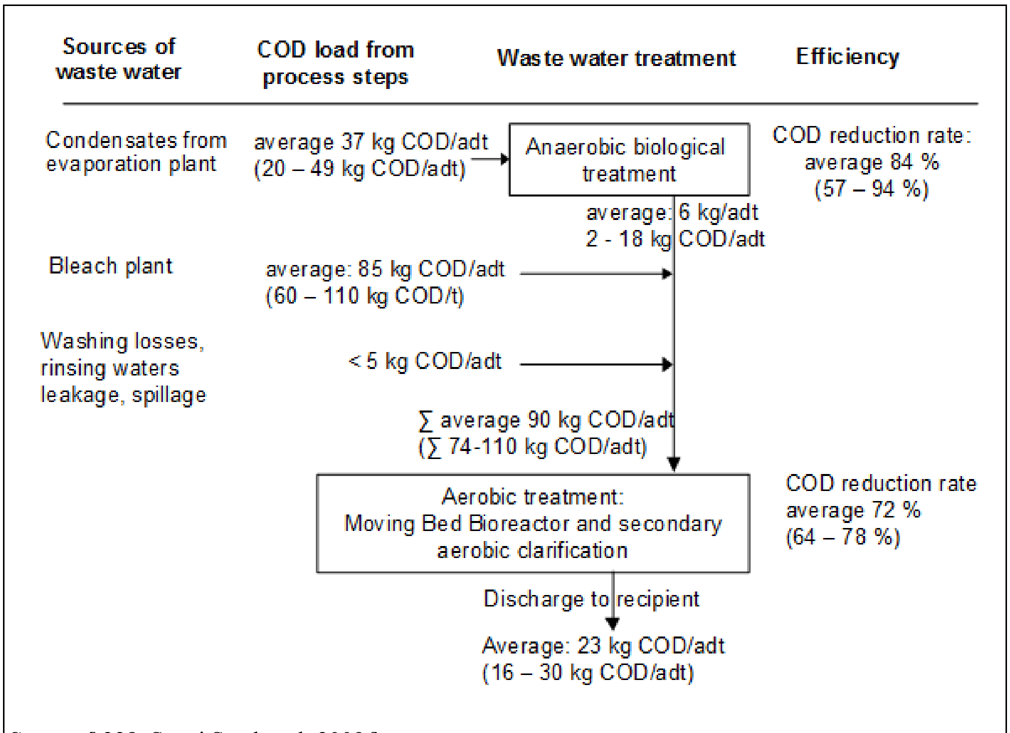
Description
See Section 2.9.11.2.2.

Achieved environmental benefits
Anaerobic pretreatment reduces the organic pollution load of waste water, reduces the excess sludge generated in comparison to stand-alone aerobic treatment and utilises the energetic content inherent in the organic pollution load (biogas production).

Environmental performance and operational data
Figure 4.44 shows for the major sources of waste water of a sulphite pulp mill, the measured COD loads, the appropriate treatment and the removal efficiencies achieved. Stripping of SO_2 out of the condensate is beneficial because higher SO_2 concentrations would disturb the biological process.

Stripping of contaminated condensates and reuse of condensates in the process reduces the fresh water intake of a mill and the organic load to the waste water treatment plant. In a stripping column, steam is led counter-currently through the previously filtered process condensates which contain reduced sulphur compounds, terpenes, methanol and other organic compounds. The volatile substances of the condensate accumulate in the overhead vapour as non-condensable gases and methanol and are withdrawn from the system. The stripped non-condensable gases from the most concentrated condensates are fed into the collection system for strong malodorous gases and are incinerated. Stripped gases from moderately contaminated condensates are collected in the low volume high concentration gas system (LVHC) and incinerated.

The differences in terms of the COD load of the condensate between softwood and hardwood are quite small.



Source: [228, Sappi Stockstadt 2009]

Figure 4.44: **Example of organic loads and removal efficiencies of anaerobic and aerobic waste water treatment in Sappi Fine Paper Europe**

In order to achieve a stable and constant performance of the treatment plant, it is beneficial to control the following parameters: the COD inflow which should be as stable as possible (which is enhanced by waste water recirculation); steady waste water temperature and pH values; control of organic acids and calcium (preferably Ca <200 mg/l) and sufficient supply of nutrients (N and P) to feed the biomass.

COD removal efficiencies from anaerobic treatment amount to about 85 %. The treatment efficiency for the aerobic treatment of the rest of the waste waters from the mill achieve about 55 % to 72 % COD reduction. Depending on the process-integrated measures before the effluent treatment and the specific layout of the delignification and bleaching stages, final effluent loads of 15 – 25 kg COD/t can be achieved.

In the example mill of Figure 4.44, the sludge generation is in the range of 0.01 – 0.05 kg organic dry solids/kg COD reduced.

Cross-media effects
No information submitted.

Technical considerations relevant to applicability
This technique can be installed in both new and existing mills.

Condensates from evaporation of weak liquor from sulphite mills contain relatively high concentrations of readily biodegradable organic substances. They can be efficiently treated in a separate anaerobic treatment. A few mills also treat high COD load effluents from the bleach plant in the anaerobic plant. This option however needs previous pilot trials to assess possible inhibition or disturbances of the active anaerobic biomass.

Economics
No data available.

Driving force for implementation
Reduction of COD loads.

Example plants
Several mills in AT, DE, FR and PT have applied this technique.

Reference literature
[228, Sappi Stockstadt 2009]

4.3.16 Aerobic biological waste water treatment

Description
See Section 2.9.11.2.1

Achieved environmental benefits
Reduction of emissions of organic matter (COD, BOD), AOX, phosphorus, nitrogen and chelating agents to water.

Environmental performance and operational data
Aerobic biological treatment such as activated sludge treatment for effluents from sulphite pulp mills has been successfully used for over 20 years. The four examples below present details of practical experience. Many treatment systems foresee measures to separate normal influents and peak flows to achieve the smooth operation of the plant. If concentration peaks of COD or unusual variations in temperature and hydraulic load in the inlet effluent are detected, the given partial waste water stream is led to an emergency or equalisation basin where it is intermediately stored and discharged stepwise to the major waste water flow. This concept results in relatively few variations in emissions and a continuously high performance of the treatment plant.

The consumption of electrical energy in activated sludge treatment is in the range of 1.2 – 2 kWh/kg of reduced BOD (aeration and pumping). The sludge generation in activated sludge treatment is in the range of 0.4 – 0.7 kg DS/kg of BOD reduced [1, Finnish BAT Report 1997].

The efficiency of the treatment plants vary to a certain extent depending on the type of effluents treated and their design, operation, maintenance and control. The following four examples demonstrate the different concepts realised and the environmental benefits achieved.

Example 1: Integrated magnesium bisulphite pulp and coated fine paper, Sappi Alfeld

i) Production

120 000 ADt of magnesium bisulphite pulp per year, 355 000 tonnes of coated fine paper.

ii) Major effluents treated

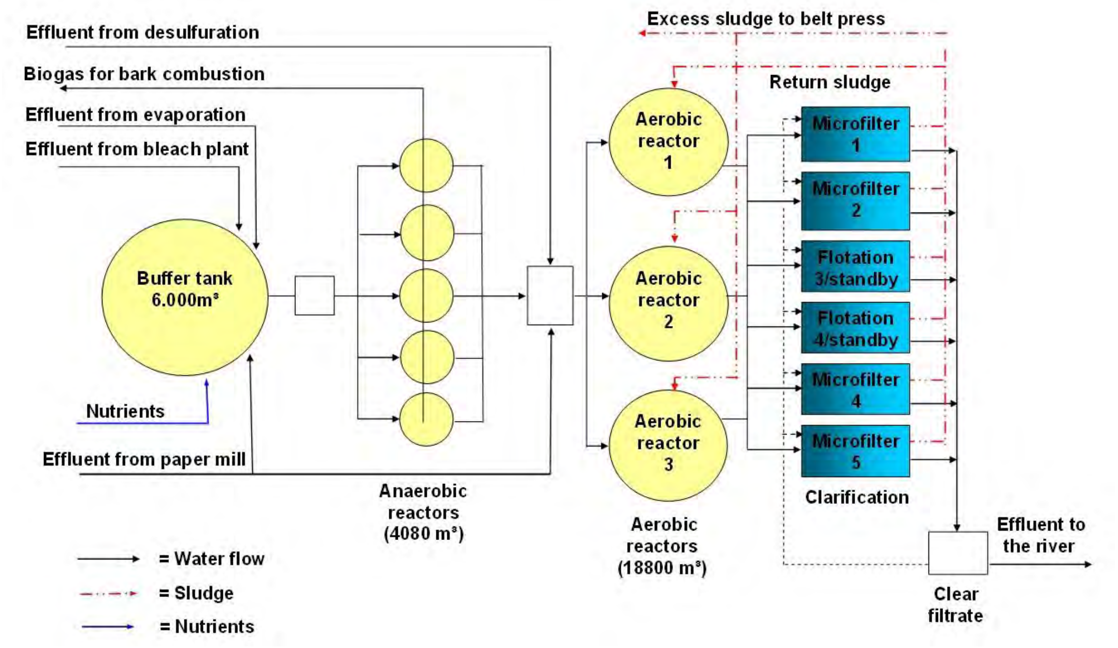
The COD load from the production of pulp contributes to more than 95 % of the total COD load of the effluent inlet. The rest of the COD load of less than 5 % is generated by paper production. The treated waste water streams are: bleach plant effluents (preclarified) including washing losses, evaporation condensates, desulphurisation effluent and the effluent of the paper mill (preclarified).

iii) Incoming flow and organic load

The pulp mill effluent is about 38 m^3/ADt in total (bleach plant: 28 m^3/ADt, evaporation: 6 m^3/ADt, desulphurisation: 4 m^3/ADt). The effluent of the paper mill is about 17 m^3/t of paper. The COD load from the pulp mill is 134 kg COD/ADt in total (bleach plant: 89 kg COD/ADt, evaporation: 42 kg COD/ADt, desulphurisation: 3 kg COD/ADt). The COD load from paper mill is 6 kg/t (average 2008).

iv) Type of treatment

The preclarified effluents of the paper mill and those of the pulp mill (except the effluent from desulphurisation) are pumped to a buffer tank of 6 000 m^3 via different pipes. The UASB reactors (5 reactors of 816 m^3 each) are fed from this buffer tank (see Figure 4.45). The activated sludge plant with its three aerobic reactors of 6 000 m^3 each and four micro-filtration units for TSS and sludge separation takes the effluent of the anaerobic stage and the effluent of the desulphurisation process. The effluent of the paper mill can partly be bypassed directly to the aerobic reactors, that way increasing the hydraulic retention time in the anaerobic reactors. The micro-filtration units consist of a drum covered by a fabric with a 100 µm pore size. They achieve TSS values well below 30 mg/l. The retrofitting of the former flotation units (two of which are still operating) was carried out in 2009. In the near future, the flotation units will only play a role as a back-up system.



Source: Sappi Alfeld Germany, status July 2009

Figure 4.45: **Process diagram of the effluent treatment plant for an integrated pulp and paper mill manufacturing magnesium bisulphite pulp**

v) Major design parameter

The average COD load of the anaerobic stage is about 11 kg/m^3 per day, a typical figure for state-of-the-art UASB reactors. The average BOD sludge load of the aerobic process is below 0.15 kg /kg of SS per day, which is very appropriate for an aerobic treatment.

Table 4.18: Organic load of the biological waste water treatment plant

Organic load parameters	Anaerobic stage		Aerobic stage		
	t/d	kg/m^3·d	t/d	kg/m^3·d	kg/kg SS·d
COD load average	43.36	10.63	29.11	1 549	0.34
maximum	52.03	12.75	34.94	1 858	0.41
BOD load average	16.24	3.98	9.12	0.485	0.11
maximum	19.49	4.78	10.95	0.582	0.13
Sludge load = ~ food/biomass or kg BOD/kg SS·d					

vi) Dosage of nutrients (N and P)

A solution of ammonia phosphate is dosed to the evaporation effluent. It is controlled by N and P tests of the 24-hour effluent sample.

vii) Energy consumption

The consumption of electrical energy in the waste water treatment process is about 0.9 kWh/kg of COD eliminated.

viii) Monitoring

According to the competent authority, the following parameters have to be monitored: water flow, water temperature, turbidity, pH and O_2 continuously; COD, P, N and TSS daily and BOD weekly, all from 24-hour composite mixed samples.

ix) Removal efficiency

COD: 82 %; BOD: 98 %.

x) Economics

The total investment of the biological effluent treatment system including sludge dewatering and drying equipment amounts to about EUR 18 million (calculated for a new plant at current price levels). The total operating costs are about EUR 0.5/m^3, excluding waste water fees and costs for waste disposal.

xi) Measure to guarantee stable and smooth operation

The effluent treatment plant is of state-of-the-art quality with a data control system. Standby flotation units can cover the effluent of two microfilters in case of a break. The buffer tank covers effluent peaks. In case of emergency, there is a basin in the area of the pulp mill to cover the volume of the biggest acid tank. In case of fire, surface water will be stored in a separate flood control basin. The plant is supervised by 24-hour shift control. This concept results in a continuous high performance of the treatment plant.

xii) Sludge generation and treatment

The biological excess sludge is dewatered together with the sludge from the primary clarification and is then treated in a sludge dryer down to 85 % dry content. The dried sludge is incinerated in the bark boiler.

xiii) Achieved environmental performance

In Table 4.19 the achieved concentrations and loads are presented as both yearly and monthly averages. The values are derived from daily average samplings of COD and TSS. Total N and total P figures are also taken from daily average samplings. BOD_5 is determined once a week.

AOX figures are far below the German threshold value for AOX. For that reason, the AOX concentration is measured only once a month by the competent authority.

Table 4.19: Monthly and yearly average values of the discharge from an integrated magnesium bisulphite pulp mill after biological treatment

Month in 2008	**Production of pulp (ADt/day)**	**Influent COD (only pulp)**		**Measured monthly average concentration after biological treatment and calculated specific loads (pulp and paper)/ADt pulp**					
		Flow (m^3/t)	**Load (kg COD/ADt)**	**COD (mg/l)**	**COD (kg/ADt)**	**BOD_5 (mg/l)**	**BOD_5 (kg/ADt)**	**TSS (mg/l)**	**TSS (kg/ADt)**
Jan	348	34	128	242	21	12	1.0	45	4
Feb	355	34	126	247	21	9	0.7	56	5
Mar	316	37	133	298	26	15	1.3	117	10
April	312	38	126	239	22	11	1.0	37	3
May	288	36	110	268	24	12	1.2	56	3
June	325	37	119	244	23	10	0.9	27	3
July	336	37	126	272	26	14	1.3	33	3
Aug	304	39	134	242	24	11	1.0	37	4
Sep	305	37	139	238	23	8	0.8	37	4
Oct	310	37	140	302	28	11	1.0	87	8
Nov	305	40	136	286	27	11	1.1	101	10
Dec	252	48	135	258	27	13	1.4	72	7
Yearly average (pulp & paper)	**313**	**38**	**129**	**261**	**24**	**11**	**1.1**	**59**	**5**
***portion of pulp, see xiv**	**313**	**38**	**129**		**21**		**0.3**		**1.6**

In Table 4.20 the daily average values for a typical month are given for the same mill.

Table 4.20: Daily average values of the discharge from an integrated magnesium bisulphite pulp mill after biological treatment

Days in April 2008	Production of pulp (ADt/day)	Influent COD (only pulp)		Measured daily average concentration after biological treatment and calculated specific loads (pulp and paper)/ADt pulp					
		Flow (m^3/t)	Load (kg COD/ADt)	COD (mg/l)	COD (kg/ADt)	BOD_5 (mg/l)	BOD_5 (kg/ADt)	TSS (mg/l)	TSS (kg/ADt)
1 Apr	354	33	106	281	24			31	3
2 Apr	348	34	99	197	16	6.7	0.5	22	2
3 Apr	322	34	112	171	15			30	3
4 Apr	316	38	122	188	18			39	4
5 Apr	311	38	150	251	23			39	4
6 Apr	321	37	146	324	28			61	5
7 Apr	305	36	98	288	27			56	5
8 Apr	328	34	106	197	17			43	4
9 Apr	294	37	102	196	19	12.0	1.1	43	4
10 Apr	241	43	119	174	20			32	4
11 Apr	256	50	163	185	22			44	5
12 Apr	273	42	151	235	24			55	6
13 Apr	300	43	158	269	26			69	7
14 Apr	332	37	145	309	27			66	6
15 Apr	370	33	127	290	22			28	2
16 Apr	380	33	131	267	21	10.7	0.8	33	3
17 Apr	370	33	119	276	23			20	2
18 Apr	370	38	117	256	20			21	2
19 Apr	364	33	121	276	22			32	2
20 Apr	332	34	97	240	20			21	2
21 Apr	311	32	84	205	20			48	5
22 Apr	311	40	132	224	23			66	7
23 Apr	311	40	155	251	24	12.9	1.2	29	3
24 Apr	316	37	153	281	26			27	2
25 Apr	348	34	140	309	27			29	3
26 Apr	354	35	122	266	23			17	1
27 Apr	338	37	121	220	20			25	2
28 Apr	316	41	120	185	18			35	3
29 Apr	295	41	129	175	18			31	3
30 Apr	268	42	147	204	23	10.6	1.2	26	3
Monthly average value (pulp and paper)	**322**	**37**	**126**	**240**	**22**	**10.6**	**1.0**	**37**	**3.6**
***portion of pulp, see xiv**	**322**	**37**	**126**		**19**		**0.3**		**0.9**

xiv) Sampling, analysis and data interpretation

The effluent load of the paper mill is included in all figures in the tables. Regarding the COD, the share of the pulp mill (see * in Table 4.19) can be approximated in the monthly average figures by subtracting 3 kg COD/ADt originating from paper production from the total effluent. After treatment, the COD load from this paper mill corresponds (on average) to around 1.1 kg/ADt of paper. Calculating with 350 000 t of paper in 2008, this adds up to 424 t of COD that results from paper production only. This load is subtracted from the total COD load generated from both pulp and paper production. In this case, around 3 kg COD/t from the total organic load can be related to paper production. Regarding BOD_5 and TSS, the approximation uses the effluent volume ratio of pulp compared to the total effluent which is 0.31.

xv) Standards for measurement

COD: DIN 38409-41; BOD: EN 1899-1; TSS: not specified; nutrients are measured with Lange cuvette tests.

Example 2: Magnesium bisulphite market pulp, Biocel Paskov A.S.

i) Production

280 000 t of magnesium bisulphite market pulp per year, 29 % ECF and 71 % ECF-light pulp (similar to TCF); 24 000 t of fodder yeast per year, 87 000 t of lignosulphonates per year (roughly 15 % of all thick liquor is sold as lignosulphonate at 55 % DS and 45 % DS).

ii) Major effluents treated

Condensates from the evaporation plant, effluents from the bleach plant. The COD load from the production of by-products fodder yeast contributes to about 2 % of the total COD load of the effluent.

iii) Incoming flow and organic load

The waste water flow of the pulp department is about 33 – 39 m^3/ADt; other flows (from yeast) are around 1 m^3 per tonne (of pulp); and the influent COD load is 55 kg/ADt.

iv) Type of treatment

Averagely loaded activated sludge plant (see Figure 4.46). The treatment consists of a primary treatment and a subsequent biological treatment with one sludge system but with different types of aeration in the sequence: aerated sludge recovery – anoxic selector – oxic selector with pure oxygen – oxygen activated sludge stage in two lines (two-stage operation using the highest purity oxygen in the first stage; the oxygen is dissolved using surface aeration in a covered oxygen atmosphere), activated sludge process aerated by pressure air (two lines), activated sludge process with surface aeration and sedimentation tanks (two lines). The system also allows for meeting strict effluent requirements.

v) Major design parameter

Sludge load of approximately 0.44 kg of BOD/kg of SS per day; the retention time in the aeration basin is about eleven hours.

vi) Dosage of nutrients (N and P)

As a nitrogen source, ammonia water with 25 % NH_3 is added which equals 3.8 t/day. A computer program controls the dosage by balancing the measured concentrations of N-NH_4 and N-NO_3 in the outflow and the estimated BOD_5 and flow of the influent; phosphoric acid is added as 55 % P_2O_5, which equals 0.27 t/day; a computer program controls the P dosage by balancing the measured concentrations of P-PO_4 in the effluents and the estimated BOD_5 and flow of the influent. If the measured concentration of N-NH_4 and N-NO_3 or P-PO_4 in the effluents is higher than the target value, the dosage of the nutrients is decreased according to an established rule of the computer program which also calculates and optimises the flow and BOD_5 load of the influent.

vii) Energy consumption

The consumption of electrical energy in activated sludge treatment is around 1.5 kWh/kg of reduced BOD (aeration and pumping).

viii) Monitoring

Measured outlet parameters are: COD (1/day), BOD_5 (1/day), AOX (1/day), N-NH_4 (3/day), N-NO_3 (3/day), P-PO_4 (3/day), total P (1/week), pH (on–line), temperature (on–line), TSS (1/day), total dissolved solids (105 °C) (1/day), total dissolved inorganic solids (550 °C) (1/day), conductivity (on-line), SO_4^{2-} (1/day), Cl^- (1/day). The computer-based process control contributes to achieving the smooth running of the waste water treatment plant (WWTP).

ix) Removal efficiency

In 2008 the removal efficiency was 80.8 % for COD and for 99.2 % BOD_5.

x) Economics

The operating costs in 2008 were EUR 18.2/ADt.

xi) Measures to guarantee stable and smooth operation

Use of an equalisation basin; control of COD. If accidental releases of peak organic loads occur, part of the waste water with considerably higher COD is bypassed to an equalisation basin and from there it is pumped stepwise to the WWTP.

xii) Sludge generation and treatment

The sludge generation is in the range of 0.4 – 0.7 kg DS/kg of BOD_5 reduced with a weighted average of 0.54 kg DS/kg of BOD reduced. Both the excess sludge from the bottom of the sludge recovery tank and the primary sludge that is thickened in the gravitation thickener are pumped to a mixing tank. Then, the sludge is dewatered with the addition of flocculants, first on a dewatering belt table and then on a belt press (two lines). The sludge is conditioned by the addition of lime. The sludge is delivered to companies for biogas generation or composting.

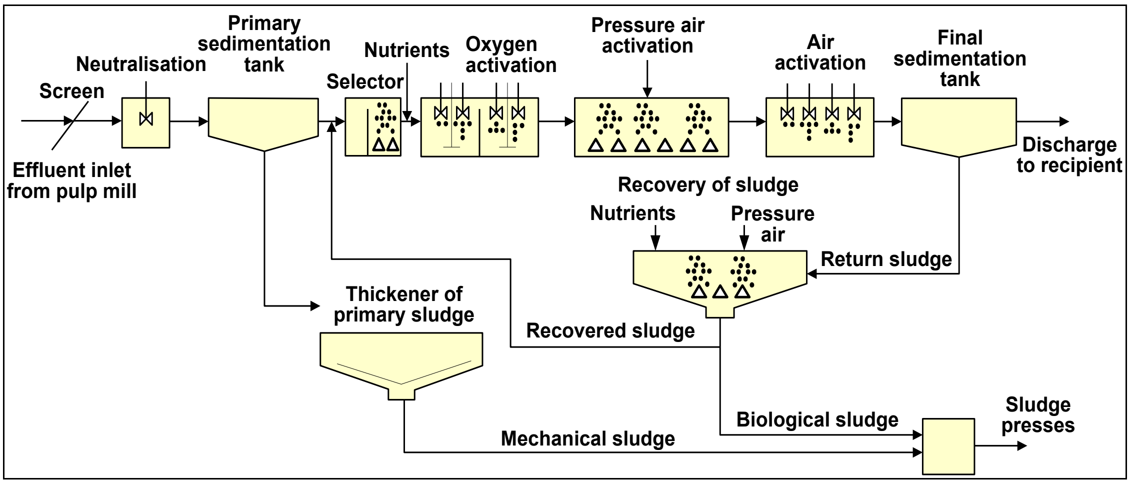


Figure 4.46: **Process diagram of the waste water treatment plant for a pulp mill manufacturing magnesium bisulphite market pulp**

xiii) Achieved environmental performance

In Table 4.21 the measured effluent concentrations and loads expressed as yearly and monthly values are given. For a typical month, in Table 4.22 the daily average values are also shown. The values are derived from daily average samplings of COD, BOD_5 and TSS. All these analyses are performed once a day from mixed 24-hour samples.

Table 4.21: Monthly and yearly average values of the discharge from a magnesium bisulphite market pulp mill after biological treatment

Month in 2008	Production of pulp (ADt/day)	Influent		Influent load (kg COD/ADt)	Measured monthly average concentration after biological treatment and calculated specific loads					
		COD (mg/l)	flow (m^3/t)		COD (mg/l)	COD (kg/ADt)	BOD_5 (mg/l)	BOD_5 (kg/ADt)	TSS (mg/l)	TSS (kg/ADt)
Jan	760	1 981	34.9	56.6	335	11.4	4	0.13	14	0.48
Feb	794	1 967	32.0	53.7	308	9.7	7	0.23	23	0.72
Mar	787	1 995	30.6	52.6	295	9.0	4	0.11	14	0.43
April	844	1 948	29.9	49.6	295	8.8	6	0.17	19	0.58
May	817	1 940	32.3	51.9	293	9.5	9	0.28	22	0.70
June	770	1 886	37.2	52.3	313	11.3	9	0.32	17	0.63
July	832	1 851	36.2	49.0	307	9.4	7	0.26	19	0.68
Aug	777	1 613	36.9	45.8	260	9.6	5	0.18	17	0.63
Sep	828	2 030	33.0	51.1	262	10.1	7	0.22	17	0.57
Oct	159*	1 849	162.6	236.6*	308	22.8*	6	0.46*	18	1.28*
Nov	761	1 948	32.5	49.5	315	9.4	8	0.26	19	0.61
Dec	715	1 884	33.8	49.4	289	9.6	9	0.29	17	0.58
Monthly average value	**159* - 844**	**1 613 - 2 030**	**30-163**	**45.8-236.6***	**260-335**	**8.8-22.8***	**4-9**	**0.11-0.46***	**14-23**	**0.43-1.28***
Yearly average value	**737**	**1 908**	**44.3**	**54.9**	**298**	**10**	**7**	**0.24**	**18**	**0.66**

NB:

(*) In October 2008, there was a shutdown of the fibre line with minimum pulp production for three weeks. However, the WWTP had to continue operating and be fed in order to guarantee the survival of the biomass by adding waste water from equalisation basins. Therefore, the calculated load is twice as high as for the rest of the year.

Table 4.22: Daily average values of the discharge from a magnesium bisulphite market pulp mill after biological treatment

Day	Production of pulp (ADt/day)	Influent		Influent load (kg COD/ADt)	Measured daily average concentration after biological treatment and calculated specific loads					
		COD (mg/l)	Flow (m^3/t)		COD (mg/l)	COD (kg/ADt)	BOD_5 (mg/l)	BOD_5 (kg/ADt)	TSS (mg/l)	TSS (kg/ADt)
1	236 ECO(1)	1 659	91.7	152.3	260	29.26	10	1.13	21	2.36
2	967 ECO(1)	1 538	22.9	35.3	223	6.26	12	0.34	29	0.81
3	733 ECO(1)	1 764	30.2	53.4	242	9.02	11	0.41	26	0.97
4	798 ECO(1)	1 937	27.1	52.6	251	8.42	10	0.34	21	0.70
5	802 ECO(1)	2 188	27.3	59.7	310	9.95	7	0.22	10	0.32
6	919 ECO(1)	2 298	23.1	53.2	345	9.60	4	0.11	21	0.58
7	857 ECO(1)	2 392	24.0	57.5	366	10.57	5	0.14	21	0.61
8	865 ECF	2 198	24.1	53.0	365	10.60	4	0.12	16	0.46
9	821 ECF	2 062	26.2	54.2	286	9.10	7	0.22	18	0.57
10	942 ECF	2 275	23.7	53.9	307	8.73	5	0.14	7	0.20
11	837 ECF	2 049	25.0	51.3	288	8.48	6	0.18	19	0.56
12	667 ECF	1 936	34.2	66.4	314	12.57	6	0.24	14	0.56
13	982 ECO(1)	2 006	22.1	44.4	255	6.63	5	0.13	11	0.29
14	973 ECO(1)	1 966	21.8	42.9	276	6.93	5	0.13	20	0.50
15	843 ECO(1)	1 975	25.4	50.3	296	8.54	3	0.09	37	1.07
16	847 ECO(1)	2 029	24.8	50.3	288	9.04	7	0.22	15	0.47
17	816 ECO(1)	1 876	25.8	48.4	271	8.77	5	0.16	14	0.45
18	777 ECO(1)	1 900	29.4	56.0	274	9.76	5	0.18	9	0.32
19	874 ECO(1)	1 596	27.5	44.0	260	8.10	6	0.19	7	0.22
20	804 ECO(1)	1 637	29.3	48.1	213	7.49	5	0.18	11	0.39
21	514 ECO(1)	1 538	46.6	71.7	180	9.77	5	0.27	37	2.01
22	950 ECO(1)	1 570	24.4	38.3	220	6.50	7	0.21	36	1.06
23	727 ECF	1 987	30.1	59.8	253	9.52	11	0.41	21	0.79
24	785 ECF	1 764	28.3	50.0	296	10.13	9	0.31	16	0.55
25	820 ECF	1 728	25.7	44.4	261	8.29	13	0.41	15	0.48
26	850 ECF	2 538	21.0	53.4	329	8.69	14	0.37	25	0.66
27	832 ECO(1)	2 103	27.9	58.7	461	14.48	17	0.53	56	1.76
28	826 ECO(1)	1 971	25.8	51.0	420	13.90	23	0.76	21	0.69
29	830 ECO(1)	2 067	26.9	55.6	320	10.98	11	0.38	15	0.51
30	856 ECO(1)	1 959	25.3	49.7	351	11.14	12	0.38	34	1.08
31	912 ECO(1)	1 911	23.5	45.0	323	9.79	17	0.52	49	1.49
MEDIAN	832.0	1 966	25.8	52.59	288	9.10	7	0.22	20	0.57
Maximum	982	2 538	91.7	152.31	461	29.26	23	1.13	56	2.36
Minimum	236	1 538	21.0	35.32	180	6.26	3	0.09	7	0.20

NB:
(1) The mill uses the brand 'ECO pulp' for a pulp bleached with small portions of ClO_2.

The inlet COD values do not include shutdowns. They are measured during the days when the production runs. In contrast, the effluent values after the WWTP include all days of the year and all operational conditions.

Total phosphorus is measured only once a week and the average effluent value is 1.15 mg/l with a few peak values up to 2 mg/l. Most of the values are higher than 1 mg P/l. It seems that these values are minimum values for the normal functioning of such a treatment plant (to properly degrade COD and BOD). When phosphorus is close to 0 mg/l, sludge bulking can be observed. Further consequences are a decreasing sludge reserve and reduced WWTP efficiency. Higher P emissions are not allowed by the environmental authorities. Total inorganic nitrogen (the sum of $N\text{-}NO_3\text{-}N$ and $NH_4\text{-}N$) varies between 0 and 15 mg/l as a daily average. The range of the monthly averages is between 3.6 mg N_{inorg}/l and 6.8 mg N_{inorg}/l and as a yearly average around 5.2 mg N_{inorg}/l based on 24-hour mixed samples. A concentration of around 5 mg N_{inorg}/l seems to be the minimum value that is needed for the normal functioning of such an activated sludge plant in order to properly degrade the organic substances.

xiv) Sampling, analysis and data interpretation

Sampling is carried out once a day by means of a time-proportional sample and in the case of the nutrients three times per day. Sampling points are before and after the biological stages of the WWTP and some samples are taken in between. The methods used for chemical analysis are ISO EN methods (acronym for standards of the International Organization for Standardization that are transposed into European standards). The calculation of the emission loads refers to the corresponding production, flow and concentration.

Example 3: NSSC fluting mill, Stora Enso Oyj, Heinola Fluting Mill

i) Production

285 000 t of SC fluting per year which contains >90 % NSSC pulp and <10 % CLC pulp. CLC pulp means pulp manufactured from clean carton clippings.

ii) Major effluents treated

Major effluents are the condensates from the evaporation plant, circulation water with fibres, collectable water from the liquor plant and power plant, leakage water from the landfill and sanitary water.

iii) Incoming flow and organic load

The waste water flow from producing NSSC pulp and SC fluting is about 18 m^3/t of SC fluting as a yearly average. The incoming COD load is about 30 – 35 kg/t of SC fluting as a yearly average.

iv) Type of treatment

The waste water treatment plant consists of a preclarifier, a MBP plant (minimum biosludge process), an activated sludge plant, a subclarifier, and flotation and sludge handling (see Figure 4.47).

v) Major design parameter

An activated sludge plant is designed for 25 tonnes of COD/d. The hydraulic retention time in the activated sludge plant is 4 – 5 days. The sludge load expressed as COD (because the mill does not have enough BOD data available for BOD/kg of SS per day could be used) was around 0.55 COD/kg of SS per day from 2007 to 2009.

vi) Dosage of nutrients (N and P)

The target NH_4^+ amount is 5 mg of soluble N/l at the end of the aeration basin. The target for phosphorus is <1 mg of PO_4–P/l in the effluent of the aeration basin.

vii) Energy consumption

The power consumption for the total waste water treatment process is about 0.9 kWh/kg of reduced COD or about 5 200 MWh/year.

viii) Monitoring

For authorities, pH, TSS and COD_{Cr} are measured five times a week from clarified water from 24-hour mixed samples. In addition, total phosphorus is measured twice a week from 24-hour mixed samples. For BOD_7, 24-hour mixed samples are taken every day and conserved. Around 30 samples per month are then mixed and measured once a month. Total nitrogen samples are taken twice per week. Around eight samples per month are mixed and measured once a month. Samples are time-proportional. In addition to the measurements required for the competent authorities, laboratory analyses of some samples to control the operation of waste water treatment are carried out. On-line measurements are also used to control, for example, water flows, pH, temperature, oxygen, phosphate, nitrate and redox potential.

ix) Removal efficiency

Most of time, the removal efficiency is >85 % for COD (removal efficiency for BOD_5 is not determined).

x) Economics

The operating costs are <EUR 10/tonne SC fluting.

xi) Measure to guarantee stable and smooth operation

On-line measurements and the use of an extra basin for exceptional emissions contribute to stabilising the operation of the biological system. On-line measurements are used to detect abnormal emissions. For example, water flows, pH, temperature, oxygen, phosphate, nitrate and redox potential are measured on-line. The equalising reservoir is used when exceptional emissions occur, for example when the overflow of the circulation water from the fluting mill is led to the waste water treatment plant (normally circulating water from the fluting mill is used in debarking).

xii) Sludge generation and treatment

About 8.4 kg DS of sludge/tonne SC fluting was generated in 2008. From 2006 to 2008, the average sludge generation was about 0.43 kg DS of sludge/kg of COD removed. All of the sludge fractions (primary sludge, biosludge from the thickener, sludge from flotation and sludge from the chip washing) are combined in a mix tank and mixed sludge is dewatered in the belt press. Dewatered sludge is utilised for example in landfill construction or is burnt.

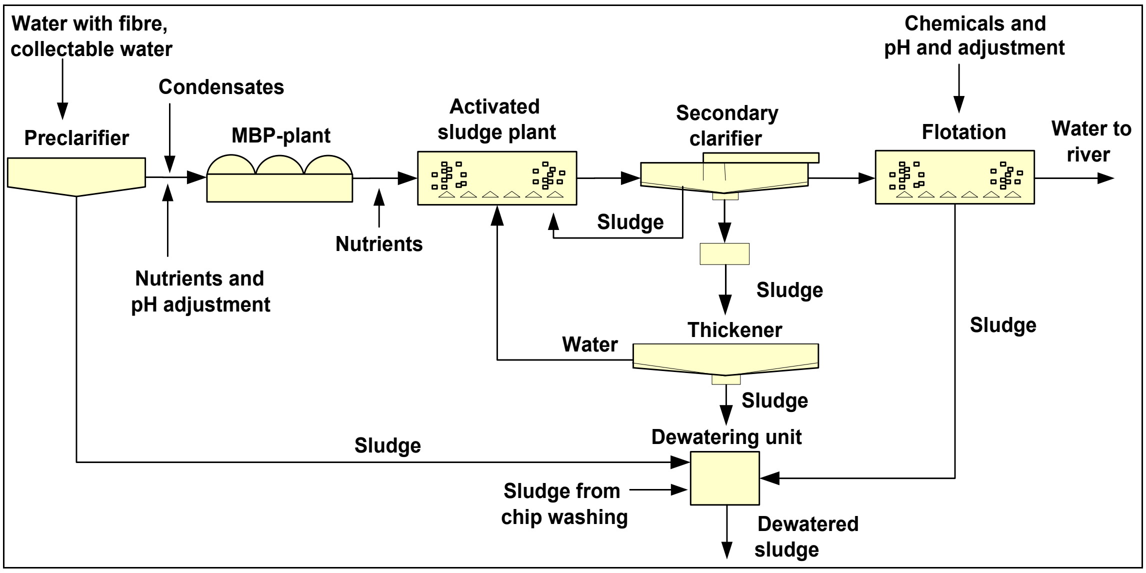


Figure 4.47: Process diagram of the waste water treatment plant of an integrated mill producing NSSC pulp and SC fluting

xiii) Achieved environmental performance

Table 4.23 and Table 4.24 show waste water emissions of a typical year (2007) and the daily average values for a typical month (February).

Table 4.23: Monthly and yearly average emission values after waste water treatment from an integrated mill producing NSSC pulp and SC fluting

Month in 2007	Production of SC fluting (t/day)	Influent		Influent load (kg COD/ADt)	Measured monthly average concentration after biological treatment and calculated specific loads					
		COD (mg/l)	flow (m^3/t)		COD (mg/l)	COD (kg/ADt)	BOD_7 (mg/l)	BOD_7 (kg/ADt)	TSS (mg/l)	TSS (kg/ADt)
Jan	743	5 473	4.8	26.4	685	3.2	19	0.09	48	0.23
Feb	771	6 348	5.1	32.2	906	4.4	69	0.33	151	0.73
Mar	807	5 367	4.8	25.6	851	3.8	62	0.28	207	0.93
April	804	5 161	4.9	25.3	610	2.8	65	0.30	89	0.41
May	772	4 253	5.5	23.4	540	2.8	44	0.23	83	0.43
June	770	4 619	4.4	20.3	563	2.4	17	0.07	97	0.41
July	766	4 223	4.5	19.0	413	1.8	18	0.08	105	0.45
Aug	673	4 070	4.9	20.1	605	3.2	86	0.45	89	0.47
Sep	604	5 224	5.5	28.9	979	5.0	53	0.27	87	0.45
Oct	744	4 913	5.6	27.3	823	4.3	28	0.15	110	0.57
Nov	785	4 625	5.3	24.5	534	2.6	26	0.13	240	1.15
Dec	788	4 856	4.9	24.0	505	2.3	49	0.23	192	0.89
Monthly average value	**604-807**	**4 070-6 348**	**4.4-5.6**	**19.0-32.2**	**413-979**	**1.8-5.0**	**17-86**	**0.07-0.45**	**48-240**	**0.23-1.15**
Yearly average value	**753**	**4 928**	**5.0**	**24.8**	**668**	**3.2**	**45**	**0.22**	**125**	**0.59**

Table 4.24: Daily mean values of the discharge after waste water treatment for a typical month from an integrated mill producing NSSC pulp and SC fluting

Day (2007)	Production of SC fluting (t/day)	Influent		Influent load (kg COD/ADt)	Measured daily average concentration and calculated specific loads			
		COD (mg/l)	flow (m^3/t)		COD (mg/l)	COD (kg/ADt)	TSS (mg/l)	TSS (kg/ADt)
1	774	6 414	5.6	36.1	970	5.3	73	0.4
2	491	6 691	8.4	56.0	930	7.5	130	1.0
3	871	6 653	3.6	24.1	930	3.2	130	0.4
4	785	6 783	4.9	33.1	930	4.4	130	0.6
5	821	6 357	5.0	31.9	900	4.3	120	0.6
6	898	5 962	4.8	28.8	820	3.7	94	0.4
7	796	5 969	5.6	33.4	810	4.3	88	0.5
8	681	5 570	6.1	34.2	770	4.5	130	0.8
9	846	6 368	4.9	31.2	730	3.4	56	0.3
10	831	6 362	4.7	29.7	730	3.3	56	0.2
11	847	6 385	4.1	26.4	730	3.0	56	0.2
12	764	6 269	4.6	28.9	750	3.4	87	0.4
13	631	6 600	6.4	42.3	820	5.2	150	0.9
14	437	5 386	7.1	38.5	850	6.1	150	1.1
15	720	5 592	4.7	26.5	860	4.0	160	0.7
16	797	6 730	4.4	29.9	820	3.6	150	0.7
17	945	6 189	4.3	26.6	820	3.4	150	0.6
18	829	6 254	4.6	28.5	820	3.6	150	0.7
19	767	5 827	5.4	31.4	1 000	5.1	220	1.1
20	785	5 756	5.3	30.3	1 100	5.5	400	2.0
21	907	5 543	4.1	22.5	930	3.5	210	0.8
22	801	4 939	5.4	26.7	870	4.3	180	0.9
23	714	6 554	6.0	39.4	790	4.4	100	0.6
24	707	6 532	5.3	34.4	790	4.0	100	0.5
25	824	6 522	3.7	24.1	790	2.7	100	0.3
26	855	8 133	5.0	40.6	1 000	4.7	150	0.7
27	759	9 254	5.5	50.6	1 300	6.9	270	1.4
28	693	6 896	6.1	41.9	1 700	9.6	420	2.4
Monthly average	771	6 375	5.2	33.1	902	4.5	150	0.8
Maximum	945	9 254	8.4	56.0	1 700	9.6	420	2.37
Minimum	437	4 939	3.6	22.5	730	2.7	56	0.23

xiv) Sampling, analysis and data interpretation

Sampling is carried out by an automatic sampler. The collection of samples for the laboratory is carried out mostly once a day. Laboratory methods used are SFS or SFS-EN methods. The calculation of the final emission levels is made on the grounds of concentrations and flows ($g/m^3 \times m^3/d$).

Example 4: Speciality pulp mill with ammonium base, Tembec Tartas

This example includes a sulphite mill that produces mainly speciality pulp, some fluff pulp for tissue products and various products based on lignosulphonates. The aerobic biological treatment consists of an aerated lagoon. The mill produces ECF pulp. The use of NH_4 as a base is unique in Europe.

i) Production
150 000 ADt of ammonium bisulphite pulp per year for speciality grades, of which 10 – 20 % is fluff pulp for hygiene products.

ii) Major effluents treated
The effluents from the hot alkali extraction stage (the majority of the COD load) are concentrated and burnt in a soda boiler as is done for dissolved matters from the cooking plant. This part of the COD load is therefore not considered for the description below. The condensates from the evaporation plant (23 % of the COD load from the mill) are primarily treated in an anaerobic plant. The treated effluents are then sent towards the aerated lagoon. The effluent from the first chlorine dioxide stage D1 (14 % of the COD load from the mill) is non-biodegradable. The COD:BOD ratio of the D1 stage is 8:10. This effluent is not currently treated in the aerobic plant and is mixed with treated effluent before discharge. The effluents from the rest of the bleaching line (63 % of the COD load of the mill) including the E/O-D2 stages, spillages and untreated condensates are treated in an aerobic system.

iii) Type of treatment
Biological treatment is carried out by an aerated lagoon (see Figure 4.48). The principles of the biodegradation of dissolved organic substances are the same as for an activated sludge plant. The low-loaded aerated lagoon differs from the activated sludge plants in some aspects:

- High electricity power is needed (1.5 MW_e installed).
- It is a very robust system that constitutes an efficient barrier with the environment (300 000 m^3 or 8.1 hectares with a fully mixed compartment).
- No excess sludge is produced when there is a low volumetric load of BOD.
- Very sensitive to low temperatures, implantation must be preferably reserved for warmer climates to avoid very low temperatures in winter. On the other hand, the temperature of effluents does not exceed 30 °C, so no cooling system is needed.

Design and operation should avoid short circuits of waste water streams.

iv) Major design parameter: The system is designed with a very low load of BOD_5. The volumetric loading (the ratio between incoming BOD_5 and volume of the reactor) is 0.08 kg of BOD_5/m^3 per day. The hydraulic retention time is 12 days.

v) Dosage of nutrients (N and P)
As a nutrient for the biomass, phosphoric acid is added according to a P:BOD_5 ratio of 0.8 %. No addition of nitrogen is needed because of the ammonium-based cooking plant; the management of the spillages containing NH_4 needs frequent control of different elements of the process that are still being improved. Variability in N emissions can be explained to a large extent by the uncontrolled entry of spillages into the treatment system.

vi) Energy consumption
The consumption of electrical energy in aerated treatment is around 3 kWh/kg of reduced BOD_5 and 2 kWh/kg of reduced COD because, in this case, when 1 kg of BOD_5 is removed, the COD reduction is 1.5 kg (possibly due to stripping effects).

vii) Monitoring
COD and BOD_5 are monitored daily as a time-proportional 24-hour mixed sample. The pH is controlled continuously to keep the pH at 5.5 – 6.5. Phosphorus is dosed with a volumetric

pump. The consumption of phosphorus is controlled daily at the dosage point and measured once a week in the effluents and monthly by a mass balance. Total N is controlled daily (24-hour mixed sample). AOX is controlled monthly (24-hour sample) with the ISO method and daily in correlation with the ClO_2 consumption. The electric consumption of the 27 aerators that run at a constant power in order to avoid unwanted settlement of the suspended biomass is controlled daily.

viii) Removal efficiency

Aerated lagoon + D1 bypass: COD: 44 %; BOD_5: 88 %.

Aerated lagoon only: COD: 53 %; BOD: 88 %.

The BOD_5 removal is not complete because a major part of the BOD_5 measured in the effluent originates from the TSS that is not retained. If the plant better removed the residual TSS, BOD_5 concentrations of 25 mg/l would be achievable.

ix) Operating costs (costs for anaerobic plant not included)

The main costs include power consumption for the surface aerators and pumps: EUR 3.7 million/year. Chemicals for neutralisation and nutrients = EUR 1.4 million/year.

x) Measures to guarantee stable and smooth operation

Use of an equalisation basin for storing peak COD load waste water streams in order to equalise the COD charge to the aerated lagoon. The design concept of the plant leads to relatively stable operational conditions; first there is a 'fully mixed' (large volume with retention time of seven days) compartment designed to equalise the BOD and COD charge. Two thirds of the aerators are concentrated in this first part as shown in Figure 4.48. This zone is followed by a second 'piston flow' part where the lysis of the biomass and the mineralisation of suspended solids takes place. This design leads to a very stable load discharged into the environment regardless of what has happened in the mill.

xi) Sludge generation and treatment

The aerated lagoon generates nearly no sludge in excess because of large retention times in very large volumes. The sludge generation is in the range of 0.15 – 0.2 kg/tonne of BOD_5 reduced compared to around 0.6 kg of excess sludge (as dry solids)/kg of BOD_5 eliminated in activated sludge plants. Sludge is mineralised in the final part where soluble BOD is deficient (the released BOD measured in the effluents comes from particulate biomass or TSS).

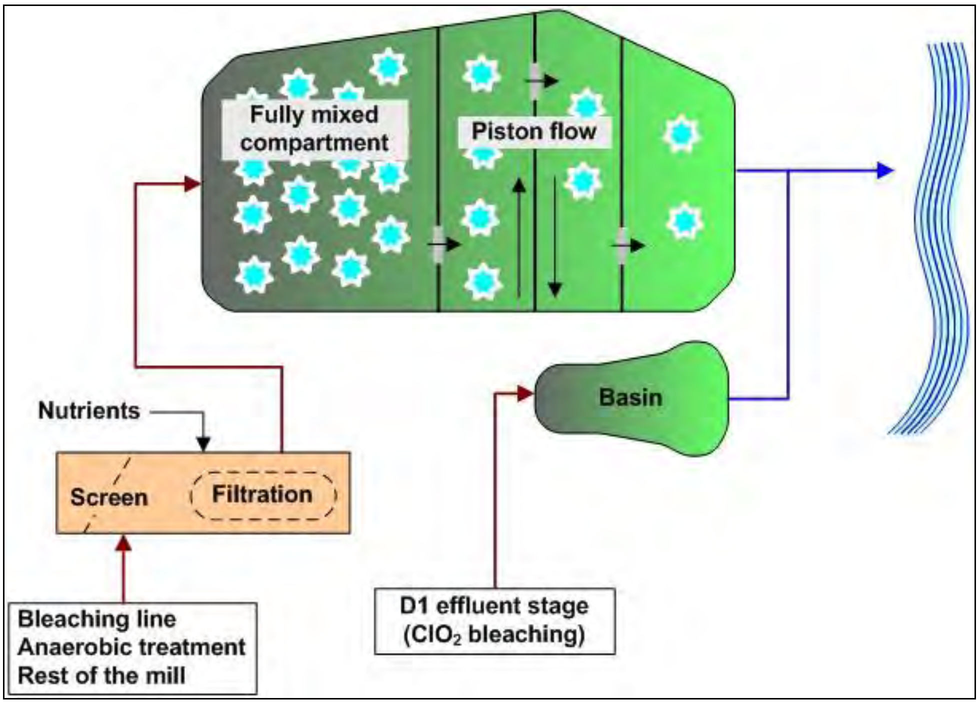


Figure 4.48: **Process diagram of the effluent treatment plant (aerated lagoon) for a pulp mill manufacturing ammonium bisulphite speciality pulp**

xii) Achieved environmental performance

In Table 4.25 the achieved outflow concentrations and loads expressed as yearly, monthly and daily average values are compiled. The values are derived from 24-hour mixed sampling of COD, BOD_5 and TSS. The data refer to the measured effluent concentrations of the aerated lagoon for the months March to September 2009. Start-ups/shutdowns of the mill or exceptional circumstances are included in the data as there is rainwater from the site. This is the case for example in March, with consequences for the April data too (shutdown/start-up of the mill).

The long-term variations observed are caused by the temporary malfunctioning of the alkaline evaporation plant for the effluents from the first bleaching stage (97 % availability) which leads to higher COD loads. From time to time, there is a shutdown of the evaporators for maintenance reasons. In this case, the high COD load effluents are stored in a separate basin and are then gradually treated in the lagoon over the next month. Seasonal variation of temperature constitutes another reason for the variations in the discharged load as the biological treatment is sensitive to temperature variations. Short-term variations can be ascribed to weather conditions (especially sudden water flow increase in case of longer and heavy rainfall) and to poor settleability of the sludge in some cases which leads to losses of the biomass with the effluent. Changes of grades of pulp that is produced by campaigns can also affect the variations of emissions.

Table 4.25: Waste water discharges from an ammonium bisulphite pulp mill for speciality grades after biological treatment (aerated lagoon)

Averaging period	Net saleable pulp production (ADt/day)	Influent COD in (mg/l) and load (kg COD/ADt)	Measured average concentration after biological treatment and calculated corresponding loads					
			COD (mg/l)	COD (kg/ADt)	BOD_5 (mg/l)	BOD_5 (kg/ADt)	TSS (mg/l)	TSS (kg/ADt)
	Range (min.-max. values)							
Daily average values([1])	280 – 490	850 – 2 600 mg/l 50 – 130 kg/t	530 – 1 000	25 – 60	10 – 110	1 – 6	23 - 170	1.5 – 10
Monthly average value([2])	325 – 373	1 337 – 1 972 mg/l 72.7 – 106.3 kg/t	600 - 933	32.1 – 50.1	17 – 94	1.0 - 5.4	46 – 125	4.7 – 7.7
Yearly average value([2])	350	1 535 mg/l 88.1 kg/t	713	41	57	3.3	96	5.7

Explanatory note

(1) In order to present a more representative data set, for the daily average specific load (e.g. kg COD/ADt), values with a pulp production of less than 70 % of the average daily production, corresponding to 367 ADt per day, are dismissed because otherwise the calculated values may misleadingly appear to indicate a changed environmental performance of the plant. In reality, these values are more the result of simple mathematics (small denominator). In our example mill, the measured values are not considered for the calculation of the daily average values when the production falls below 275 ADt/day. Very low levels (5 values) and exceptional high peaks (6 values) are also dismissed: low emission level = 2.5th percentile; high emission level = 97.5th percentile. Considered data are from March to September 2009.

(2) For the monthly and yearly averages all data during the seven months are taken into account.

Source: [215, Aubriot 2009]

The untreated flow from the chlorine dioxide stage (D1) is not included in the emission levels given in Table 4.25. Adding them to the achieved specific emission load increases the emissions of COD, BOD and TSS as follows: COD: 60 kg/ADt, BOD_5: 4.5 kg/ADt, TSS: 6.2 kg/ADt.

The suspended solids concentration in the effluent is relatively high. This is due to the poor and slow settleability of the suspended particles. The low biomass content makes the sedimentation of TSS very ineffective. A normal sedimentation basin does not work efficiently. As a consequence, the BOD value is higher than in plants that effectively remove the TSS. Normally, a BOD value of below 25 mg/l is achievable.

Total phosphorus is normally 3 mg/l with a few peak values up to 5 mg/l. As there is no need to add more P than the quantity that leads to 0.5 – 1 mg P/l in the effluent, the mill is gradually reducing the dosage of phosphorus and intends to reach lower values in the future. Total nitrogen varies between 15 mg/l and 70 mg/l as a daily average (25 – 50 mg/l as a monthly average). The higher values are caused by excess ammonium compounds discharged from the process, especially during the malfunctioning of the mill. Operators still have difficulties to control these unwanted releases.

The AOX content (total effluent: aerated lagoon and D1 effluent) varies from 1.5 mg/l to 8 mg/l, representing 0.2 kg/ADt to 0.75 kg/ADt. This variability is due to the different grades of speciality pulps manufactured.

xiii) Sampling, analysis and data interpretation

Sampling points are the inlet and outlet of each treatment plant (anaerobic and aerobic plant, evaporation of alkaline stage effluents, D1 stage). The frequency of sampling is: for the anaerobic plant (inlet-outlet) daily for COD. For the 24-hour composite sample an automatic device is used. BOD is determined once a week; the aerated lagoon (inlet-outlet) is controlled daily for COD, BOD_5, TSS and N on a 24-hour composite sample device. Analysis methods are ISO standards for BOD_5 and TSS; rapid tests for COD and N which are also periodically controlled with ISO standards. The results of the rapid tests are regularly provided to the competent authorities and show a very high correlation with the ISO methods.

Table 4.26 shows the achieved emission levels of a selection of pulp mills in Europe that have implemented a combination of process-integrated techniques (see Sections 4.3.1 – 4.3.15 plus primary treatment) and a biological waste water treatment but not necessarily all of them and not necessarily to their full extent.

Table 4.26: Examples of achieved emission levels to water after biological treatment of well-performing sulphite pulp mills in Europe

Example pulp mills	Reported achieved emission levels after biological treatment (annual averages 2008) (1)							Type of waste water treatment
	COD (kg/ADt)	BOD$_5$ (kg/ADt)	AOX (kg/ADt)	TSS (kg/ADt)	Total P (kg/ADt)	Total N (2) (kg/ADt)	Flow (3) (m^3/ADt)	
Mill 1, DE, integrated paper pulp	25.4	1.2	(TCF)	1.2	0.04	0.13 (NH$_4$-N)	65	Anaerobic +activated sludge with pure O$_2$
Mill 2, DE integrated paper pulp	23	0.5	0.002 (TCF)	0.4	0.009	0.085 (N$_{inorg}$)	26	Anaerobic +activated sludge
Mill 3, DE integrated paper pulp	21	0.43	0.0006 (TCF)	3.7	0.011	0.006 (N$_{inorg}$)	34	Anaerobic +activated sludge
Mill 1, AT, integrated paper pulp	26	2.9	0.001 (TCF)	1.27	0.060	0.3	34	Anaerobic +activated sludge
Biocel Paskov, CZ market paper pulp	10	0.24	0.03 (ECF)	0.61	0.02 (PO$_4^{3-}$)	0.18 (N$_{inorg}$)	34	Activated sludge
Nymölla, SE, integrated magnefite	30	0.7 (BOD$_7$)	(TCF)	1.0	0.029	0.17	70	Membrane (UF) +activated sludge
Lenzing, AT, dissolving pulp	4	not detectable	<0.002 (TCF)	0.22	<0.1 kg/t	<0.1 kg/t	38	Evaporation/ incineration + activated sludge + coal powder + biofilter
Tembec Tartas, FR, speciality pulp (4)	43 (58)	3.6 (4.1)	0.2 – 0.75 (ECF)	5.4 (6.1)	0.25	2.5 (NH$_4$ used as base)	75	Evaporation/ incineration + anaerobic + aerated lagoon, D1 stage (ClO$_2$) untreated

(1) For integrated pulp and paper mills the data refer to the pulp production only.
(2) Total N for German pulp and paper mills includes only inorganic nitrogen compounds, i.e. organic N compounds are not included.
(3) Cooling water and other clean water are discharged separately and are not included.
(4) Values in brackets include the untreated effluent from the D1 stage; values without brackets refer to the outflow of the aerated lagoon.
Source: [250, Questionnaires 2009]

The list of mills is a selection of mills where data were available or provided. The data were provided by the technical experts of the mills via the filled-in questionnaires and further clarified by personal communication with operators. The method of analysis is the one used in each respective country.

Cross-media effects

Aerobic biological waste water treatment consumes energy (e.g. for aerators and pumps) and generates sludge that normally requires treatment before utilisation or disposal.

Technical considerations relevant to applicability

Biological treatment can be applied to both new and existing mills.

Economics
See cost data in the four example plants above.

Example plants
Most sulphite pulp mills in Europe have applied aerobic waste water treatment. Many mills pretreat the evaporator condensates in anaerobic reactors (see Section 4.3.15) that are followed by aerobic treatment as described above.

Reference literature
Personal communication with operators of the many sulphite mills.

4.3.17 Tertiary waste water treatment - chemical precipitation

See Section 2.9.11.3.1.

4.3.18 Optimising the recovery boiler by controlling the firing conditions

Description
The combustion of the concentrated spent liquor is carried out in an oxidising atmosphere with a slight excess of oxygen (2 – 7 %). Odorous organic substances that are released from the spent liquor and from ground-level weak gases in many mills are also burnt in the recovery boiler. For load compensation or start-up operation, fuel oil or natural gas is added. During combustion the cooking chemicals are nearly completely (95 – 97 %) split into a solid (MgO ash) and a gaseous phase (SO_2 in the flue-gas). All the MgO is in the fly ash that is separated by use of electrostatic precipitators or multicyclones, dissolved in water and subsequently used for scrubbing SO_2 out of the flue-gas. The recovered cooking chemicals MgO and SO_2 are sent back to the cooking plant.

The concentrated spent liquor is injected into the boiler by spray nozzles and burnt in a two-stage combustion in order to control the NO_X emissions. However, from the beginning, the combustion is operated with excess oxygen in order to guarantee a complete combustion of the chemicals and to achieve relatively high temperatures. During combustion it should be ensured that pure MgO is formed without un-burnt soot particles ($MgSO_4$ + ligninsulphonates + $O_2 \rightarrow MgO + SO_2 + CO_2 + H_2O$). This reaction needs a temperature of about 1 250 °C or higher. So, the magnesium bisulphite recovery process demands controlled oxidation conditions (remaining oxygen content after combustion = <1.5 %) to minimise the formation of $MgSO_4$ and SO_3 and temperatures between 1 250 °C and 1 300 °C in order to generate a clean ash with maximum reactivity in contact with water.

The recovery boiler from sulphite pulp mills is similar to boilers that use liquid fuels with a high ash content. The heat from the flue-gas is used in a conventional two-pass boiler. Figure 4.49 shows an example of the flow of the hot flue-gas passing the superheaters, economisers and the air preheaters before it enters the electrostatic precipitator that is followed by the multistage scrubbers. There are also other types of boilers in use in sulphite pulp mills.

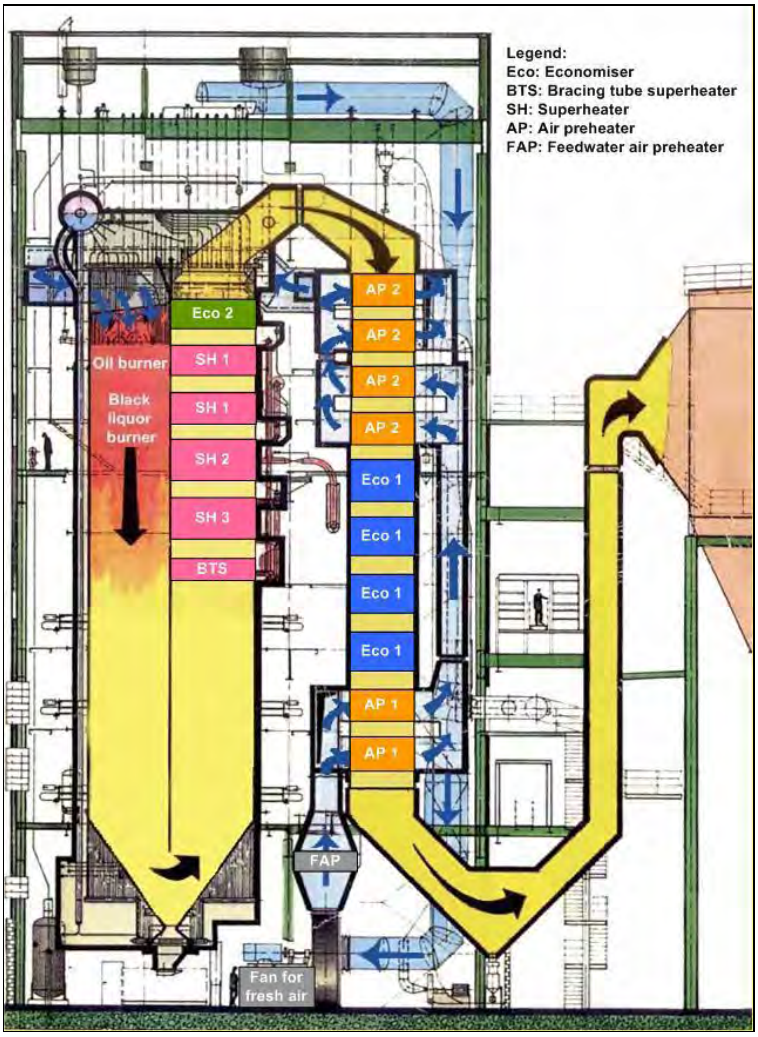


Figure 4.49: **Schematic view of a recovery boiler of a sulphite pulp mill (M-real Hallein, 1985)**

Depending on the type of boiler installed, the emission of nitrogen oxides can be controlled by modified combustion conditions (primary methods). In some cases, depending on the type and design of the boiler, cooler air can be introduced into the boiler to cool the flame within the defined target temperature window (around 1 200 °C). To achieve an operational mode with optimised NO_X emissions, the oxygen input must be kept as low as possible. However, from a certain point onwards, higher CO concentrations are measured. If carbon oxide increases, more oxygen may be introduced into the combustion chamber.

The design of the recovery boiler, e.g. the injection of concentrated spent liquor and optimised mixing between spent liquor droplets and combustion air, can lower the CO and NO_X concentrations to a certain extent. Load conditions do not significantly affect the NO_X emissions.

Achieved environmental benefits
The technique reduces NO_X emissions and seeks to control the CO emissions simultaneously.

Environmental performance and operational data
Without secondary measures, NO_X emissions between 200 mg/Nm^3 and 300 mg/Nm^3 (O_2 content 5 %) as daily average values are achievable. Control of the firing conditions is limited because a temperature of at least 1 150 – 1 200 °C has to be guaranteed in the combustion chamber. These high temperatures cause elevated NO_X concentrations at the outlet of the combustion chamber. CO concentrations in the range of 5 – 20 mg/Nm^3 as a daily average at 5 % O_2 content are normally achievable. There is relatively little variation for both CO and NO_X

and virtually no strong peak values occur. The emission values in Table 4.27 cover all operational conditions including start-up and additional firing with fuel oil or natural gas. During start-up, shutdown, unsteady state conditions or change of fuels (e.g. natural gas operation), the emissions from the recovery boiler are at the upper end of the ranges reported in Table 4.27. CO and NO_X are measured continuously.

Table 4.27: Measured CO and NO_X values from recovery boilers of sulphite pulp mills

Sulphite pulp mills	Type of value	CO (mg/Nm^3)	NO_X (as NO_2) (mg/Nm^3)	NO_X (as NO_2) (kg/ADt)	Remarks
Mill 1, DE, paper pulp [254, Kunz 2009]	**Limit value**	175	450	--	Data from the whole of 2008; 23 % beech, 77 % spruce. Reference oxygen content 3 %; values in brackets refer to 5 % O_2 content
	Yearly average	16 (14)	243 (216)	1.16	
	Minimum daily mean	5 (4.5)	127 (113)		
	Maximum daily mean	41 (36)	296 (263)		
Mill 2, AT, dissolving pulp [255, Peter 2009]	**Limit value**	--	325	--	Min.-max. data from two typical months; yearly average covers all of 2008; 100 % beech; start-up of the recovery boiler: 2007. Reference oxygen content is 5 %.
	Yearly average	7	266	2.5 (**)	
	Minimum daily mean	2	240		
	Maximum daily mean	15	301		
Mill 3, AT, paper pulp [256, Kogler 2009]	**Limit value**	--	350(*)	--	Min.-max. data cover data from three typical days; yearly average covers all of 2008; 100 % spruce; recovery boiler was built in 1985. Reference oxygen content is 5 %. Mill operates with low O_2 concentration (1.5 %).
	Yearly average	140	175	1.17	
	Minimum daily mean	174	189		
	Maximum daily mean	189	190		

Note:
All concentration values refer to dry flue-gas in normal operating conditions (0 °C, 1 013 mbar). Limit values refer to daily mean values. Data are derived from mill visits in 2009 and personal communication with operators.
(*) In this case, the limit value refers to half-hourly mean values.
(**) As dissolving pulp mills have a lower yield when producing cellulose for the textile industry, they have to combust more dry substances per tonne of pulp. Therefore, the gas flow is at a minimum around 8 000 m^3/ADt, resulting in higher specific NO_X emission loads of about 2.5 kg/ADt (as NO_2).

The emission data of Mill 3 in Table 4.27 show that running the recovery boiler with low oxygen (around 1.5 %) and higher CO emissions (around 140 mg/Nm^3 at 5 % O_2) can lower the NO_X emissions to slightly below 200 mg/Nm^3 at 5 % O_2 without secondary measures.

Cross-media effects

No environmental side-effects or disadvantages to other media are caused by this technique.

Technical considerations relevant to applicability

Measures are applicable to both new and existing mills.

Economics

No information provided.

Driving force for implementation

Environmental regulations and the aim of operators to run the recovery boilers efficiently (complete combustion, control of combustion temperature, low emissions) are the driving forces for the implementation of this technique.

Example plants

Many existing pulp mills in Europe have implemented and are running recovery boilers as discussed above. New sulphite recovery boilers have been built recently at Lenzing AG, AT,

(2007) and Sappi Saiccor, South Africa, (2008), both manufacturing chemical cellulose (dissolving pulp).

Reference literature
[267, Lenzing 2009]

4.3.19 Staged injection of spent liquor

Description
The injection of spent sulphite liquor into the boiler at various vertically staged levels prevents the formation of NO_X, and provides for complete combustion.

Achieved environmental benefits
The reduction of NO_X emissions from recovery boilers.

Cross-media effects
No information provided.

Technical considerations relevant to applicability
Applicable to new large recovery boilers and major retrofits.

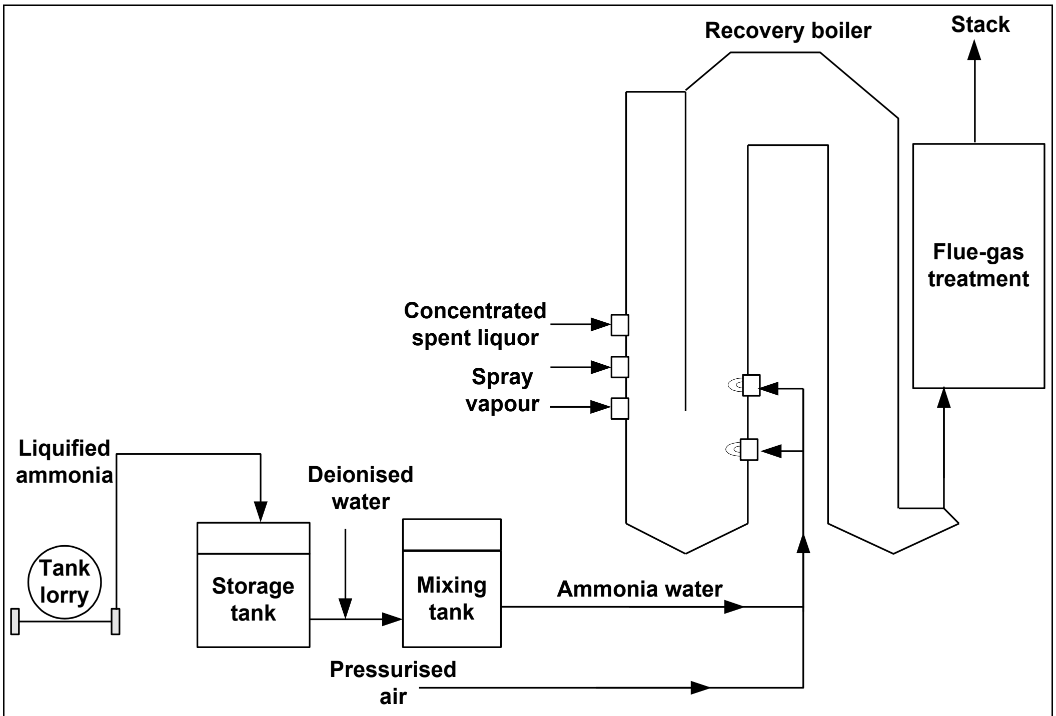
Economics
No information provided.

Driving force for implementation
Improve heat distribution all over the recovery boiler.

4.3.20 SNCR (ammonia or urea injection) in the recovery boiler

Description
For the emissions from recovery boilers, the reduction of NO_X by injection of NH_3 can be achieved under good mixing conditions and temperatures in the range of 800 – 1 000 °C. For the reduction of NO_X, no catalytic converter is necessary. Therefore, this process is called 'selective non-catalytic reduction' (SNCR). There are no applications of 'selective catalytic reduction' (SCR) in recovery boilers of sulphite pulp mills in the European paper industry although technically it should be possible.

An installation for SNCR for a sulphite pulp recovery boiler consists of a storage and dosage station for the reducing agents (NH_3 or urea), supply pipes, devices for the injection of the reactant into the suitable zone of the recovery boiler and the reaction zone where the reduction of NO_X takes place. If an existing recovery boiler is retrofitted with the SNCR technique, the combustion chamber needs to be adapted accordingly: tiny holes have to be drilled for the ammonia water inlets and lances and pipes installed. The injected ammonia reacts with NO to N_2 and water. A minor percentage may leave the reaction zone as unwanted ammonia emissions (the 'ammonia slip'). The injection of NH_3 must be done at an appropriate stage, just where the optimum temperature window (in the example mill below at 910 – 920 °C) can be found (see Figure 4.50).



Source: [253, Mondi Neusiedler/Ybbstaler Zellstoff 2009]

Figure 4.50: Schematic view of the ammonia injection into the recovery boiler

Achieved environmental benefits

The SNCR technique allows for reducing the emissions of nitrogen oxides by adding a reducing agent (ammonia water or urea). Further details are presented under the heading 'Environmental performance and operational data' further below (AT, SE).

Environmental performance and operational data

The examples below present details of practical experience with this technique. The operation and efficiency of the SNCR technique on sulphite pulp mill recovery boilers vary to a certain extent between the mills that have implemented this technique. There are differences in terms of the reducing agents used, the dosage and the target values to be achieved. However, in all known cases the SNCR technique meets the expected results and is running without technical problems. It is considered a stable process.

Example: Mondi Neusiedler GmbH and Ybbstaler Zellstoff GmbH

i) Basic data

The mill operates with the acid bisulphite pulping process. The net production of pulp in 2008 was 50 000 ADt. Only wood chips are used, and the percentage of wood species used is 98 % spruce and 2 % fir. The base used is magnesium oxide, the year of construction of the SNCR technique is 1993/94, and the gas flow is around 6 600 Nm^3/ADt (dry, normal operating conditions) which corresponds to around 880 000 Nm^3/day. A minor amount of raw gas is added to the flame to support combustion (1 500 Nm^3/d), and the rated thermal input is 21.5 MW_{th}. Besides the concentrated spent liquor, biosludge from the waste water treatment plant is also incinerated in the recovery boiler (60 – 70 tonnes of biosludge per day at 4 – 6 % dry solids content; the sludge is dewatered by presses and centrifugal decanters to about 20 % DS). The share of biomass of the total mass incinerated in the recovery boiler is around 4 – 6 %. Around 9.5 m^3 of concentrated liquor are burnt per hour (including biosludge) in the recovery boiler.

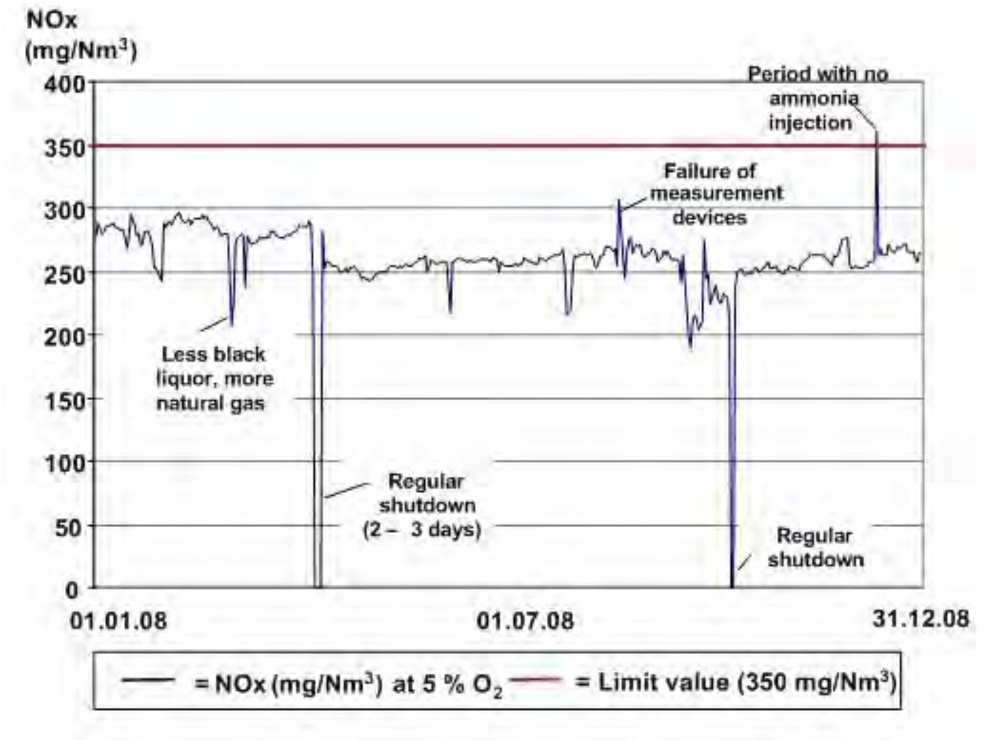
ii) Operational experience

Some changes have been made to the recovery boiler for the injection of the diluted ammonia: some tiny holes had to be drilled for the ammonia water inlet and supply pipes were installed (see Figure 4.50 above). The ammonia is transferred to a double-walled storage tank by a gas displacement device. The mill was already handling ammonia, as ammonia is also used for conditioning the boiler feed water. From the storage tank for liquefied ammonia (25 %), the reducing agent is mixed with deionised water to a 10 – 11 % solution of ammonia water. The mixture is injected into the combustion chamber at 910 – 920 °C. The dosing of NH_3 water is determined by the continuously measured NO_X target value which depends on the requirements set by the competent authority. The current dosage is around 50 l/h at an average flue-gas flow of 35 000 – 37 000 Nm^3/h (approximately 1.5 ml of NH_3/Nm^3). No negative effects on the chemical recovery cycle have been observed during more than 10 years of operation.

iii) Achieved performance: The NO_X concentration in the flue-gas of the recovery boiler of the example mill is higher than in other mills because biosludge from the waste water treatment plant is also incinerated in the recovery boiler. In 1994, the performance of the new installation was tested after the start-up of operation by TÜV Bayern, Austria. Before 1994, i.e. without adding the biosludge to the recovery boiler, the concentration of NO_X in the off-gas of the recovery boiler had been determined as being around 220 mg/Nm^3 (5 % O_2). When the concentrated spent liquor was burnt together with 4.5 % biosludge, the NO_X emissions were around 340 – 350 mg of NO_X (as NO_2)/Nm^3 (5 % oxygen content, normal operating conditions, dry gas). By injection of around 80 l of ammonia water per hour, the average concentration could be lowered to about 185 mg of NO_X/Nm^3. The CO concentration was around 30 mg/Nm^3 (5 % O_2) at that time. At this dosage, no relevant ammonia slip was determined (<1 mg NH_3/Nm^3), [251, TÜV-Bayern 2009].

In order to operate well below the current limit value and to save chemical costs, today the NO_X target value is 250 mg/Nm^3 (5 % O_2). To reach this level, around 50 l of NH_3 per hour are injected into the recovery boiler (this corresponds to around 8 – 9 l of NH_3/ADt). Test results and practical experience have shown that even lower values could be achieved [251, TÜV-Bayern 2009]: 185 mg NO_X/Nm^3 at 5 % O_2 at an ammonia dosage of around 80 l/h without detecting a relevant ammonia slip.

Normally, the variation of NO_X is very low and there are only small fluctuations of around 270 mg/Nm^3, e.g. during soot blowing of the superheater surfaces (see Figure 4.51). In Figure 4.51, the peak in August is caused by a failure of the measurement device. In one day during December, the ammonia dosing was interrupted so the emission without SNCR can be seen (around 370 mg/Nm^3). In April and October, three days of regular maintenance shutdown of the recovery boiler can be seen. Lower peaks occur when less concentrated liquor and more natural gas is fired.



Source: [253, Mondi Neusiedler/Ybbstaler Zellstoff 2009]

Figure 4.51: Daily mean NO_X emissions from the recovery boiler as determined by the automatic emission monitoring system during 2008

NO_X and CO are measured continuously by automatic NO_X (chemiluminescence) and CO analysers (infrared absorption). The ammonia slip is measured periodically once every three years by an external auditor (e.g. in March 2009 measurement results were 0.3 mg of NH_3/Nm^3; in 2006, 0.4 mg of NH_3/Nm^3 was determined according to ÖNORM M 6242).

The emissions of NO_X expressed as a yearly average are currently 262 mg of NO_2/Nm^3 (at 5 % O_2) which corresponds to 1.68 kg of NO_X/ADt with ammonia injection. Without ammonia injection the emissions of NO_X would be around 20 - 30 % higher.

Table 4.28 summarises the measured emission levels achieved by the use of ammonia injection (SNCR) that were reported in the emission declaration of 2008. For the ammonia slip, the competent authority set a limit value of 10 mg of NH_3/Nm^3; the measured values were always below 1 mg of NH_3/Nm^3 (measured according to VDI guideline 3496).

Table 4.28: Measured NO_X and CO emissions of an Austrian sulphite pulp mill recovery boiler (21.5 MW_{th})

	NO_X (as NO_2) without SNCR	NO_X (as NO_2) with SNCR	CO	Pulp production	Gas flow (3)	NO_X (as NO_2)	CO
Units	**mg/Nm^3**	**mg/Nm^3**	**mg/Nm^3**	**ADt/month**	**Nm^3/ADt**	**kg/ADt(2)**	**g/ADt**
Limit value (1)		**350**	**50**				
Jan	330 - 350	278	8	3 928	6 542	1.82	0.05
Feb		287	17	3 824	6 909	1.98	0.12
Mar		273	16	4 085	6 448	1.76	0.10
April		258	19	3 508	6 517	1.68	0.12
May		254	21	4 339	6 711	1.70	0.14
June		257	16	4 282	6 281	1.61	0.10
July		256	25	4 480	6 297	1.61	0.16
Aug		265	24	4 454	6 284	1.67	0.15
Sep		244	34	4 068	6 368	1.55	0.22
Oct		247	26	3 654	6 344	1.57	0.16
Nov		260	25	4 299	6 087	1.58	0.15
Dec		263	33	4 229	6 430	1.69	0.21
Yearly average value	--	**262**	**22**	**4 096**	**6 434**	**1.69**	**0.14**
Monthly average value	--	**244-287**	**8-33**	--	--	**1.55-1.98**	**0.05-0.22**
Daily average value (range)(3)	--	**200-290**	**5-45**	--	--	--	--

NB:

(1) The emission limit values and the measured values including the gas flow refer to daily means at standard conditions (0 °C, 1 013 mbar, after subtraction of the water vapour content (dry gas)). Reference O_2: 5 %. According to the Austrian Air Protection Law, 95 % of all daily means shall not exceed the established mass concentration.

(2) The specific load (kg/ADt) is calculated by multiplying the mean monthly concentration value (mg/Nm^3) by the mean flue-gas volume (Nm^3/h) and the operating hours (h) per month. The total yearly load of all 12 months (kg NO_X) is added up and then divided by the yearly pulp production (ADt). The recovery boiler operated for 8 603 hours in 2008.

(3) Standstill of the boiler, failures of the measurement device and ammonia dosing are not included.

There is another SNCR application in the two recovery boilers of the Stora Enso Nymölla sulphite pulp mill in Sweden. The mill is running the recovery boilers at high capacity. For the NO_X reduction, a 35 % solution of urea with additives (organic amines) is injected into the recovery boilers. These chemicals are easier and safer to handle but also more expensive than ammonia. Around 7 – 8 kg of urea solution/ADt are added to the recovery boilers which reduces the concentration of NO_X in the flue-gases by around 20 – 30 %. Experience had shown that adding more urea would not lead to lower values. NO_X and CO are measured continuously and reported to the mill information system. The yearly average value of NO_X in the flue-gases from the minor recovery boiler is 150 ppm (or 308 mg/Nm^3). The NO_X value from the major boiler is 115 ppm (or 236 mg/Nm^3) with the O_2 content not reported.

If no urea solution had been used, the concentrations would be estimated to be 370 – 400 mg of NO_X/Nm^3 and 287 – 308 mg of NO_X/Nm^3 respectively. That means that if the dosage of the reducing agent is stopped, the NO_X emissions increase about 20 – 30 %. The possible ammonia slip is measured periodically by external auditors. The value has always been below the detection limit.

Cross-media effects

There are no solid or liquid residues generated by the use of SNCR. A chemical as a reducing agent is needed for the reduction of NO_X. In the case of Mondi Neusiedler, in 2008 on average 3 000 kg of ammonia per month (at 25 %) were injected into the recovery boiler which adds up to 34 tonnes of NH_3/year (at 25 %) to bring the NO_X level from around 320 mg/Nm^3 down to 250 – 260 mg/Nm^3 (at 5 % O_2). This corresponds to a reduction of around 60 mg of NO_X/Nm^3.

At a daily flue-gas flow of 880 000 Nm^3/day, around 53 kg of NO_X/day or around 19 tonnes of NO_X/year are reduced. That means a ratio of ammonia input to NO_X reduced of around 1.8 is applied, or for the reduction of 1 kg of NO_X in the flue-gas 1.8 kg of NH_3 (ammonia, 25 % of which is diluted to approximately 10 – 11 %) is needed.

The efficiency of the SNCR technique is circumscribed by the unwanted 'ammonia slip' in the flue-gas which is normally limited by the air protection legislation and by the costs for the ammonia that has to be injected into the recovery boiler. In order to keep the ammonia slip as low as possible, a high NH_3:NO_X ratio is avoided. In the case of Mondi Neusiedler (ammonia reduction to a target value of 250 mg of NO_X/Nm^3), a limit value of 10 mg/Nm^3 for NH_3 slip has been set by the competent authority. During periodic measurements, no relevant NH_3 emissions have been measured, i.e. emission levels are normally below 1 mg of NH_3/Nm^3 (e.g. in March 2009, 0.3 mg of NH_3/Nm^3 was measured). Relevant ammonia slip was also not detected during test periods or special operating conditions during which for a limited period of time the NO_X emission levels were lowered from around 330 – 350 mg/Nm^3 down to 180 – 170 mg/Nm^3 by ammonia injection which corresponds to a NO_X reduction rate of about 50 %.

Technical considerations relevant to applicability
Retrofitting of existing recovery boilers may be limited due to scaling problems and associated increased cleaning and maintenance requirements. For ammonium-based mills, no application was reported but, due to specific conditions in the waste gas, SNCR is not expected to have any effect. Not applicable to sodium-based mills due to the explosion risk.

Economics
In 1994, investment costs for the SNCR equipment were EUR 250 000. In 2009, investment costs were estimated to EUR 400 000. As the process was considered innovative in 1993, the example mill in AT received around 30 % environmental subsidies for the project. Operational costs are around EUR 2 000 – 3 000 of maintenance costs per year and around EUR 5 500 per year for ammonia (1 tonne of NH_3 25 % cost around EUR 157 in 2008). With regard to the manufactured tonne of pulp, the operating costs are in the range of EUR 0.15/ADt.

Driving force for implementation
The example mill did not operate a bark boiler because only sawmill residues were used for pulping. Therefore, it was planned to burn the dewatered biosludge from the waste water treatment plant together with the concentrated spent liquor in the recovery boiler. This would have caused higher NO_X emissions. The competent authority asked the company to reduce the NO_X emissions. In 1993, the SNCR project was realised together with incineration of the dewatered biosludge in the recovery boiler. Example Mill 2 in SE is running the recovery boilers at the maximum design capacity at high temperatures. The competent authorities asked them to implement NO_X reduction measures more than 10 years ago.

Example plants
Mondi Neusiedler GmbH and Ybbstaler Zellstoff, AT, Stora Enso Nymölla, SE, and Sappi Ehingen, DE, have applied SNCR on one of the two recovery boilers.

Reference literature
[247, TÜV Süd 2009], [251, TÜV-Bayern 2009], [253, Mondi Neusiedler/Ybbstaler Zellstoff 2009].

4.3.21 ESP or multistage cyclone and multistage venturi scrubbers or multistage double inlet downstream scrubbers on the recovery boiler

Description

The recovery boiler is the major source of SO_2 and of particulate emissions of a sulphite pulp mill. Other point sources are the biomass or bark boiler, steam blocks or other combustion units operated on site (see Section 2.6). Process-related, diffuse SO_2 emissions to be considered are normally collected and introduced in the recovery boiler as combustion air (see Section 4.3.22).

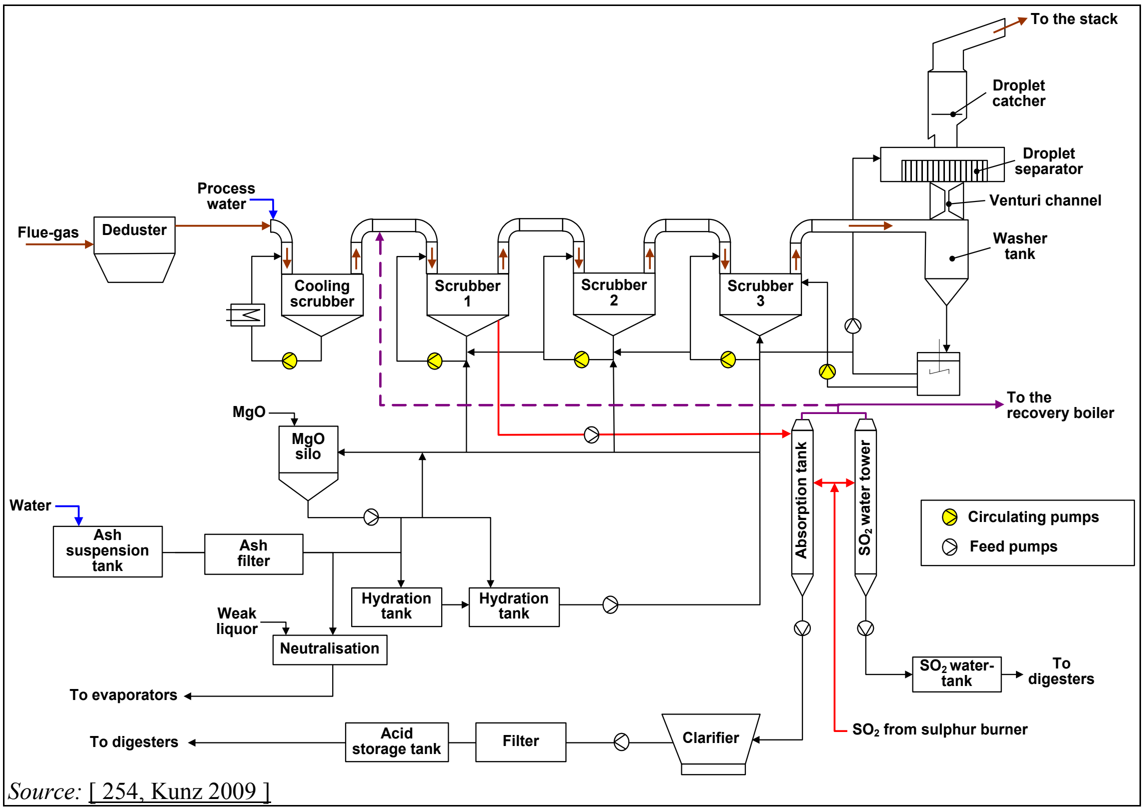
The chemicals used in the cooking plant appear in the flue-gas in the form of light MgO ash and the sulphur as SO_2. The MgO is recovered in a wet scrubber to a slurry of MgOH, which reacts with the SO_2 to form fresh cooking liquor in another scrubber. In sulphite pulp mills, the recovery plant simultaneously fulfils the purpose of flue-gas cleaning and recovery of cooking chemicals.

The separation of dust is carried out in an electrostatic precipitator or in a multistage cyclone. Normally they are dimensioned in such a way that the cleaned gas leaving the filter releases at a maximum of 50 mg of dust/Nm^3.

For the magnesium sulphite process, the dust retained in the ESP consists mainly of MgO but also to a lesser extent of Ca, Na or Ca compounds. The recovered MgO ash is suspended with water and cleaned by washing and slaking to form $Mg(OH)_2$ which is then used as an alkaline scrubbing solution in the multistage scrubbers in order to recover the sulphur component of the cooking chemicals. After the removal of dust, the flue-gas is cooled down by passing through a cooling scrubber operated with water and it then enters a flue-gas scrubber with three or more stages where the SO_2 emissions are scrubbed with this alkaline solution. The solution of $Mg(OH)_2$ as a washing media is moved counter-current to the SO_2-rich flue-gas flow and is transformed to magnesium bisulphite ($Mg(HSO_3)_2$). The solution is purged at the first scrubber with the highest SO_2 concentration. The single stages of the scrubbers are operated and controlled according to the pH value. The product of the scrubbers is the diluted acid. The SO_2-rich solution is returned to the liquor preparation where make-up SO_2 is added.

For the ammonium sulphite process, the ammonia base (NH_3) is not recovered, as it is decomposed in the combustion process in nitrogen. In this case, a 100 % fresh NH_3 solution is needed as a scrubbing agent.

In Figure 4.52 a simplified flow chart of a flue-gas desulphurisation plant is shown together with its integration in the cooking chemical preparation.



Source: [254, Kunz 2009]

Figure 4.52: Simplified flow chart of a flue-gas desulphurisation plant (multistage scrubbers and final washer) and its integration in cooking chemical preparation

Achieved environmental benefits

By the use of this technique the majority of the cooking chemicals are recovered which leads to significant savings of raw materials. The chemical recovery (in the case of the magnesium sulphite process) simultaneously reduces the dust emissions to nearly zero and the initially very SO_2-rich exhaust gas is cleaned to levels of around 100 – 300 mg SO_2/Nm^3 during normal operating conditions.

Environmental performance and operational data

Various types of scrubbers for the recovery of SO_2 are used in all sulphite mills in order to recover the chemicals from the spent cooking liquor. The recovery rate for SO_2 can be 99.4 – 99.8 % compared to the untreated emissions that leave the recovery boiler.

With regard to the emission data from the recovery boilers of sulphite pulp mills, in most mills, two different operating conditions have to be distinguished: 'normal operating conditions' and periods of 'acid operation' (flushing and cleaning of the incrustation in the scrubbers and washer). The latter refer to an operation mode where the scrubbers are cleaned to prevent incrustations of magnesium monosulphite ($MgSO_3$). Unwanted not readily soluble $MgSO_3$ is formed in pipes, tanks and washers and over time leads to scaling and incrustations if not cleaned regularly. During the 'acid mode', the SO_2-containing flue-gas is sent to the scrubber that is operated without adding the $Mg(OH_2)$ to the washing liquid that is circulated in the scrubbers. This leads to a decrease of the pH values and dissolves the magnesium monosulphite. During the cleaning cycles of the scrubber, the emissions increase as one of the scrubbers or the final washer is not operated and must be compensated for by the residual scrubbers. Common frequencies and time intervals for the acid operation mode are around 12 times a year and in total around 96 hours per year during which one scrubber or washer is not operated and the others take over the desulphurisation of the flue-gases. In total, acid operation may take about eight hours per month and a cleaning cycle may last six hours. Normally, scrubbers or washers operated with higher pH values are more often in the need of an acid flushing. For instance, a German mill reported that for the last washer, after the four-stage scrubbers, that operates with the highest pH value (sulphite stage), the maximum permitted operating time per cleaning under 'acid operation' is nine hours and should in total not exceed 365 hours per year. Other mills may also have shorter time intervals for preventive flushing of the washers. The results from the mills' reporting data are shown in Figure 4.53.

The cleaning of the flue-gas desulphurisation plant can be carried out sequentially or as a the scrubbers can be completely shut down during cleaning. The latter option leads to higher emissions so some mills had to retrofit their process, e.g. by adding an additional washer in order to guarantee that a sufficient number of scrubbers/washers are always running. Despite the preventive cleaning of the flue-gas desulphurisation plant once or twice a year, a complete maintenance or revision of the device is carried out during the yearly downtime of the plant.

In most cases, these two different operating conditions should be considered when emissions are reported as concentrations (mg SO_2/Nm^3). In contrast, the specific SO_2 load expressed as SO_2/ADt usually covers all operational modes during the year and therefore includes all operating conditions. In Germany and Austria, for example, there are different limit values for 'normal operating conditions' and 'exceptional cleaning operations'.

Variations of the described dust/SO_2 control systems are applied in all magnesium-based sulphite mills. However, different reduction efficiencies for SO_2 removal are reported. SO_2 emissions also depend on the design and operation of the flue-gas washers. Dust emissions depend as well on the design of the droplet catcher after the final washer and the type of wood used (see example 2 further below). The released sulphur dioxide emission levels are closely related to the system for recovery of spent cooking liquor (see Figure 4.30). The flue-gas from the incineration of the concentrated black liquor carries a considerable amount of SO_2 gas which depends on the sulphidity of the spent liquor. In order to recover more pure SO_2 (and not only bisulphites) and to increase the quality of the recovered raw acid, some mills have implemented a SO_2 liquefaction step for the liquefaction of the strong SO_2-containing off-gas from the digesters (two mills in DE and AT). Another, albeit more expensive, technique to recover more SO_2 from the flue-gas is the separation of magnesium monosulphite and its transformation into magnesium and liquid SO_2 in a separate furnace (one mill in AT). Also, this measure reduces the need for fresh make-up sulphur dioxide that in some cases may limit the recovery of SO_2 from the flue-gas.

To control these emissions, the proper layout and operation of all the emission control devices (multicyclone or electrostatic precipitator, multistage scrubbers) are necessary.

During normal operating conditions, 100 – 300 mg SO_2/Nm^3 is achieved as a daily average value, with a reference oxygen content of 5 %. Sulphur dioxide is measured continuously and led to the computer that registers the emission profile on-line.

During the regular flushing and cleaning of the scrubbers/washers in the 'acid operation' mode, concentrations of SO_2 in the flue-gas increase and values of up to 300 – 500 mg/Nm^3 with some higher values up to 650 mg SO_2/Nm^3 as a daily average value, and with a reference oxygen content of 5 %, can be achieved. Some mills report slightly higher SO_2 emissions especially during the cleaning mode. The time interval for the cleaning of the scrubbers is normally once or twice per month and lasts 6 – 12 hours. Dust emissions are not affected by the 'acid operation' mode.

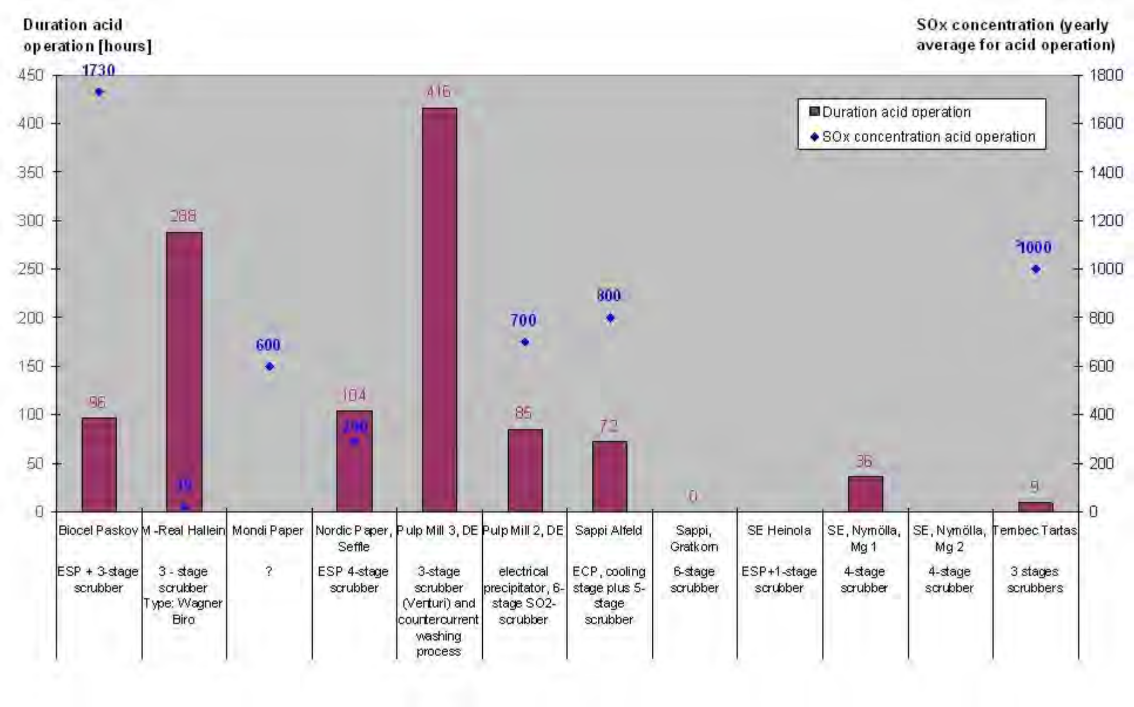


Figure 4.53: **Reported duration of acid operation**

In many mills dust emissions of 5 – 20 mg/Nm^3 as a daily average value, and with a reference oxygen content of 5 %, are achieved. In most cases, dust is measured periodically by single measurements.

Concerning dust emissions, it should be taken into account that the concentrated spent liquor is dispersed finely into the combustion chamber of the recovery boiler. There, aerosols such as oxidised Na and K compounds may be built which in some cases cannot be completely separated in the subsequent wet flue-gas treatment. Besides the formation of aerosols (particle size <1 µm) that depend on the entry of alkali metals with the wood and the combustion temperature, the charge of fresh water into the last scrubber and the efficiency of the last droplet separator before the cleaned gas enters the stack affect the dust removal efficiency of the scrubbers. At some mills, dust emissions are reported to be slightly higher, i.e. 30 mg/Nm^3, because of the higher potassium content of some wood species such as beech. The potassium content of beech is twice as high as that of spruce (1 045 mg/kg of wood versus 510 mg/kg of wood). For installations with a higher K_2O/Na_2O content in the concentrated spent liquor (e.g. when mainly beech is used), the flue-gas scrubbers using counter-current washers instead of venturi stages are more efficient for dust removal [277, Loquenz 2007].

Below, two examples of the performance of SO_2 emission control systems are given: a smaller (50 000 t/yr) sulphite pulp mill, and a recently built recovery boiler with a chemical recovery system.

Example 1: Mondi Neusiedler GmbH and Ybbstaler Zellstoff GmbH

Mondi Neusiedler, Austria, is an example of a small sulphite pulp mill manufacturing around 50 000 tonnes of bleached sulphite pulp for papermaking from softwood (84 % to 88 % ISO brightness) and around 100 000 tonnes of uncoated fine paper. It operates three-stage scrubber with very few 'acid modes' as it has shifted the maintenance of the scrubbers and pipes to the two regular shutdowns during the year. Larger mills possess one or two more flue-gas scrubbers or washers and every month operate one scrubber in a preventive acid 'maintenance mode'. Data on these small mills are presented further below.

i) Basic data

The mill uses the acid bisulphite pulping process; TCF bleaching (the bleaching sequence is EOP-P-P); the net production of pulp in 2008 was 50 000 ADt; only wood chips are used; the percentage of wood species used is 98 % spruce and 2 % fir); magnesium oxide is used as a base; the pH in the digesters is 2; the year of construction of the ESP and the scrubbers is 1987; the gas flow is 6 600 Nm^3/ADt (dry, normal operating conditions) which corresponds to 880 000 Nm^3/day; a small amount of natural gas is added to the flame to support combustion (1 500 Nm^3/day).

ii) Abatement techniques applied

The flue-gas cleaning system consists of an electrostatic precipitator and a counterflow three-stage scrubber. Three venturi-type scrubbers are installed. For the small mill, the number is considered sufficient since during acid operation the gas flow of the recovery boiler is reduced. No scrubber is operated continuously in the maintenance mode. Instead, around once a month, one venturi is cleaned by an acid solution for four to eight hours during which only two scrubbers are working at a reduced capacity of the recovery boiler. Additionally, the pulp mill has two downtimes of three or four days per year during which the scrubbers are mechanically cleaned and maintained.

iii) Achieved emissions

The mill reported emissions in 2008 during 'normal operating conditions' and during periods of 'acid operation'. The latter refer to an operational mode where the scrubbers are cleaned of incrustations ($MgSO_3$, $CaSO_4$). During this acid mode the SO_2-rich flue-gas is sent to the scrubbers that are operated without adding the $Mg(OH_2)$ to the washing liquid. The wash medium circulated in the scrubbers is only water, partly absorbing the SO_2 of the flue-gas, thus turning the conditions into acid and washing the surfaces and nozzles of the scrubber. Therefore, the emissions rise during the cleaning cycles of the scrubber. In the case of the example, the acid operation mode is not normally applied but instead usually when emission levels rise. On average, for four to eight hours once a month only two scrubbers are working and the third is cleaned by an acid solution. The limit value for SO_2 during that period is 600 mg/Nm^3. Measured values can reach emission levels of 400 – 600 mg SO_2/Nm^3 in some cases. If the measurement exceeds this limit, it is reported separately. The total number of incidents reported in 2008 were 18 short time peaks (half-hourly values). The yearly average specific SO_2 load (SO_2/ADt) covers all operational modes during the year. No changes in dust level are observed during acid operation.

Table 4.29: Atmospheric emissions at 5 % oxygen from the recovery boiler of a small Austrian sulphite pulp mill manufacturing 50 000 ADt pulp/year for papermaking

Reference periods	SO_2	Dust	Gas flow	SO_2 (as SO_2)	Dust	SO_2
	Normal operation: ESP + three scrubbers					Acid operation (0 – 8 h/month): ESP + two scrubbers
Units	mg/Nm^3	mg/Nm^3	Nm3/t	kg/t	kg/t	mg/Nm^3
Limit value (^{1})	300	40				600
Yearly average value	75	1	6 581	0.48	0.004	
Monthly average value	14 – 179	1		0.09 – 1.14	0.004	
6 months with lower values	14 – 55	1		0.09 – 0.38	0.004	
6 months with higher values	68 – 179	1-5		0.44 – 1.14	0.004	
Daily average values	14 – 300	1 – 5	6 087 – 7 275	--	--	0 – 8 hrs/month: 400 – 600

Note:
(^{1}) The emission limit values and the measured values including the gas flow refer to daily means and standard conditions (0 °C, 1 013 mbar, after subtraction of the water vapour content (dry gas)). The reference oxygen content is 5 %. According to the Austrian Air Protection Law, 95 % of all daily means shall not exceed the established mass concentration.

After the thorough maintenance of the scrubbers twice a year during the regular shutdown, SO_2 emission levels are around 15 – 20 mg/Nm^3 for several weeks. Over time the emission levels build up towards higher values. Normal values as a daily average are 20 – 100 for 10 months of the year (in 2008). The emission levels at their maximum can reach 450 mg/Nm^3 for around one or two days of operation. If this happens, a pipe or a part of the scrubbers is clogged with encrusted material which is then immediately removed. During that time only two scrubbers are in operation and therefore higher SO_2 emissions occur.

Dust emissions are not monitored continuously because they are almost completely recovered by the ESP and the three-stage scrubbers. In this mill, the wet scrubbers remove dust very efficiently down to undetectable levels.

Example 2: Lenzing AG

This is an example of the most recently built sulphite pulp recovery boilers including the associated chemical recovery plant (2007). Lenzing AG, Austria, is a pulp mill manufacturing dissolving pulp for viscose. There are other mills that reach similar performance levels. However, most of them have higher SO_2 emissions during 'acid operation mode'.

i) Basic data

The mill uses the acid bisulphite process for the manufacturing of pulp for the textile industry; the net production of pulp in 2008 was 246 411 bone dry tonnes/year or 273 790 ADt/year; the wood species used is 100 % beech; the base used is magnesium; the pH in the digesters is 1.2 – 1.5; the new recovery boiler was built in 2007; the gas flow of the new boiler is 8 200 Nm^3/ADt (dry, normal operating conditions) which corresponds to 130 900 Nm^3/h (at 5 % O_2); a small amount of natural gas and fuel oil is added to the flame to support combustion.

When assessing the specific emission data originating from the recovery boiler, it should be taken into consideration that at the site a total of three recovery boilers of different ages and types of construction are operated. They have different SO_2 removal efficiency. The oldest and specifically worst recovery boiler is operated in standby mode. The new recovery boiler has a proportion of 50 % in terms of load capacity.

ii) Abatement techniques applied

The flue-gas cleaning system for MgO and SO_2 removal consists of four technical units: 1) a dry dust separator (multistage cyclone) that separates dry MgO being used for neutralising the spent liquor from the digesters; 2) a cooling scrubber that saturates the flue-gas with water and removes further MgO, hydratising it into $Mg(OH)_2$; 3) the flue-gas that leaves the saturator enters into a counterflow four-stage venturi washer with two bisulphite and two monosulphite scrubbers (plus a cooling scrubber that cools down the incoming flue-gas); 4) the $Mg(OH)_2$ thin sludge is separated from the water in a clarifying tank and then used as washing liquid for the scrubbers.

The wet absorption system (multistage double inlet downstream scrubber) consists of a downwards pass-through double-flow bisulphite stage equipped with circulating pumps; a second upwards pass-through bisulphite stage that is followed by two (in series) connected upwards pass-through (mono)sulphite stages. The injected $Mg(OH)_2$ solution is absorbed by the flue-gas and removed by a downstream droplet catcher from which it is recirculated. The two (mono)sulphite stages are connected in series and are operated at pHs of 6.9 and 7. They transform SO_2 and $Mg(OH)_2$ into almost insoluble magnesium monosulphite ($MgSO_3$). Each venturi washer has an internal circulation of the $Mg(OH)_2$ solution. The crystal ($MgSO_3$) is transferred to the second bisulphite stage and from there to the first bisulphite stage where it is extensively transformed into $Mg(HSO_3)_2$, the unclarified raw acid.

During 'normal operating conditions' the absorber stages are operated in series. To remove the built-up incrustations from the absorbers, they are regularly cleaned in an 'acid mode'. While one of the monosulphite stages is being cleaned the recovery rate for SO_2 is temporarily reduced; the emissions of SO_2 can reach 650 mg/Nm^3. Normally the cleaning cycle lasts around 12 hours for the first and 18 hours for the second monosulphite stage and is carried out once or twice a month.

iii) Achieved emissions

The mill reported emissions in 2008 during 'normal operating conditions' and during periods of 'acid operation'. The specific SO_2 load expressed as SO_2/ADt as a yearly average value covers all operational modes during the year. The emission levels presented in Table 4.30 refer to the newest recovery boiler built in 2008 only, which has a share of 50 % in terms of thick liquor load. The SO_2 removal efficiency during 'normal operation' is around 99.8 %; for dust removal around 95 %. Sulphur dioxide emissions are measured continuously by automatic analysers and are usually between 20 – 80 mg SO_2/Nm^3 as a daily average value (5 % O_2). There are higher values during the acid flushing operational mode of around 150 – 350 mg SO_2/Nm^3 as a daily mean or reaching up to 650 mg SO_2/Nm^3 as half-hourly measured value. The higher values are determined during 1 – 2 days a month (see above). During that time, only three scrubbers are in operation.

Table 4.30: Atmospheric emissions from the recovery boiler equipped with five-stage scrubbers of a large Austrian sulphite pulp mill manufacturing 273 790 tonnes of viscose pulp/year for the textile industry

	SO_2 (as SO_2)	**Dust**	**Gas flow**	**SO_2 (as SO_2)**	**Dust**	**SO_2 (as SO_2)**	**Dust**
	Normal operation: multicyclones + four scrubbers					**Acid operation (1 – 2 days/month): cyclones + three scrubbers**	
Units	**mg/Nm^3**	**mg/Nm^3**	**kNm3/t**	**kg/ADt**	**kg/ADt**	**mg/Nm^3**	**mg/Nm^3**
Limit value (^{1})	**300**	**50**		**--**	**--**	**650**	**50**
Jan	53	22	130.3				
Feb	35	22	124.5				
Mar	31	22	131.7				
April	64	22	142.6				
May	67	22	138.6				
June	85	22	129.4				
July	45	22	121.4				
Aug	27	22	124.1				
Sep	33	22	133.5				
Oct	56	22	123.9				
Nov	59	22	133.7				
Dec	57	22	135.9				
Yearly average value	**52**	**22**	**130.9**	**0.42**	**0.18**		
Monthly average value	**27 – 85 (including all operation modes)**	**22**					
Daily average value	**20 – 80(*)**	**22**				**150 – 350**	**22**

NB:

(^{1}) The emission limit values and the measured values including the gas flow refer to daily means and standard conditions (0 °C, 1 013 mbar, after subtraction of the water vapour content (dry gas)). The reference oxygen content is 5 %. According to the Austrian Air Protection Law, all daily means shall not exceed the established mass concentration.

(*) Daily mean values refer to 'normal operating conditions' in 2008. For the acid operation mode, the daily mean values are given in the right hand column. During the 'acid operational mode' half-hourly measured emission levels may reach values of up to 650 mg SO_2/Nm^3.

Source: [267, Lenzing 2009]

The evaluation of the measured data is carried out on-line by a computer-based system. O_2, SO_2, NO_X and CO are measured on-line. Dust is measured once a year by an external laboratory. The amount of fuel is recorded and the corresponding gas flow calculated. Multiplying the gas flow determined (Nm^3/h) with the operating hours gives the loads released to air.

It should be noted that for the manufacturing of dissolving pulp, the pulp yield is lower than for paper pulp production. As a consequence, the quantity of the thick liquor generated is higher as is the specific gas flow (Nm^3/ADt). This effect has to be taken into account when comparing specific loads to air from different recovery boilers of sulphite pulp mills.

In the example mill, the total dust emissions from the recovery boiler after leaving the scrubbers are around 0.2 kg/ADt. The main reason for the higher dust emissions is that the potassium content of beech is twice as high as that of spruce (1 045 mg/kg of wood versus 510 mg/kg of wood). In the combustion chamber, gaseous K_2SO_4 is generated which, by quenching, is transformed into an aerosol in the boiler. The aerosol of potassium sulphate cannot even be removed by the five-stage wet scrubber as described above. Only a reduction of the temperature in the combustion chamber can lower the remaining dust emissions. Analysis of the particle size distribution of the released dust has shown very small particle sizes: 70 – 95 % of the dust has a particle size of 0.8 µm or <0.8 µm. Analysis of the chemical composition of the released dust showed a high proportion of K and Na and very little Mg although magnesium is used as an absorbent solution in the scrubbers. More than 50 % of the dust is sulphate; potassium has by far the largest share among the kations.

Achieved emissions of example European pulp mills that have implemented ESPs and/or multicyclones

The emissions from recovery boilers from sulphite pulp mills that have implemented dust abatement (ESPs or multicyclones) and multistage scrubbers or washers for the recovery of SO_2 and the inorganic dust from the flue-gas are summarised in Table 4.31. The data in the table are taken from filled-in questionnaires and personal communication with mill operators. The total emissions do not include the auxiliary or bark boilers. The list of mills is a selection of well performing mills where data were available or provided and is therefore not intended to be complete. Sampling and analysis were performed according to the quality assurance measures that apply in the given countries. Further details on monitoring can be found in Section 2.2.2.2. The emissions of the gaseous components were determined with standardised measurement methods, i.e. with officially approved measurement instruments. It can be concluded that in some cases the number of stages of the desulphurisation plant has less influence on the emission level than the design of the scrubbers (inner and outer circle, upwards/downwards flowthrough, droplet catchers) and the operation (pH, flow speed, concentration of wash solution, actual load compared to maximum design capacity) and maintenance of the absorber stages (cleaning sequences and modes). Efficient systems guarantee a close contact between absorbent solution and exhaust gas flow. Relatively short time intervals for the 'cleaning mode' of a scrubber may lead to slightly higher SO_2 emissions and vice versa.

Table 4.31: Examples of emissions to air from recovery boilers of some pulp mills in Europe, excluding emissions from auxiliary boilers (reference year: 2008)

Mills	Dust (1) (mg/Nm^3)	Daily average SO_2 (2) range (mg/Nm^3)		Yearly average SO_2 (3) (mg/Nm^3)	SO_2 from recovery boilers (4) (kg SO_2-S/ADt)	Type of desulphurisation: number of stages, type (venturi scrubber/washer)
		Normal operation	Cleaning mode			
# 2, DE	22	107	500/1 000	144	0.56	ESP+5-stage scrubber
# 2, DE	4	No data		131	0.77	ESP+5-stage scrubber
# 1, AT	No data	15 – 80	200 – 300	No data	0.31	ESP+3-stage scrubbers
# 2, AT	1	15 – 100	200 – 300	75	0.48	ESP+3-stage scrubbers
# 3, AT	22	20 – 80	150 – 350	52	0.21	Multicyclone, wet filter+4-stage scrubbers
# 1, SE	0	No data		No data	0.36	ESP+6-stage scrubber
# 1, PT	27	No data		16	0.1	ESP+5-stage scrubber
# 1, CZ	10-13	13 – 329	No data	156	0.56	ESP+3 venturi washers

NB:
(1) Dust emissions are measured periodically. Data refer to the average over the sampling period (e.g. 6 – 8 hours); the range of the measured values is given where available. The reference oxygen content is 5 – 6 %.
(2) Data refer to normal operating conditions and exclude failure of measurements or equipment. If applicable, data are given separately for normal operation and the 'acid operation mode' that normally occurs around once per month to clean the washers.
(3) Yearly average value from continuous measurements; the reference oxygen content is 5 – 6 %.
(4) Calculated from flue-gas flow, days of operation, concentration and net production (ADt). Yearly average specific load values refer to SO_2-S and not to SO_2.
Source: [236, COM 2009]

Cross-media effects

No relevant negative cross-media effects are to be expected. In the case of the magnesium sulphite process, the contaminants of the flue-gas are recovered and reused as cooking chemicals. The separated fly ash (mainly MgO and to a minor extent Na_2O, K_2O and CaO and their sulphates and chlorides, silicates and ferrous compounds) is suspended in water, hydrolysed and the generated $Mg(OH)_2$ is recovered from the bottom of the hydration tanks. The overflow contains mainly inorganic compounds and is sent to the waste water treatment plant.

Technical considerations relevant to applicability
The measures for SO_2 emission reduction can be considered a process-integrated technique because the liquids used in the scrubbers ($Mg(OH)_2$) and the washed-off SO_2 are reused in the process as a cooking chemical. The technique is applicable to both new and existing mills.

Economics
No data available.

Driving force for implementation
The recovery of SO_2 from the incineration of spent liquor is essential for the preparation of cooking liquor and carried out for both economic and environmental reasons. However, better performing systems are usually implemented for further reduction of the acidification potential of SO_2. Better performing systems are characterised by an additional scrubber stage for SO_2 absorption.

Example plants
Numerous plants in Europe use similar systems.

Reference literature
[236, COM 2009], [267, Lenzing 2009] [SEPA-report 4008, 1992], [data from site visits 2009].

4.3.22 Collection of odorous gases and diffuse process SO_2 emissions and combustion in the recovery boiler or washing in scrubbers

Description
Aside from the recovery boiler and the bark boiler, there are other relevant potential releases of SO_2 generated in the process: fugitive releases, i.e. not channelled gas from the acid liquor production, digesters, diffusers or blow tanks, contain high SO_2 concentrations. Lower SO_2 concentrations can be released from the brown stock washing. The higher the concentration of SO_2 in the cooking liquor, the higher the potential fugitive emissions from the processes. For example, the gases withdrawn from the cooking plant (see Figure 4.54) contain a significant percentage of the sulphur dioxide charged to the digester as a cooking chemical. They are usually collected and recovered in absorption tanks with different pressure levels both for economic and environmental reasons. SO_2 releases from washing and screening operations and from the vents of some of the steps of the evaporators can also be recovered by collecting the gases and introducing them in the recovery boiler as combustion air. The sulphur dioxide is then recovered from the exhaust gas of the recovery boiler by counter-current multistage scrubbers and reused as a cooking chemical (see Figure 4.54). The overflow can be sent to a one- or two-stage alkaline scrubber (NaOH) which is designed as a kind of back-up system that can be charged with the SO_2-containing exhaust gas in case of failures of the recovery boiler. This gas treatment is not an option for pulp mills which use calcium as a base and do not operate a recovery unit but produce products from all of the spent sulphite liquor. Measures to control the diffuse process SO_2 emissions include recovery and reuse of SO_2 gas from stripping of the SSL after evaporation as a cooking chemical. Some minor quantities of SO_2 (large volumes, low concentration) go to the scrubber system(s). This means that in the case of a calcium mill with a biorefinery concept, the diffuse emissions from the digester section and the ethanol plant should be at the same level as the emissions from a mill with a soluble base and a recovery system.

Odorous gases arise from the same processes as the SO_2-containing gases that are simultaneously released from these processes. Many mills have installed a system for the collection of various vent gases from different processes. The majority of these diffuse odorous gases are collected by the weak gas collection system and used as combustion air in the recovery boiler.

Odorous gases arise in the cooking plant, the evaporation plant, at diffusers and in the brown stock washing. The reduction of odorous gases is carried out mainly by collecting the most relevant fugitive gases and leading them to combustion in the recovery boiler where the exhaust gases are treated by multistage flue-gas scrubbers. Other measures are water seals in the back-pressure pipe from digesters or flue-gas scrubbers for the fugitive emissions from the digesters. In Figure 4.54, the SO_2 circuit in a sulphite mill and the major sources of the diffuse SO_2 emissions that are collected and burnt in the recovery boiler are shown (Figure 4.54 does not cover the situation of mills that use calcium as a base and do not operate a recovery boiler; these mills apply different techniques for reducing SO_2-containing diffuse gases).

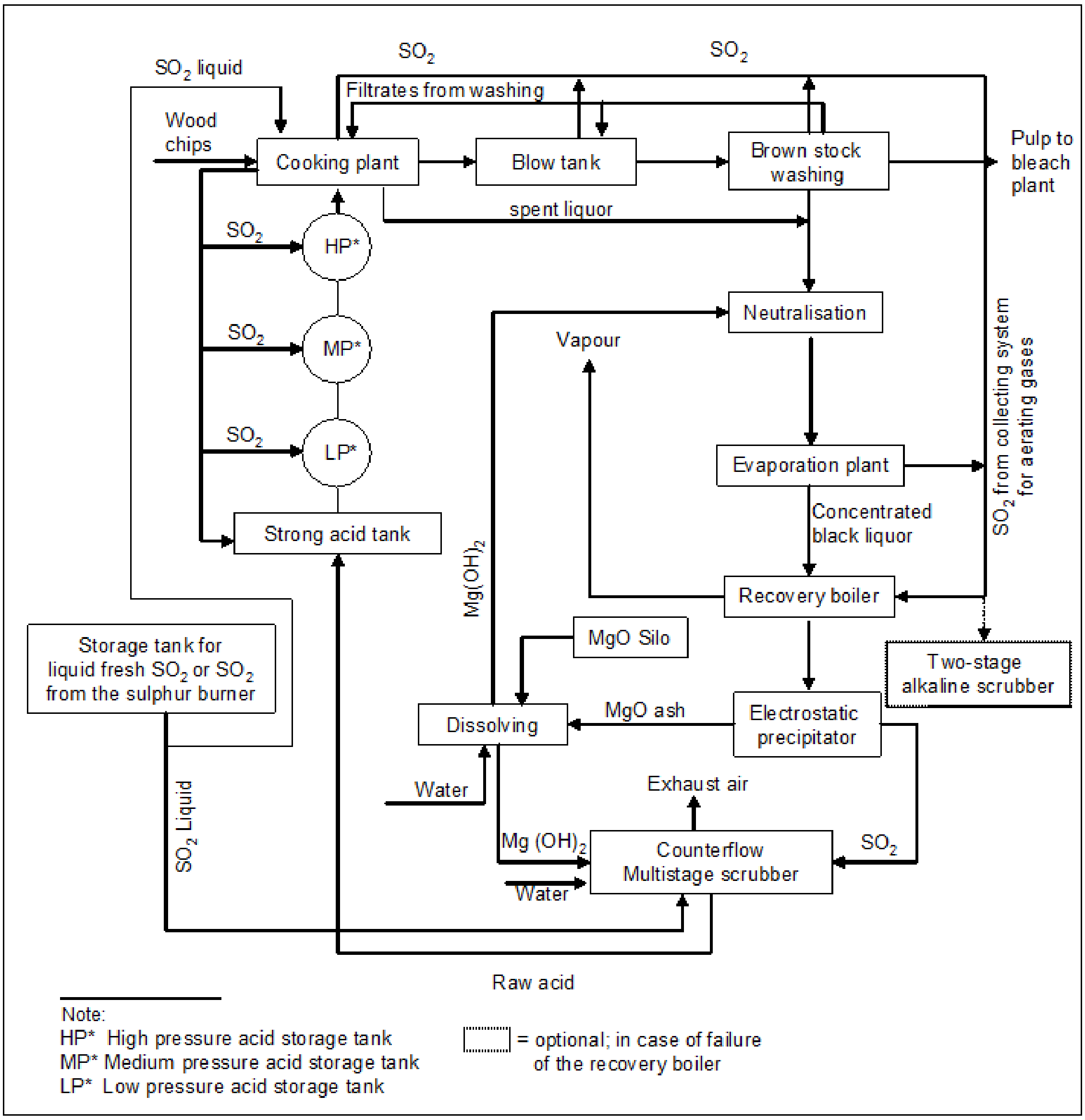


Figure 4.54: SO_2 circuit in a sulphite mill and major sources of the diffuse SO_2 emissions that are collected and burnt in the recovery boiler

Achieved environmental benefits

The collection of vent gases from the cooking plant, brown stock washing and the evaporation departments leads to a significant reduction of SO_2 emissions which otherwise would be released to the environment. It also allows for savings in terms of the consumption of SO_2 make-up chemicals.

Environmental performance and operational data
Well designed and operated gas collection systems for the capture of SO_2-containing process gases from all relevant process stages should allow for recovering almost all of the fugitive SO_2 emissions of the mill. The vacuum devices and pipes should be monitored automatically so that possible failures of the gas collection system are immediately detected and reported to the control room staff. There are mills where the back-up system operates in a stand-by mode so that the start-up phase is very short. If the gas collection system is operated in such a way, no significant measurable diffuse SO_2 emissions are released to the environment.

Cross-media effects
There are no significant negative cross-media effects associated with this technique. The energy needed for the vacuum devices of the gas collection system is compensated for by chemical savings (fresh SO_2).

Technical considerations relevant to applicability
The technique can be applied to all plants, both new and existing, although in retrospect the implementation of the technique is technically and economically more demanding (requiring more complicated installation of vent gas equipment and change of the pipes).

Economics
No information provided.

Driving force for implementation
National legislation regarding emissions to air and protection of workers' health (maximum allowable workplace concentration) is the major driving force for the implementation of this technique. SO_2-containing exhaust gases from the process are usually recovered both for economic (SO_2 is a cooking chemical) and environmental reasons.

Example plants
All magnesium-based sulphite pulp mills in Germany and Austria.

Reference literature
Not provided.

4.3.23 Measures to prevent uncontrolled operating conditions and to reduce the consequences of accidents

As an example of how to prevent uncontrolled operating conditions in sulphite pulp mills, the security measures for SO_2 supply and storage are described in this section (see also Section 4.1.6).

Description
In order to compensate for losses, make-up sulphur dioxide is necessary in the chemical circuit of a sulphite pulp plant. This demand is generally satisfied by the supply of SO_2 liquid. In general, it is stored in adequate storage tanks. The whole pulp mill area where liquid SO_2 is stored, handled and used (covering installations for refilling, storage, and in some cases also liquefaction of sulphur dioxide and including the piping for the SO_2 liquid) is investigated as part of a security analysis, which is updated regularly when changes have been made. For further areas of the mill in which SO_2 is used, a safety investigation is carried out (e.g. installation for the treatment of odorous gases, digester house, container field and exhaust gas led to the desulphurisation plant). Possible risks of the transport by train of liquid SO_2 are checked in a security control as well. The public is reported of the dangers of sulphur dioxide and the right behaviour during the uncontrolled operation of the plant.

The following technical equipment and measures belong to risk-reduced and responsible SO_2 supply, storage, handling and use:

- double-walled hosepipes or fixed SO_2 pipes;
- secure electricity supply;
- use of automatic SO_2 analysers;
- environmentally sound treatment of SO_2 in case of a failure of the normal operation (suction and treatment or reserve storage).

Besides these measures, the following organisational activities can be implemented:

- regular checking and maintenance of all the technical units where liquid SO_2 is stored, handled and used;
- alarm plan including reasonable measures to be taken in case of uncontrolled development;
- qualified staff in charge of major accidents;
- training of employees;
- information to the public.

Alternatively to the use of liquid SO_2, elemental sulphur can be used. In this case, elemental sulphur is incinerated in a sulphur burner, the released heat recovered in a small heat recovery boiler and the SO_2 extracted in absorption towers (see Section 4.1.6). This also prevents all possible risks of the handling of concentrated liquid SO_2.

Achieved environmental benefits
An immediate limitation of emissions is not going to be achieved with these measures. The probability of a major accident as well as the effects of the uncontrolled operation of the plant are however limited considerably.

Environmental performance and operational data
The described security system for SO_2 supply and storage is for instance applied at the Sappi Fine Paper mills in Alfeld and Ehingen (DE) with success.

Cross-media effects
No cross-media effects are expected.

Technical considerations relevant to applicability
Applicable to both new and existing mills.

Economics
No data available.

Driving force for implementation
The intention to operate the pulp mill with less risk to the environment and the adjacent neighbourhood is the driving force for the implementation of this technique.

Example plants
Numerous plants in Europe use similar security systems.

Reference literature
Not available.

4.3.24 Reduction of energy consumption (energy efficiency)

With regard to energy efficiency, useful information can be found in the Reference Document on Best Available Techniques for Energy Efficiency (ENE) [268, COM 2009]. The measures for energy savings are briefly listed below, distinguishing the consumption of heat or steam from the use of electrical energy.

Description

In order to reduce the consumption of fresh steam and electrical power, and to increase the generation of steam and electrical power internally, a number of measures are available.

I. Measures for reducing heat losses and for low heat consumption:

i. high dry solids content of bark
ii. high efficiency steam boilers, e.g. low flue-gas temperatures
iii. effective secondary heating systems, e.g. hot water about 85 °C
iv. well closed-up water system
v. relatively well closed-up bleaching plant
vi. high pulp concentration (MC or HC technique)
vii. use of secondary heat to heat buildings
viii. good process control
ix. energy management system
x. optimise integrated heat exchanger network.

II. Measures for low consumption of electric power:

i. as high a pulp consistency as possible in screening and cleaning
ii. speed control of various large motors
iii. efficient vacuum pumps
iv. proper sizing of pipes, pumps and fans
v. optimised tank levels.

III. Measures for a high generation of electric power:

i. high boiler pressure
ii. outlet steam pressure in the back-pressure turbine as low as is technically feasible
iii. condensing turbine for power production from excess steam
iv. high turbine efficiency
v. preheating of air and fuel charged to boilers.

The effect of these energy-saving measures can often not be easily shown in the form of energy consumption values because improvements depend on the situation of the mill before the measures were implemented.

Achieved environmental benefits

The energy-saving techniques reduce the thermal and electrical energy consumption. They save resources and reduce the indirect emissions and waste that are associated with energy generation. The less energy is used, the less fossil or other fuels are used and the less emissions to air, including carbon dioxide, are generated.

Environmental performance and operational data

When applying the energy-saving measures mentioned before, the indicative energy consumption levels can be found in Table 4.32.

Table 4.32: Indicative energy consumption levels for gross process heat and power for different types of sulphite pulp mills

Type of sulphite pulp mill	Indicative consumption level for gross process heat in kWh/ADt	Indicative consumption level for electricity in kWh/ADt	Remarks
Production of bleached sulphite or magnefite paper grade pulp (pumpable pulp)	2 100 – 2 400	400 – 700	Levels refer to manufacturing of pumpable pulp; pulp drying would additionally consume approx. 780 – 840 kWh/ADt heat and 100 kWh/ADt power
Production of bleached sulphite paper grade pulp (market pulp)	2 900 – 3 200	500 – 800	Levels refer to air dry pulp, i.e. include pulp dryer; if steam-consuming processes for by-products are included, energy consumption may increase accordingly
Production of bleached sulphite pulp for viscose	3 200 – 3 500	700 – 800	Levels refer to air dry pulp (including dryers) and include an ozone bleaching stage

The following system boundaries were considered for the indicative energy consumption levels given in Table 4.32 above:

(1) The energy consumption levels refer to entire mills' net production and include pumps, agitators and compressed air. Peripheral subsystems for raw and waste water, sludge and rejects such as dissolved air flotation, reject screw presses or sludge presses, and waste water treatment are also covered.
(2) The figures represent the gross energy consumption and do not take into consideration the fact that most of the mills produce a significant proportion of the energy themselves by incinerating part or all of their spent liquor. Several of the mills also produce steam from burning bark, sludge etc., which is also not taken into account for gross energy.
(3) The ranges include all process units related to sulphite pulping, starting with the wood yard and ending either at the storage tank where the pumpable pulp (ready for use) is stored (for integrated mills) or after the pulp dryer (for market pulp).
(4) The figures for power consumption do not consider the primary energy input of fuels for the generation of power but represent the process heat and power used.
(5) For heat, the consumption values refer to the thermal capacity of the steam used.

Cross-media effects
No negative cross-media effects have been observed.

Technical considerations relevant to applicability
Applicable, in principle, to all sulphite pulp mills.

Economics
In 2008, electrical energy costs typically accounted for around 15 % of the total costs for pulp production. Fossil fuels account for around 11 % of the total costs. Therefore, energy savings improve the competiveness of mills.

Driving force for implementation
Energy use is one of the key cost factors for all pulp mills. Economic requirements call for seeking cost savings where the return on investment allows.

Example plants and reference literature
Many sulphite pulp mills in Europe.

4.3.25 Techniques for noise reduction

See Section 2.9.13.

4.4 Emerging techniques

Directly or indirectly, sulphite pulp mills base their activities on renewable forest raw materials. Development work to minimise the environmental impact of the mills goes in two different directions:

1. converting by-products to energy in the form of electricity, steam and district heating;
2. development of the biorefinery technology: wood, water, electricity and other raw materials are delivered to the pulp mill and, besides the pulp, the mill could deliver other products that can replace oil and oil-based products, directly or indirectly.

For the global forest industry, moving gradually away from fossil fuels is an economic necessity due to the high energy costs for the industry in recent years. Biorefineries are seen as a very promising route to meeting sustainability and environmental preservation targets. The biorefinery concept has the potential to provide maximum economic and environmental returns by efficiently utilising all components of the wood. However, for some of the concepts, the relatively high associated emissions to water remain an unsolved challenge.

Converting sulphite mills to biorefineries for the combined production of biofuel, biomaterials, biochemicals, proteins and bioenergy has a promising long-term potential, and also in the event that all the cellulose is converted to chemicals and no cellulose is supplied from the mill. However, substantial development of processes, products and markets is needed. A few initiatives in this direction have already been started in Europe.

5 MECHANICAL PULPING AND CHEMIMECHANICAL PULPING

In mechanical pulping the wood fibres are separated from one another by mechanical energy applied to the wood matrix causing the bonds between the fibres to break gradually and fibre bundles, single fibres and fibre fragments to be released. It is the mixture of fibres and fibre fragments that gives mechanical pulp its favourable printing properties. In mechanical pulping, the objective is to maintain the main part of the lignin in order to achieve a high yield with acceptable strength properties and brightness. Mechanical pulps have a low resistance to ageing which results in a tendency to discolour.

The main processes and techniques are the production of groundwood pulp (GW), pressure groundwood pulp (PGW), thermomechanical pulp (TMP), chemimechanical pulp (CMP) or chemithermomechanical pulp (CTMP). The main pulping processes, raw materials, yields on wood and end uses of pulps are summarised in Table 5.1.

Table 5.1: Main pulping processes, raw materials, yields and end uses of mechanical pulps

Pulping process	Raw materials	Yield on wood	Typical end uses
GW	Spruce and fir (softwood)	95 – 98.5 %	Printing & writing papers and newsprint
TMP	Spruce and fir (softwood)	93 – 97.5 %	Printing & writing papers and newsprint
CMP	Spruce, but also aspen and beech, NaOH, Na_2SO_3 and H_2O_2	80 – 90 %	Printing & writing papers, tissue and packaging boards
CTMP	Spruce, but also aspen and beech, NaOH, Na_2SO_3 and H_2O_2	90 – 94 %	Printing & writing papers, tissue and packaging boards

Figure 5.1 gives an overview of the mains steps in mechanical pulping.

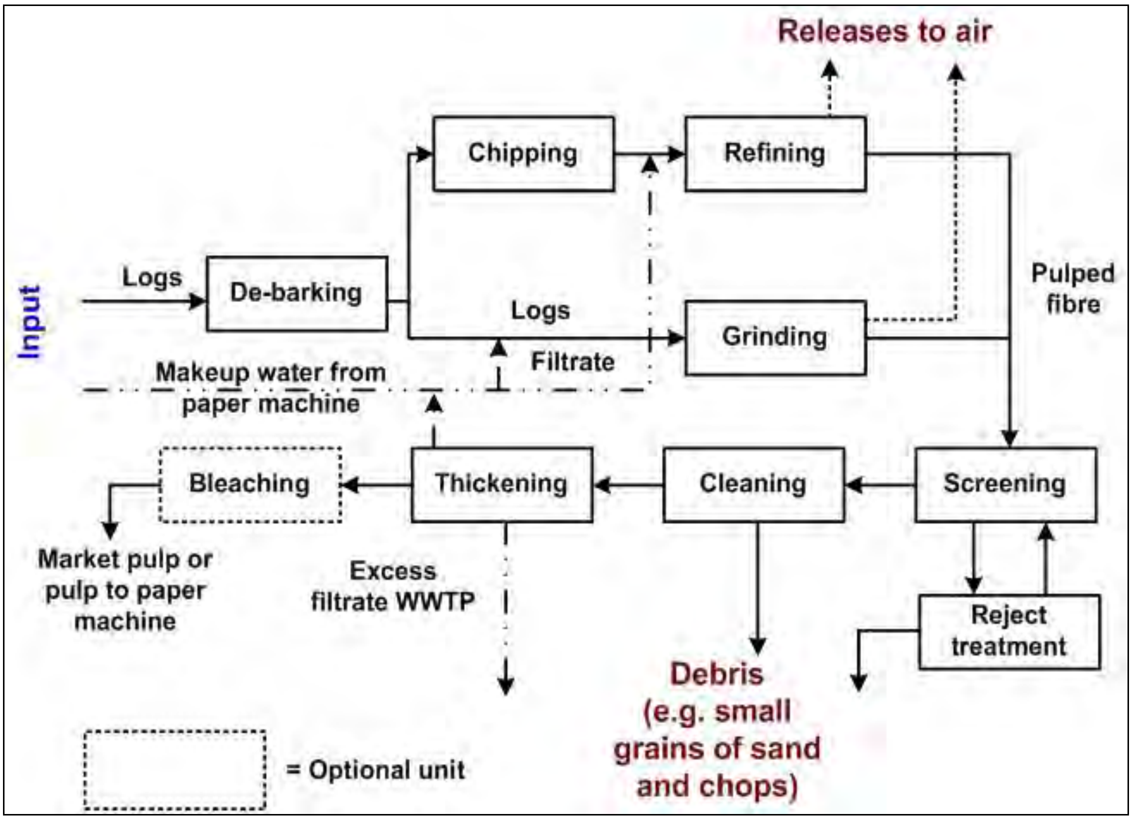


Figure 5.1: **Main steps in mechanical pulping**

There are two main processes used for the manufacturing of mechanical pulping. In GW pulping or in PGW pulping, logs are pressed against a rotating grinder stone with the simultaneous addition of water. Refiner mechanical pulps (RMP), like those from TMP and CTMP are produced by defibrating wood chips between metal refiner discs. The elements causing the mechanical action – grits on a pulp stone in the grinder and bar edges on a steel disc in the refiner – will give the resulting pulps a typical blend of fibres and fibre fragments. Groundwood pulp has a higher proportion of fine material and damaged fibres, giving the pulp good optical and paper-surface properties. The more gentle the treatment in the refiners, the higher the yield of the intact long fibres that are produced, which gives the pulp higher strength, which is valuable in furnishes for products with a high requirement for runnability.

The characteristics and the usability of the pulp can be affected by increasing the residence time, the processing temperature and, in the case of refining, by the chemical treatment of the chips. Higher grinding temperature or pulp quality requirements (e.g. requirement for long fibres) tend to increase energy consumption. Chemical treatment will increase the pollutant level because of the lower pulping yield. Its impact on energy consumption will depend on the wood species, whether it is softwood or hardwood and the chosen chemical system. The CTMP process, in which the wood is presoftened with chemicals, is generally considered to be a mechanical pulping technique since the chemicals principally soften the lignin prior to the mechanical stage rather than fully dissolve it out as in true chemical pulping processes.

Most mechanical pulping is integrated with paper manufacture. Mechanical pulp is typically included in a paper furnish to increase the opacity, the printability and, for certain products (e.g. graphic papers or board), the stiffness and the bulk of the paper product.

5.1 Applied processes and techniques

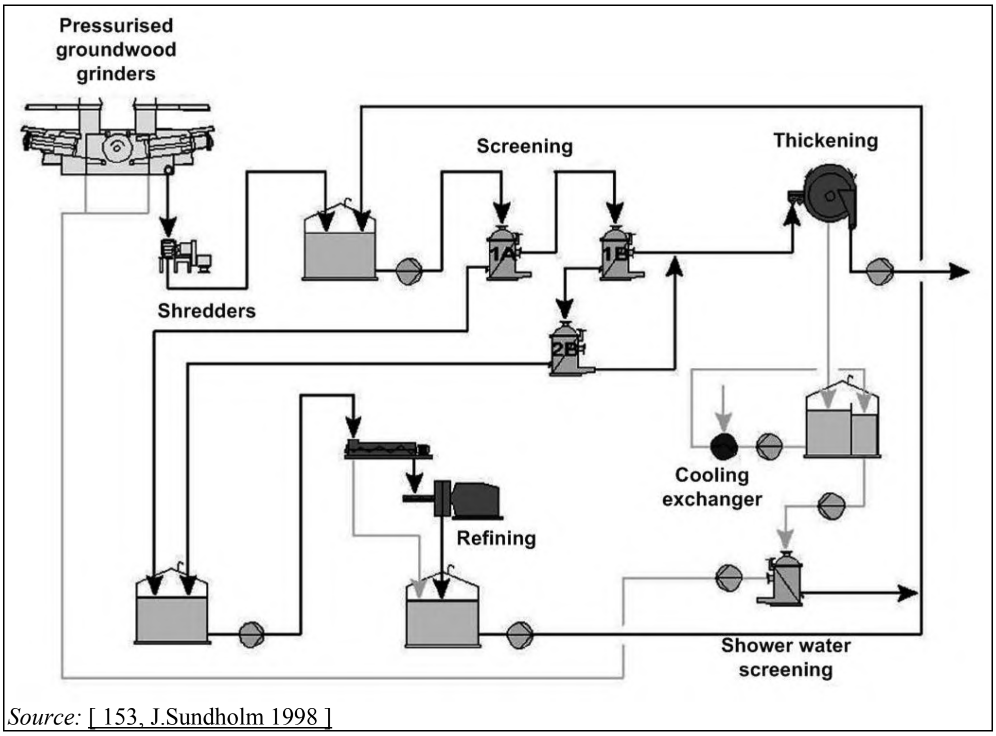
5.1.1 Wood handling

The logs required for the groundwood process are obtained by thinning out forests and are usually 8 – 30 cm in diameter. If the wood for mechanical pulping is stored, drying should be prevented, e.g. through storage in water or the sprinkling of log piles. This may require water collection systems in the wood yard in order to avoid the discharge of organic substances collectively characterised as COD and toxicity. The bark has to be removed before the logs are processed. In the debarking of pulpwood, debarking usually takes place in drums through the impact of friction forces between rolling logs. Water is often used in debarking for de-icing and washing the wood on the outlet conveyor of the debarking drum (see Section 2.3.1).

5.1.2 Groundwood pulping

Groundwood pulping consists of a fibre line, reject handling and auxiliary systems which include the storage of chemicals (see Section 2.3.2) and auxiliary steam and power generation (see Section 2.6).

The main unit processes of the manufacturing of groundwood pulp are shown in the flow scheme of Figure 5.2, the pressure groundwood (PGW) process in this case. Groundwood pulp mills are, in practice, always integrated with a paper mill and therefore the pulp is normally not dried with a drying machine.



Source: [153, J.Sundholm 1998]

Figure 5.2: **Flow scheme for a pressure groundwood process mill**

5.1.2.1 Grinding

The initial defibration takes place in grinders by forcing logs against special rotating grinding stones with the wood fibres parallel to the axis of the stones, producing a pulp at around 2 % consistency. The grinder stones used are, as a rule, of the ceramic-bound type and have to be resharpened periodically.

Nearly all electrical energy put into the grinding process is transformed into heat. As the applied grinding energy turns into heat, the wood is warmed and in the presence of enough water lignin bonds are softened, the fibres are released from the grinded wood surface and the wood disintegrates into single fibres. The energy applied corresponds to product quality (strength, opacity, etc.). Grinding stones are cooled with shower water which is also used for the disintegration of fibres and transportation to the next process stages. Therefore, for this process, the availability of water is of primary importance (heat dissipation and friction reduction of the fibres).

The specific energy requirement (kWh/t) for groundwood production is an important process parameter, e.g. an increase in the specific energy requirement is always linked with better strength properties, but also to a lower drainage capacity (freeness).

The superior strength properties of refiner mechanical pulps, especially of TMP, forced further development of the conventional grinding process for competitiveness reasons. The PGW process was developed where the grinding process takes place at overpressure (up to around 3 bar). This allows the process to be operated with white water temperatures of 95 ºC and grinder pit temperatures of 125 ºC. The more intensive softening of lignin associated with these temperatures results in improved groundwood qualities (higher strength) but the technical and financial requirements are considerably higher. Subsequently low-pressure steam is generated when the pulp is depressurised. The recovered low-pressure steam is mainly used for the production of warm process water. Another, relatively inexpensive, method to improve the quality of groundwood is the thermogrinding process. In this process, the heat losses which result from evaporation in the grinding zone are reduced and the process temperature is optimised by a water pond 200 – 500 mm deep, within which the wood logs' passage over the stone surface and the grinder can be controlled closer to optimal defibration conditions.

5.1.3 Refiner mechanical pulps

The objective of the refiner process is the same as that of groundwood manufacturing (see Section 5.1.2), i.e. the softening of lignin bonds and fibrillation of the wood fibres.

In refiner mechanical pulping, chips are ground between steel discs with bar patterns in a refiner. Depending on the required pulp quality, the refining can be repeated in a second-stage and sometimes even a third-stage refiner. The forces from the impact of the bars cause the chips to break down into fibre bundles, individual fibres and fibre fragments. With the progressing treatment, the impact also modifies the walls of the individual fibres. Most of the energy applied (friction work) transforms into heat, which flashes part of the moisture in the chips. To prevent the wood from burning in the refining zone, cooling (dilution) water has to be added. The refiners normally operate at a high discharge consistency (25 – 50 %). The large quantity of steam released in the refining process is normally captured in a heat recovery system for further use.

In the original RMP process, which is hardly used today, chips were refined at atmospheric pressure. Because of the low temperature, the process produced a high amount of damaged fibres but the optical properties of the RMP were relatively good. To improve the pulp quality, process modifications aimed at increased softness of the wood in the refining zone have been applied. These include the preheating of chips (TRMP) or pressurisation of the refiner (PRMP). These processes produce pulps of a slightly higher strength and reduced shive level at almost unchanged optical properties.

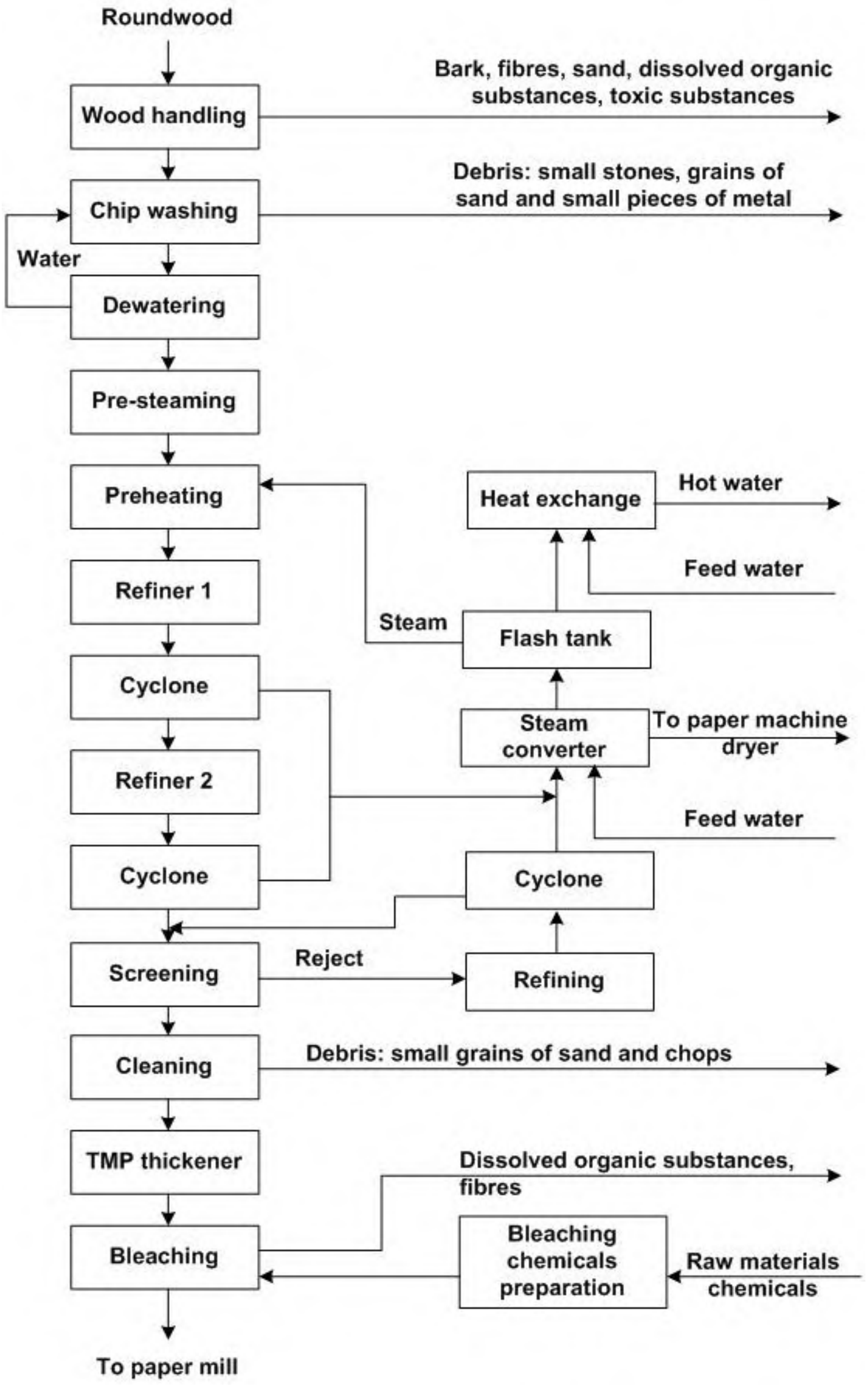
A more dramatic strength improvement and shive reduction is gained in the TMP process (see Section 5.1.4), where the chips are heated under pressurised conditions and the refining is also pressurised.

Mild chemical pretreatment of the chips also enhances the softening of the wood and improves the properties of pulp produced by refining at atmospheric pressure (CRMP) or pressurised refining (CTMP, see Section 5.1.5).

With stronger chemical treatment and refining at atmospheric pressure, pulps with high strength properties can be produced from both softwood and hardwood. These mechanical pulps (CMP) are comparable to semi-chemical pulps.

5.1.4 Thermomechanical pulping (TMP)

Thermomechanical pulping consists of a fibre line and auxiliary systems. The latter include reject handling, storage of some chemicals (see Section 2.3.2) and heat recovery (see Section 5.3.9). The main unit processes of manufacturing of TMP are shown in Figure 5.3.



Source: [131, SEPA report 1997]

Figure 5.3: Schematic of the TMP process and emissions

In this section only the TMP process itself is described in more detail, i.e. the main unit processes that have to be distinguished from groundwood pulping from an environmental point of view. For screening and cleaning, reject handling, thickening and bleaching of mechanical pulps, the reader is referred to the corresponding paragraphs of Sections 5.1.6 and 5.1.7.

In the TMP process, the screened and washed wood chips are subjected to thermal pretreatment, and the disintegration and defibration process is carried out in a series of disc refiners at overpressure.

Wood can be delivered as wood chips from sawmills or as groundwood. Sawmills and other off-site chips only require screening and storage in wood handling. If barked roundwood is used as raw material, the wood is first debarked and then chipped. Chips for mechanical pulping must not contain stones, sand, scrap metal or other hard contraries that may cause wear or damage to the refiner plates. In all chip-refining processes, the chips are therefore washed to remove contraries before refining. This results in a solid waste from the chip washer containing small stones, grains of sand and small pieces of metal. A small amount of effluent is occasionally taken out as an overflow.

After chipping and washing, the raw material is preheated with steam and then refined either in a single stage at an elevated temperature and pressure or in a two-stage refining system in which the first stage is followed by a second refining stage under pressure or at atmospheric pressure. The treatment of screening rejects is usually carried out in the reject refiner, in some cases in the second stage refiner.

A large share of the comparatively high amount of electric energy required in refiner mechanical pulping turns into heat and self-pressurises the process by steam generated from wood moisture and dilution water in the refiners. Because of the pressurised conditions (pressures of up to 6 bar), a significant amount of energy can be recovered for use, e. g. in paper or pulp drying. The energy of the generated steam may also be recovered as hot water. After refining, the pulp is discharged and diluted, screened and cleaned. After screening follows dewatering and storage in a large pulp tower at 3 % to 10 % consistency. The application of more mechanical energy instead of chemical dissolution results in more pronounced fibre fragmentation and the formation of fine material. For quality reasons, only fresh wood is accepted as raw material. If the wood for mechanical pulping is stored, drying should be prevented, e. g. through storage in water or the sprinkling of log piles. This may require water collection systems in the wood yard in order to avoid the discharge of organic substances collectively characterised as COD and toxicity. The use of chips makes refiner-based pulping somewhat more versatile with regard to the supply of the raw material.

Since the wood loss during TMP manufacturing is very low and most of the wood material is converted into pulp, the heat value of the waste water in a TMP mill is too low to be recovered in the same way as in a chemical pulp mill (black liquor). The organic substances of the wood that are dissolved in water are discharged from the process after biological effluent treatment, either from the mechanical pulp plant or from the paper machines.

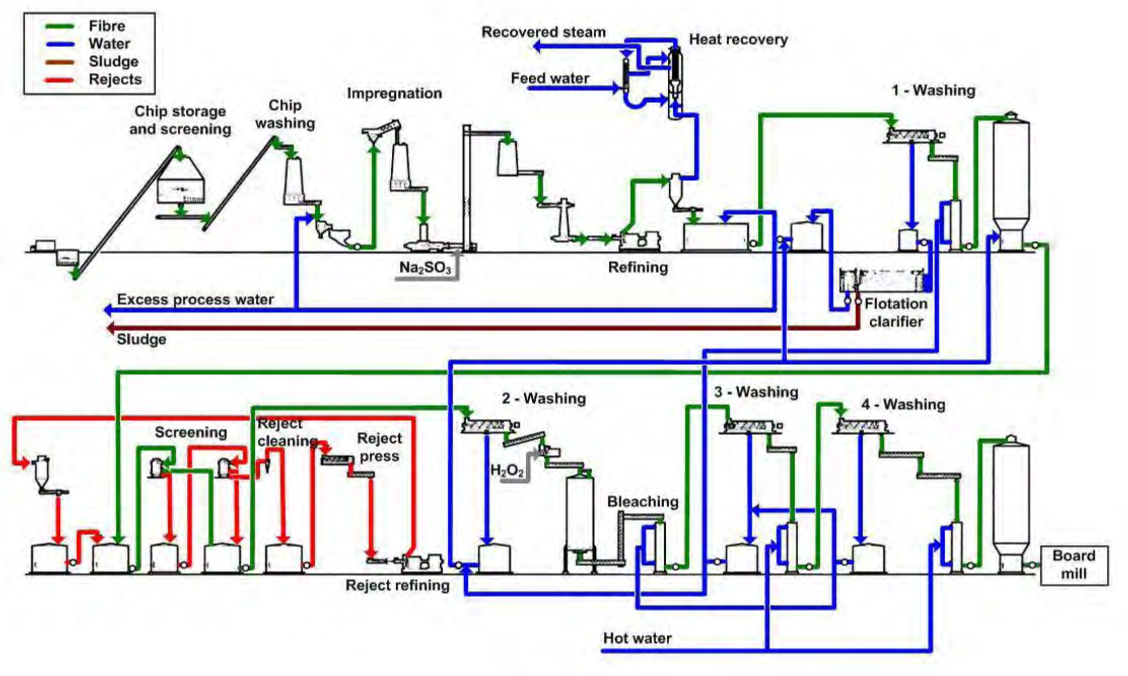
TMP is nearly almost always produced in connection with a paper mill due to the possibility to reuse the heat from refiners for the production of steam and better energy efficiency. Only one mill produces market TMP and uses pulp dryers.

5.1.5 Chemithermomechanical and chemimechanical pulping

For the production of CTMP, the TMP plant is equipped with a unit for the impregnation of the wood chips with chemicals (see Figure 5.4). Softwood chips are usually impregnated with a weak alkali sodium sulphite solution while for hardwood a stronger alkaline impregnation solution is used. The mild chemical pretreatment of the chips may enhance the softening of the wood and makes it possible to manufacture pulp with different characteristics compared to normal RMP and TMP by refining at atmospheric pressure (CRMP) or pressurised refining (CTMP). The latter combines the TMP process with the sulphonation of the wood chips. Chemical pretreatment reduces the yield by dissolving some organic wood material, in particular resin compounds. Different kinds of treatment are used for different wood species and the properties of the CTMP can be varied to a large extent by changing the amount and the nature of the chemicals. Often CRMP and CTMP are used to obtain desired pulp properties (low odour, stiffness, absorption, etc.) or when species other than spruce/fir are to be processed. The use of alkaline peroxide solutions for the pretreatment of the chips, mainly for hardwood bleached CTMP, allows the application of caustic in a wide range and, depending on the caustic charge applied, reduces the refining energy by 10 % to 20% compared to conventional impregnation (e.g. pre-conditioning refiner chemimechanical pulp)

The chemimechanical pulping methods produce pulps of sufficient strength and acceptable optical properties and can be used as the main fibrous component in printing paper, packaging board and hygienic paper furnishes.

Chemimechanical pulping consists of a fibre line and auxiliary systems. The latter include reject handling, storage of chemicals (see Section 2.3.2), heat recovery and auxiliary power generation, e.g. from the wood residues (see Section 2.6). The main unit processes of the manufacturing of CTMP can be seen in Figure 5.4.



Source: courtesy of a Finnish mill, 1998

Figure 5.4: **Schematic of the main unit operations of the CTMP process**

The CTMP process combines the TMP process with a chemical impregnation of the wood chips. In this section only the CTMP pulping process itself is described, i.e. only the main unit processes (e.g. impregnation, several washing stages) that differ from TMP pulping. For screening and cleaning, reject handling, thickening and bleaching of mechanical pulps, the reader is referred to the corresponding paragraphs of Sections 5.1.6 and 5.1.7.

After debarking, chipping, chip washing and dewatering, the wood chips are first preheated, then compressed in a chip press before being impregnated in a screw-type impregnator tower where they are immersed in an alkaline chemical solution. A subsequent reaction bin allows the chemical to penetrate into the wood chips. Sodium sulphite (Na_2SO_3) is mostly used for softwoods, and more recently alkaline peroxide (NaOH, H_2O_2) has been predominantly used for hardwoods. After chemical impregnation, the chips are stored for a short retention time at high temperatures before entering a single- or multiple-stage refiner system (rotating refining plates), similar to the TMP process.

The CMP process developed as the high yield process for hardwood species, mostly for board, tissue and fine paper. With stronger chemical treatment and refining at atmospheric pressure, pulps with high strength properties can be produced from both softwood and in particular hardwood. After chemical impregnation, the chips are cooked at a temperature ranging from 70 ºC to 170 ºC. The cooking time depends on the process and can vary between 15 minutes and a couple of hours. Different kinds of treatment are used for different wood species. Optical properties like opacity are drastically reduced and the yield can fall below 90 % through extensive dissolution of organic material. CMP can only form a minor part of the furnish for printing papers.

Both the increase in the refining temperature and the use of chemicals (alkaline treatment) increase the generation of pollutants and as a consequence a higher yield loss. The chemical pretreatment affects the refining energy consumption; to what extent and how depend on the wood species and the chosen chemical system.

CTMP is often produced in connection with a paper or board mill due to the possibility to reuse the heat from refiners for the production of steam and better energy efficiency. However, CTMP is in some cases (approximately 10 mills in Europe) manufactured as market pulp and dried with a flash dryer which achieves a 90 % DS content.

5.1.6 Screening and cleaning

All mechanical pulps contain undesired components such as large, insufficiently pulped fragments (e.g. coarse rejects) and the shives that consist of many fibre bundles. Coarse fibres and shives are taken out for treatment and are then returned to the pulp stream because they reduce the strength and the printing quality of the paper.

The screening process in mechanical pulping has another objective to that in chemical pulping, where the rejects can be withdrawn from the fibre line. The purpose is instead mainly to separate the material and, after reject refining, return it back to the main fibre line (see Figure 5.2).

A screening installation consists of various stages in order to reduce the strain on subsequent installations and to save most of the acceptable components contained in the rejects. The screening out of the coarse rejects is easy to perform, but the removal of the shives requires a more elaborate technique. The shive content of unscreened mechanical pulp may be as high as 5 % depending on the process used (see Figure 5.2 to Figure 5.4). The purpose of screening is to separate shives from the main pulp flow for refining in the reject refiner. The long and flexible fibres from the reject refiner are returned to the main pulp flow usually before the main screening step.

The coarse rejects are, for example in SGW production, removed from the main pulp stream by vibrating flat screens equipped with perforated plates or by pressure screens with holes. Hammer mills or pulpers are used for the reduction of the coarse rejects. The retained coarse shives are usually added to the rejects of the fine screening system for further processing by means of separation through pressure screens which retain shives above a certain size depending on the type of paper required.

The screening process is carried out at high dilutions (below 1 % dry content). The fine screening is followed by a centrifugal separation of fibres and other particles with different specific weights (centricleaners). Separated rejects of the last stage are thickened and treated with special reject handling equipment like reject refiners and are then recycled to the screening process (secondary screens and centricleaners). Accepted pulp from reject handling stages can be recirculated back to the main fibre line. Final rejects (sandy material) are discharged from the process as solid waste. Depending on the reject handling concept, the DS content may vary between 5 % and 30 % [14, CEPI 1997]. The screening reject rate may be as high as 30 % of the inflow and, in the case of groundwood, the energy requirements for screening, thickening and refining the screening rejects are significant (accounting for about 25 % of the total energy). Final rejects are discharged from the process as solid wastes.

The screened and cleaned mechanical pulp is thickened by use of disc filters or thickening drums and then stored in tanks and storage towers.

Reject refining
In order to return screened and cleaned rejects to the main fibre line, they are usually refined in one or two stages between rotating refining plates. The initial break-up of the coarse fibre bundles in the refiner takes place in the breaker-bar zone, where the oversize material is turned into single fibres. The fibres are passed through a thin gap by the centrifugal forces and are intensively treated at a high pulp consistency (30 – 45 %).

The reject material from screens is a useful pulp fraction, the amount of which can be in the range of 30 – 50 % and the energy consumption about 10 – 40 % of the overall specific energy demand in mechanical pulping. If efficient reject recovery and recycling is required, TMP lines can be designed, e.g. for 40 – 50 % reject refining calculated from the capacity of the fibre line.

The final rejects that cannot be returned to the fibre line are discharged from the process as solid wastes or are incinerated in a boiler.

5.1.7 Bleaching of mechanical pulps

With the increased demand for high brightness paper and board, the bleaching of mechanical pulps has become more common. The bleaching of mechanical pulps is in principle totally different to that of chemical pulps because it is based on lignin-saving methods instead of lignin removing ones. The bleaching of mechanical pulps aims at changing chromophoric groups of lignin polymers into a colourless form. Thus, the bleaching of pulp primarily increases the brightness of pulp with minimum losses of DS and overall yield from wood. The effect is not permanent and the paper yellows to an extent over time. As it does not result in permanent brightness gain, bleached mechanical pulp is more suitable for newsprint and magazine paper than for fine paper or archive papers. The lignin-saving bleaching is carried out in one or two stages depending on the final brightness requirements of the pulp. The bleaching stages are distinguished according to the bleaching agent applied.

Reductive bleaching using sodium dithionite ($Na_2S_2O_4$)
In dithionite bleaching (symbolic shorthand: Y), organic material is dissolved to a minor extent from the pulp and does therefore not significantly increase the dissolved organic material (COD) in the effluents. Dithionite, also known as sodium hydrosulphite, is used for minor brightness adjustments (requiring 1 – 5 kg of dithionite per tonne of pulp) up to full bleaching, typically using up to 12 kg of dithionite per tonne of pulp. This technique results in a minimal yield loss and a brightness which can be increased by up to 12 units from an initial brightness level of 58 – 70 % ISO to about 70 – 76 % ISO [1, Finnish BAT Report 1997]. A suitable pH value is 5.6 to 6.5 and a temperature of up to 70 ºC accelerates the bleaching process. Bleaching is carried out in upflow bleach towers to avoid contact with air. The reaction is very quick and retention times are typically in the range of 10 – 30 minutes. Residual dithionite in the pulp can cause corrosion with metallic components downstream in the process, but also with various dyes in the paper machine furnish. In most mills a metal chelating agent (e.g. EDTA, DTPA) is used to prevent metal ions from decomposing the dithionite. The consistency in conventional hydrosulphite bleaching is 3 – 5 %. Medium consistency (MC) pumping has made it possible to

bleach at 10 – 12 % consistency with increased efficiency. Due to the limited brightness increase which is possible with Y bleaching and due to the high brightness levels which are required in modern paper production, dithionite bleaching has lost its importance and has been replaced by peroxide bleach plants in many mills.

Oxidative bleaching using hydrogen peroxide (H_2O_2)
The yield drop in peroxide bleaching (symbolic shorthand: P) is approximately 2 – 3 %, mainly due to the wood-dissolving effect of the high alkalinity during bleaching, hence the COD load in the process water increases.

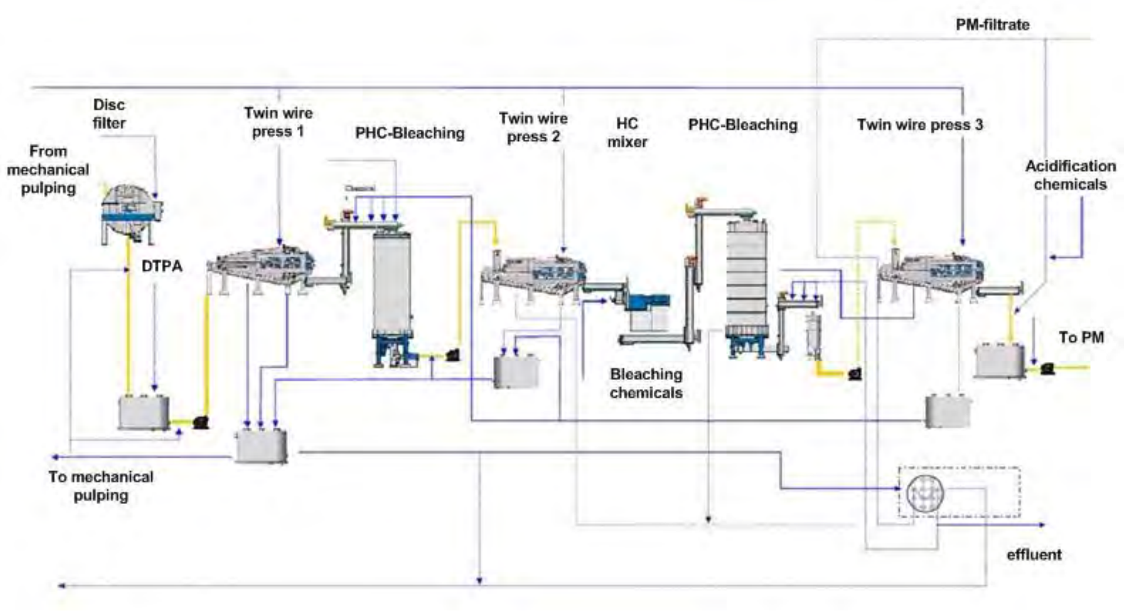
Peroxide bleaching influences the pulp properties. In addition to an increased brightness, the strength of the pulp is improved, the content of resin compounds/extractives is reduced and the water uptake capacity is increased. When applying the maximum economical amount of peroxide, an increase in brightness of up to 20 units to 78 – 85 % ISO (depending on the wood species) can be achieved [1, Finnish BAT Report 1997]. With different wood species (pine, aspen, poplar, birch, etc.) higher brightness gains of up to 40 units are also possible. With modern high-consistency peroxide bleaching techniques (25 – 35% DS, symbolic shorthand: P_{HC}) the brightness ceiling for softwood mechanical pulps is in the range of 82 – 84% ISO, and for hardwoods up to 86 % ISO can be reached. The achievable pulp brightness is also dependent on the initial pulp brightness that in turn is feedstock- and process-related. In particular, it is not only the wood species but also the degree of decay of the pulpwood which is important here.

The presence of heavy metal ions promotes the decomposition of peroxide, resulting in lower brightness and higher peroxide consumption. Therefore, sodium silicate (waterglass, Na_2SiO_3) and chelating agents (e.g. EDTA, DTPA) are added both before and during bleaching to form complexes with heavy metals (Fe, Mn, Cu, Cr), which prevents the pulp from discolouring and the peroxide from decomposing. EDTA and DTPA contain nitrogen, which will show up in the waste water. The introduction of a washing stage between pulping and bleaching is effective in reducing the problematic metals and can thus reduce the amount of chelating agent needed and improve the effectiveness of the peroxide applied. The bleached pulp is finally pH adjusted by the use of sulphuric acid, sulphur dioxide, hydrogen chloride or carbon dioxide to a pH of 5 – 7, depending on the pH level of the paper machine. Modern peroxide bleaching is conducted at a consistency level of 25 – 35 %.

Peroxide bleaching influences the pulp properties, in particular when the pulps are bleached with high amounts of chemicals. In addition to increased brightness, the strength of the pulp may improve, in particular with hardwood pulps, and the content of extractives is reduced.

In cases of high final brightness and when high amounts of peroxide are added, two-stage peroxide bleaching may be used. In this case, the residual peroxide after the second bleaching stage, which is commonly carried out at high consistency, is washed out in a washing stage and is recirculated to the first bleaching stage. Due to the dilution with the recirculated filtrate the consistency is reduced and bleaching in the first stage has to be carried out at medium consistency (10 – 15 %). Two-stage peroxide bleaching may save 10 – 20 % of chemicals compared to single-stage high-consistency bleaching.

An example of a modern high-consistency peroxide bleaching system is shown in Figure 5.5. It demonstrates a two-stage bleaching sequence applying P_{MC}-P_{HC} for a maximum final brightness target of >82 % ISO. The company produces LWC paper based on bleached stone groundwood pulp and a share of purchased chemical pulp. The COD after biological effluent treatment is <3 kg/t.



Source: Machine supplier, 2009

Figure 5.5: Modern high-consistency peroxide bleaching system in a SGW pulp-based LWC paper mill

A higher final brightness can be reached with peroxide bleaching than with dithionite bleaching but with reduced opacity. In some cases, a combination of oxidative and reductive bleaching may be more beneficial to achieve the highest pulp brightness. The stages PP - PY - YP are used, for example, to reach 80 % ISO for CTMP.

In some mills, $Ca(OH)_2$ or $Mg(OH)_2$ substitute NaOH as the alkali in peroxide bleaching (e.g. SCA Laakirchen, MD Papier Plattling). The substitution of NaOH by $Ca(OH)_2$ leads to approximately 30 % lower COD emission loads while achieving high brightness levels.

5.2 Current consumption and emission levels

5.2.1 Overview of input/output for the production of mechanical and chemimechanical pulp

An overview of raw material and energy input and the output of products and residues for further utilisation, major emissions and solid waste of mechanical pulp and paper mills is presented in Figure 5.6. The presence of some of the substances listed in the figure depends mainly on the paper grade and paper properties to be achieved and the type of energy supply.

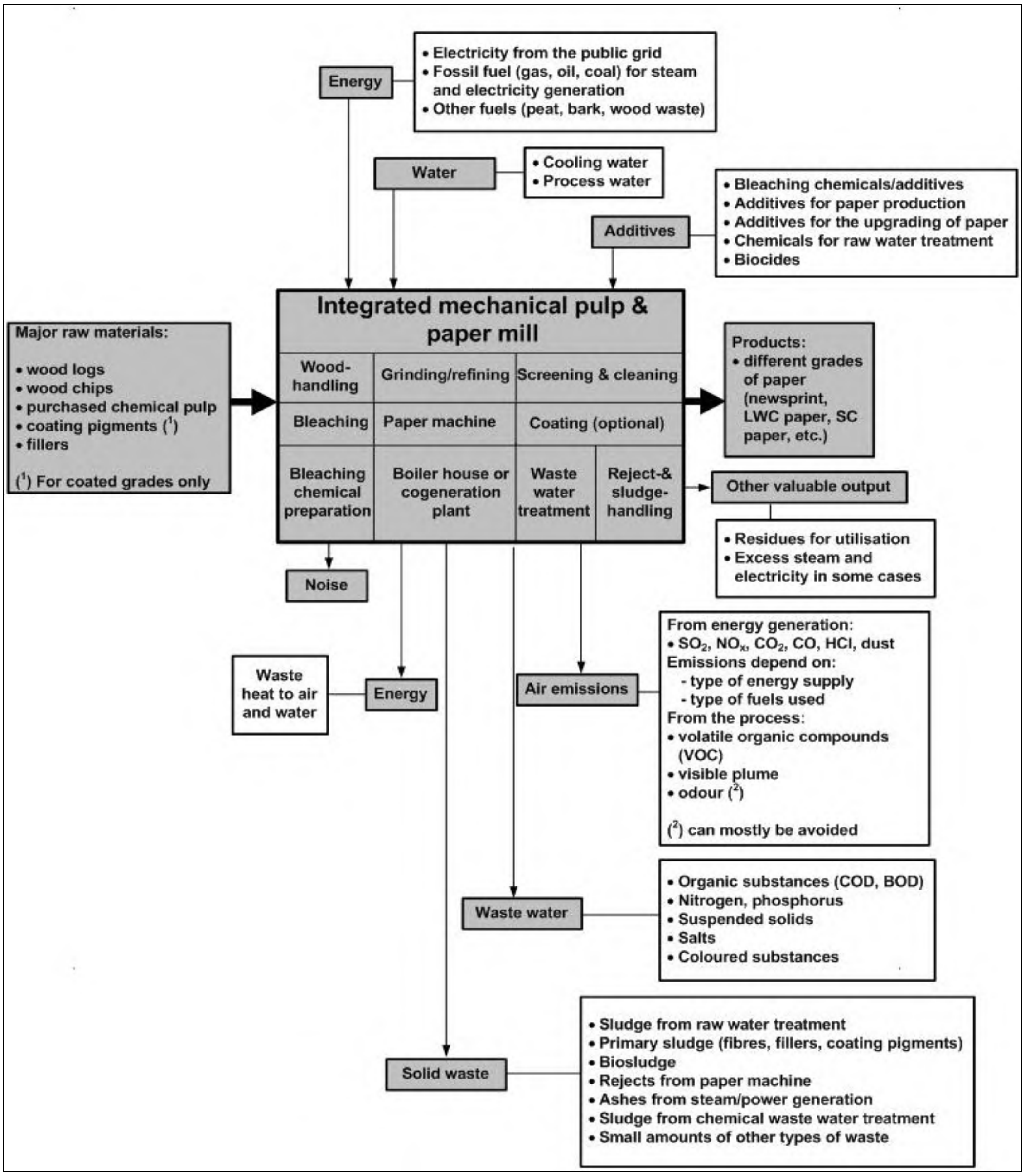


Figure 5.6: Mass stream overview of an integrated mechanical pulp and paper mill

Consumption and emission levels for raw materials used and emissions generated from a whole mill are compiled in Table 5.2. Mechanical pulp mills are mostly integrated with paper production. Furthermore, very often different fibre sources are mixed for the manufacturing of a given paper such as chemical pulp, mechanical pulp and deinked pulp that may be mixed and in the case of printing papers a relatively high amount of fillers and coatings are used.

The overall consumption and emission levels of an integrated paper mill manufacturing coated printing paper containing wood (ULWC, LWC and HWC) from TMP are given in Table 5.2. This mill uses a mix of raw materials such as fibre materials consisting of 60 % bleached TMP manufactured on site and 40 % purchased pulp (bleached kraft pulp and in a minor quantity deinked pulp). The mill produces a total of 370 000 tonnes/year of printing paper; the effluents are treated in a two-stage biological treatment (activated sludge). For a 100 % TMP integrated mill, the emissions will be higher, as the main emissions are related to TMP production.

The typical consumption and emission levels are given for a German mill (Table 5.2) and a Finnish mill (Table 5.3) and are related to integrated mechanical pulp and paper mills. They are presented to give a quick overview of the materials used and to provide guidance about the environmental impact to be expected. They are not representative in the sense that the given values cover the whole range of observed values in Europe but rather represent case studies of this type of mill.

Table 5.2: Yearly average values (reference year: 1997) of consumption and emission levels from a German mill for the manufacturing of printing paper containing wood (LWC, ULWC, HWC)

Input			Output		
Raw materials	**Value**	**Unit**	**Product**	**Value**	**Unit**
Wood chips from sawmills (1)	361	kg/t	Printing paper	1 000	kg/t
Purchased pulp (1)	259	kg/t	Excess energy	132	kWh/t
Pigments (kaolin, talc, $CaCO_3$) (1)	343.5	kg/t	**Emissions**		
Bleaching chemicals/additives (2)	27	kg/t	CO_2 (3)		kg/t
Additives for paper production (2)	4.6	kg/t	$CO_{2,\ \text{regenerative}}$ (3)		kg/t
Additives for upgrading paper (2)	57.3	kg/t	NO_X (3)		g/t
Chemicals for raw water treatment	4.2	kg/t	CO (3)		g/t
Biocides	No data	kg/t	SO_2 (3)		g/t
			Dust (3)		g/t
Energy			COD	2.7	kg/t
Natural gas	294	kWh/t	BOD_5	0.17	kg/t
Fuel oil	~3.2	kWh/t	Suspended solids		g/t
Purchased electricity	1 852	kWh/t	AOX	<0.4	g/t
Purchased steam	1 140	kWh/t	Nitrogen	24	g/t
			Phosphate	4.3	g/t
Water demand			Waste water flow	14.1	m^3/t
Surface water	22	m^3/t	Cooling water	12	m^3/t
Well water	4.4	m^3/t	**Residues**		
Drinking water (sanitary facilities)	0.2	m^3/t	Rejects and sludge (dewatered to 75 % moisture)	46	kg/t
			Sawdust	8.8	kg/t
			Metal scrap	2.5	kg/t
			Hazardous waste (e.g. used oils, mixtures of solvents)	0.3	kg/t

(1) The fibrous material refers to tonnes of absolute dry material, i.e. without moisture. In fact, the average moisture content of the raw material used is 50 % for wood chips, 9 % for purchased kraft pulp, 45 % for DIP and 0.2 % for pigments. The moisture content of the final product is about 4 – 5 %.

(2) Additives are expressed as commercial solutions containing various amounts of water. For bleaching, the following chemicals are used: 30 kg/t H_2O_2, 15 kg/t NaOH, 15 kg/t sodium silicate and 3 kg/t DTPA. The following additives are used: 43 kg/t synthetic binders (latex), <8 kg/t starch, 1 kg/t retention agent (polyacrylamide), fixing agents, poly DADMAC, hardness stabilisers, various biocides.

(3) Emissions to air could be calculated from the emissions generated at the external power plant (principle of combined heat and power) that supplies power and steam to the paper mill. All the electricity required for the TMP plant and 75 % of the heat needed for the whole site is based on external supply. Natural gas is used for infrared drying. Fuel oil is only used for the heating of buildings.

The overall typical consumption and emission levels of a CTMP mill are given in Table 5.3. The values refer to a non-integrated mill built in 1985 with some modernised equipment; the production capacity is 110 000 tonnes/year of bleached CTMP (CSF 400) for hygienic papers. The values in brackets reflect the typical levels from CTMP mills. The effluents are treated in a biological treatment plant (activated sludge).

Table 5.3: Yearly average values of consumption and emission levels from a Finnish CTMP mill

Input			Output		
Raw materials	**Value (*)**	**Unit**	**Product**	**Value (*)**	**Unit**
Wood	1 090	kg/t	CTMP pulp	1 000	kg/t
Na_2SO_3	25 (20 – 30)	kg/t	Excess energy	600 – 1 200 (1)	kWh/t
DTPA	2 (1 – 2.5)	kg/t	**Emissions**		
Bleaching chemicals (H_2O_2)	10 – 40	kg/t	NO_X	250	g/t
Chemicals for raw water treatment	0 – 2	kg/t	SO_2	240	g/t
Sodium silicate	8 – 30	kg/t	Dust	50	g/t
			COD	15 (12 – 25)	kg/t
			BOD_5	1 (0.5 – 2)	kg/t
			Suspended solids	0.5 (0.1 – 2)	kg/t
Energy			AOX	0	g/t
Wood residuals	600	kWh/t	Tot-N	400 (300 – 500)	g/t
Fuel oil	200	kWh/t	Tot-P	10 (5 – 50)	g/t
Purchased electricity	1 800 (1 500 – 3 000)	kWh/t	Waste water	20 (10 – 30)	m^3/t
			Cooling water	0 – 20	m^3/t
			Residues		
Water demand			Rejects and sludge	30 (15 – 40)	kg/t
Surface water	20 (10 – 30)	m^3/t	Ashes	7	kg/t
			Hazardous waste (e.g. used oils, mixtures of solvents)	10	kg/t

(*) The values in brackets reflect the typical levels from CTMP mills.

(1) The figures refer to the case where no drying is applied, i.e. integrated pulp and paper production. The heat energy may be used in the paper machine.

5.2.2 Consumption and emission levels arising from process units

In mechanical and chemimechanical pulping, the waste water effluents, the relatively high consumption of energy that is often generated on site and the fibre losses and sludge from different parts of the manufacturing process and above all from the waste water treatment plant are areas of environmental concern.

The most relevant uses of raw materials and emissions to water, air and soil (waste) as well as energy aspects are discussed below and cover the following:

- wood consumption,
- water use,
- waste water emissions,

- emissions to the atmosphere from refiners, energy generation and bark boilers (for emission levels from auxiliary and bark boilers, see Section 2.6.2),
- solid waste generation,
- consumption of chemicals,
- use of energy,
- noise.

As for the reported emission and consumption figures, it should be borne in mind that, due to the use of some different measurement methods in the various Member States, data are not always strictly comparable from country to country (see Section 2.2.1).

5.2.2.1 Wood consumption

In the production of groundwood pulps, wood has to be delivered as logs due to the construction of grinding machines. In TMP and CTMP pulping processes, wood is used as chips and therefore both processes can use roundwood or chips from sawmills or wood panel industries.

High yields are characteristic of mechanical pulping where the losses occurring during the process, mainly in the form of dissolved organic substances (principally lignin and hemicellulose), are low (see Table 5.1).

The use of wood is normally between 2.4 m^3/ADt and 2.6 m^3/ADt for groundwood, 2.3 m^3/ADt and 2.8 m^3/ADt for TMP and 2.8 m^3/ADt and 3.0 m^3/ADt for CTMP [14, CEPI 1997]. The unit m^3 wood/ADt is used as a trading unit in some countries. It is a term to express the volume of roundwood under bark used for pulp manufacturing; it is not synonymous with the term yield as it neglects variations in wood density (+/-15% within one wood species and up to 50 % between species). When the m^3 wood/ADt varies, it is unclear if it is the yield (tonnes of wood/tonne of pulp) or the wood density (t/m^3) that caused it.

5.2.2.2 Water use

In mechanical pulping processes, the water systems are usually closed in order to maintain high process temperatures. Fresh water is only used for sealing and cooling as surplus clarified waters from the paper machine are usually used to compensate for the water leaving the circuit with the pulp (5 – 10 m^3/tonne of pulp) and with the fibre losses and sludge. For a TMP mill, sources of emissions to water are wood handling, cleaning and bleaching (see Figure 5.3).

Most of the mechanical pulp mills are integrated mills, i.e. their water and energy management is closely linked to the paper mill that manufactures different coated or uncoated paper grades. Typical ranges of overall water use for GW, TMP and CTMP processes are shown in Table 5.4.

Table 5.4: Water use in mechanical pulping

Pulping process	m^3/ADt of pulp and paper (1)
GW	5 – 20 (1)
TMP	4 – 20 (1)
CTMP	9.5 – 30 (1)

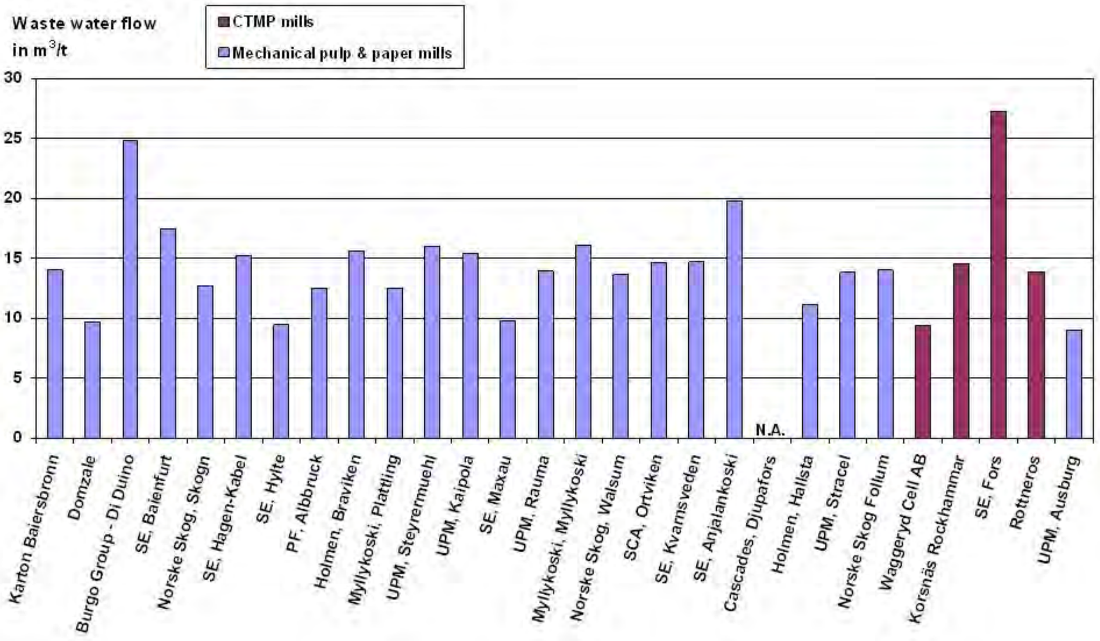
(1) The upper end of the range includes the water consumption of the paper mill for integrated production (see Section 5.3.6), whereas the lower end of the range refers to pulping only.

If the volume of the white water tank is sufficient, i.e. no addition of fresh water is needed to maintain the tank levels, a consumption of about 10 m^3 of fresh water per tonne of pulp is required. If the properties of the final product require a low content of extractives (as is the case of board pulp or fluff pulp) or fines (as is the case of fluff pulp), some more fresh water and/or additional washing stages may be needed. On the other hand, an internal treatment of the white water from the first washing stage by the use of suitable technologies (e.g. evaporation, flocculation/flotation, centrifuges) results in water consumption below 10 m^3/t. The flocculation/flotation unit removes extractives and fines and about 40 – 50 % of the COD. The latest installations use evaporators to separate the solids from the effluent and the clean condensate is reused in the process.

5.2.2.3 Waste water and emissions to water

Waste water flow

Figure 5.7 shows the specific waste water flow of mechanical and chemimechanical pulp and paper mills that responded to the EIPPCB survey. Integrated mechanical pulp and paper mills (e.g. GW, RMP, TMP) discharge between 9.4 m^3/t and 20 m^3/t (with the exception of one mill discharging up to 25 m^3/t); the manufactured grade (e.g. standard grades, or a grade with higher brightness) does not significantly affect the amount of waste water discharged from production installations. CTMP mills reported water flows between 9 m^3/ADt and 27.2 m^3/ADt.



Source: EIPPCB data collection/questionnaires, data from 2006 and 2008, [Swedish Statistics 2008], [248, Hamm 2007]

Figure 5.7: Specific waste water discharge from individual mechanical and chemimechanical pulp and paper mills

Sources of waste water and pollution parameters

In Figure 5.8, the sources of emissions to water and the main substances of concern from a CTMP mill are shown. Strict counter-current water systems are applied, i.e. clean wash water is used for the last wash press and led counter-currently to the fibre flow. The highly loaded filtrate from the wash step is discharged from the process. Fibres can be recovered and filtrate treated internally by flotation or filtration before being taken to external treatment. Sealing and cooling waters are collected and used as process water or are discharged to surface waters.

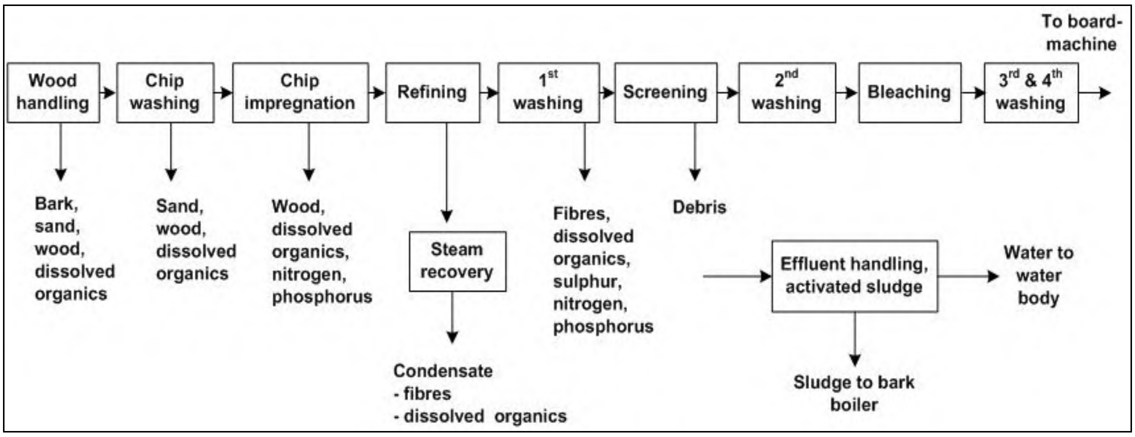


Figure 5.8: **Sources of emissions to water from a CTMP mill**

Emissions to water are dominated by oxygen-consuming organic substances that are lost in the water phase in the form of dissolved and dispersed organic substances. A yield of 86 – 97 % means that 30 – 140 kg/tonne of the wood in the form of solid and dissolved substances are lost during processing. Grinding temperature, caustic usage (during impregnation and/or bleaching) and water use (m^3/t pulp) have an impact on the yield. Wood species, seasonal variations and storage conditions of the wood also influence the amount of dissolved solids. During mechanical pulping, the stability of the cellulose and the lignin is not affected, but simple carbohydrates, hemicelluloses, lignins, extractives (e.g. fatty and resin acids), proteins and inorganic substances including nitrogen and phosphorus are dissolved and dispersed in the process water. With a decreasing yield and an increasing temperature, the organic load of the water from pulping increases.

Typical specific loads measured, such as BOD_5, COD and nutrients (phosphorus and nitrogen), for different pulps are listed in Table 5.5, together with the corresponding yield.

Table 5.5: **Typical specific loads in waste water from the mechanical pulping of Norway spruce (picea abies) before treatment**

Pulping process	Yield (%)	BOD_5 (kg/t)	COD (kg/t)	Nitrogen (g/t)	Phosphorus (g/t)
GW	95 – 98.5	8.5 – 10	20 – 30	80 – 100	20 – 25
PGW	95 – 96	10 – 13	30 – 50	90 – 110	20 – 30
PGW-S	95 – 96	11 – 14	45 – 55		
RMP	95 – 96	10 – 15	40 – 60	90 – 110	20 – 30
TMP	93 – 97.5	13 – 22	50 – 80	100 – 130	30 – 40
CTMP	90 – 94	17 – 30	60 – 100	110 – 140	35 – 45
Bleached CTMP: **Bleached softwood** **Bleached hardwood**	 91 – 93 (1) 86 – 92 (2)	 25 – 50 (1) 50 – 80 (2)	 80 – 130 (1) 120 – 200 (2)	 130 – 400 (1) No data	 50 – 60 (1) No data

(1) Figures in brackets are based on personal information from Finnish CTMP mills. BOD_7 has been converted into BOD_5 by use of the formula $BOD_7/1.16 = BOD_5$ proposed in [1, Finnish BAT Report 1997].
(2) Data source: Andritz AG, 2009.

If mechanical pulp is bleached in an alkaline peroxide step, the releases of organic pollutants increase significantly due to the alkalinity during the bleaching. The yield loss in connection with peroxide bleaching is 15 – 30 kg/tonne corresponding to an additional load of approximately 10 – 30 kg O_2/tonne measured as COD respectively. The upper values of the table above are related to peroxide bleached mechanical pulps. For TMP mills using only hydrosulphite as a bleaching chemical, COD levels of 2 500 – 3 000 mg O_2/l have been measured referring to a water flow from the TMP mill of 3 – 4 m^3/t (paper machine not included). A groundwood mill has reported COD concentrations before treatment of 1 700 – 2 000 mg COD/l.

About 20 – 30 % of the bark (referred to as dry bark) is water-soluble, of which 50 – 60 % consists of phenolic substances and about 25 % consists of soluble carbohydrates. Depending on the storage of wood, carboxylic acids and alcohols might also be found in effluent from the debarking plant. Some compounds discharged from mills show toxic effects on aquatic organisms before treatment as some of the extractive components like resin acids that may be leached from bark in the wood handling for example. The waste water from debarking is usually treated together with other waste water streams in external treatment plants.

Additives used for papermaking may cause a measurable part of the organic discharge after treatment because some substances are not readily degradable.

Emissions of coloured substances may affect the living species in the receiving water negatively, since the water transparency is decreased.

The emissions after treatment from the mills depend mainly on the design and operation of the processes and water circuits, the type and extent of bleaching (paper with the highest brightness cause higher COD loads than standard grades) and the waste water treatment applied. The efficiency of biological waste water treatment at mechanical pulp mills resembles that of chemical pulp mills. The COD reduction is however normally higher at levels between 70 % and 90 %. Moreover, at several plants, tertiary treatment is employed which polishes the effluent thereby reducing discharges further. This is particularly true for pollutants associated with TSS.

Table 5.6: Emissions of mechanical pulp mills after biological treatment

Pulping process	Flow (m^3/t)	BOD_5 (kg/t)	COD (kg/t)	Tot-P (g/t)	Tot-N (g/t)	TSS (kg/t)
CTMP	9 – 30	No data	12 – 25	2 – 10	150 – 200	0.5 – 1.5
TMP	10 – 25	Few data	2.5 – 7.2 (1)	2 – 16	20 – 500	0.06 – 0.7

(1) The COD value also depends on the product compositions; higher shares of hydrogen peroxide bleached TMP tend to result in higher final COD loads after treatment.

Source: Swedish statistics of pulp and paper mills, 2008; EIPPCB questionnaires, reference years: 2006 and 2008.

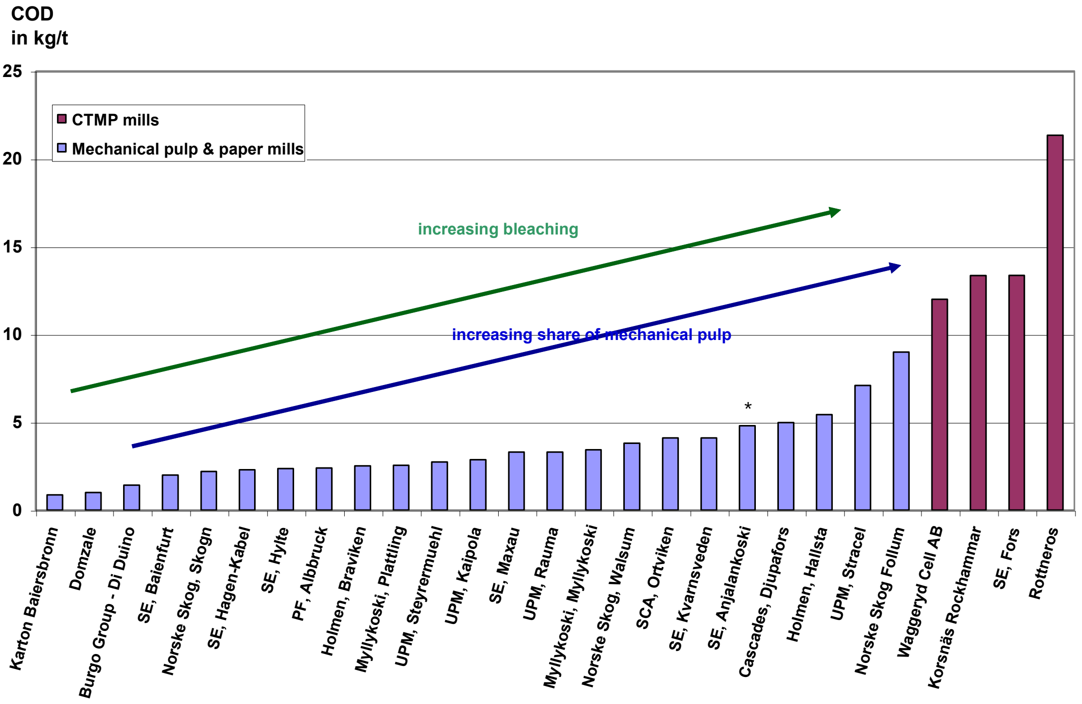
In the following sections, more detailed information on the emissions of individual waste water parameters relevant for mechanical and chemimechanical pulping is given. The data are provided – where available – as load (kg/ADt), concentration (mg/l), yearly and daily averages. Values are presented as reported (e.g. with regard to decimal places, regardless of the uncertainty factor close to the detection limit). When interpreting given concentration data, one should bear in mind the corresponding waste water flows. Due to efforts being made in some mills with regard to reducing water use and closing water loops, the concentration of pollutants might have increased. The plants with higher concentration values do not necessarily have higher emission loads.

Chemical oxygen demand

Figure 5.9 provides the reported annual average values for COD emissions from individual plants. The loads reported range from 0.87 kg/ADt to 7.13 kg/ADt for mechanical pulp and paper mills and from 12.00 kg/ADt up to 21.34 kg/ADt for CTMP plants.

In Figure 5.9, the specific COD loads for mechanical and chemimechanical pulp and paper mills are given as yearly average values after waste water treatment.

The values reported for mechanical mills cover the range of 0.87 kg/t to 7.13 kg/t, and up to 8 – 9 kg/t in the case of highly bleached mechanical pulp. Lower COD values (0.87 – 1.0 kg/t) refer to mills that manufacture mainly bleached or unbleached GW-based cartonboard, also use some purchased chemical pulp and run a biological waste water treatment. Another group of mills are those manufacturing graphic paper (e.g. LWC, ULWC paper) using various fibre sources as furnish (mainly bleached GW or PGW, sometimes a little deinked RCF, and also some purchased chemical pulp) with the pulp being bleached in one or two stages with hydrogen peroxide only or a combination of peroxide and dithionite bleaching. COD emissions of this group vary between 1.3 kg/t and 4.5 kg/t. The group of mills that uses bleached TMP (around 30 – 60 %), some deinked RCF or also bleached GW and some purchased pulp show an emission range of 2.0 to 4.5 kg/t. TMP mills that are based on 80 – 100 % TMP, most of it hydrogen peroxide bleached, reported the highest COD emissions; with emissions varying between 4.5 kg/ADt and 9 kg/ADt. The achieved brightness level (% ISO) of the final product (MFC, LWC paper) corresponds to a certain extent to the discharged COD load; the fibre furnish, the process layout and the applied waste water treatment are also relevant aspects to consider. COD levels are highly dependent on the usage of mechanical pulp.



* Data submitted in 2012 report 8 - 9 kg/t

Source: EIPPCB data collection/questionnaires, data from 2006 and 2008, [Swedish Statistics 2008], [248, Hamm 2007]

Figure 5.9 Yearly averages of specific COD loads from individual mechanical and chemimechanical pulp mills

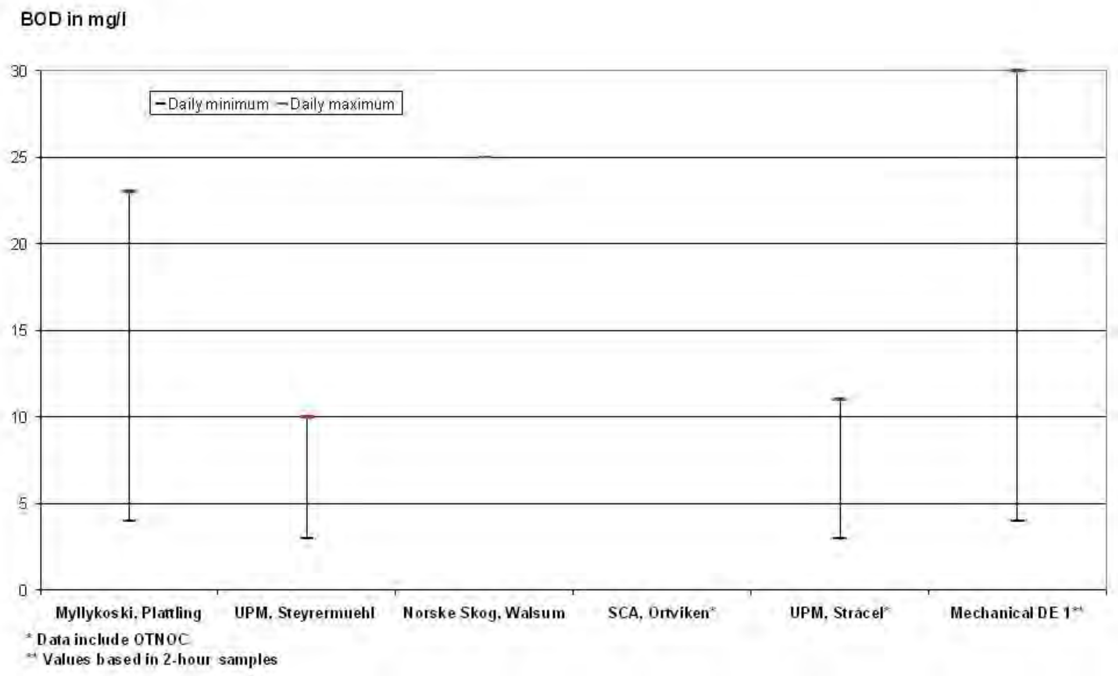
The range of emissions shown in Figure 5.9 reflects these variations in fibre furnish, share and type of mechanical pulp, the level of bleaching and the waste water treatment applied. The upper end of the COD range of mechanical pulp and paper mills is caused by mechanical pulp and paper mills that use a high proportion (≥95 %) of highly bleached TMP for almost all grades manufactured.

Three out of the four CTMP mills that responded to the EIPPCB questionnaires discharge organic loads between 12 kg COD/t and 13.5 kg COD/t as a yearly average.

For CTMP plants, there are a few possible ways to treat the waste waters: activated sludge treatment in one or two stages with or without a chemical treatment; internal treatment of the first stage white water followed by activated sludge treatment for other effluents; evaporation and burning of the most contaminated waste water and activated sludge treatment of the rest; a combination of anaerobic and aerobic treatment of waste water. Today the activated sludge treatment is the most common technique and, if properly designed, a BOD reduction of 98 % and a COD reduction of 85 % are reached. The reason why anaerobic treatment is not used more commonly for CTMP mill effluents is that anaerobic systems are relatively sensitive to disturbances caused by sulphur-containing CTMP waste water. Waste water from hardwood bleached CTMP mills using alkaline peroxide for the impregnation of the chips can be treated effectively in anaerobic stages, as could be demonstrated in several recent installations. The generated biogas can be used for energy generation either in the bark boiler or in the case of market pulp mills in the flash dryer.

There are an increasing number of paper mills in Europe that manufacture and use not only one single type of pulp but different types of pulps at one site. For instance, a paper mill manufacturing mainly newsprint and SC printing papers may use a combination of raw materials like mechanical pulp (groundwood and TMP), deinked pulp from recycled papers and a certain amount of purchased chemical pulp. In these types of mills, the water system is closely linked between the different processes.

The short-term values reported for BOD emissions are shown in Figure 5.10.

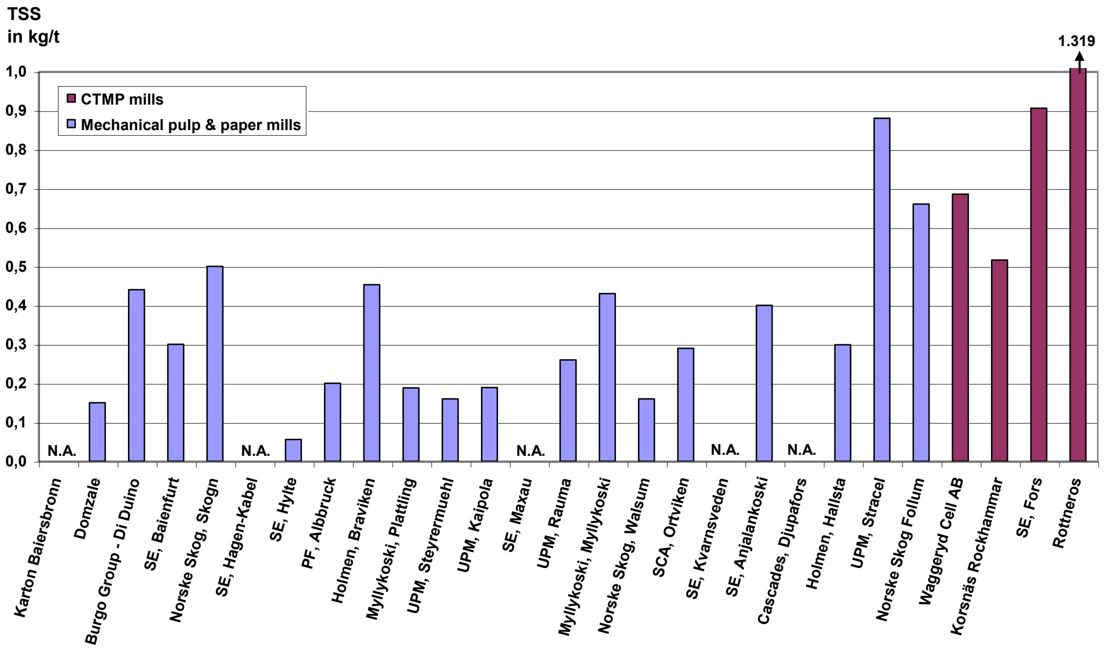


Source: EIPPCB questionnaires from 2007/2009

Figure 5.10: Short-term averages of BOD emissions from mechanical pulp mills

Total suspended solids

An overview of specific TSS loads for individual plants is given in Figure 5.11. Reported loads vary from 0.056 kg/ADt to 0.88 kg/ADt for mechanical pulp and paper mills and from 0.52 kg/ADt to 1.32 kg/ADt for CTMP plants.



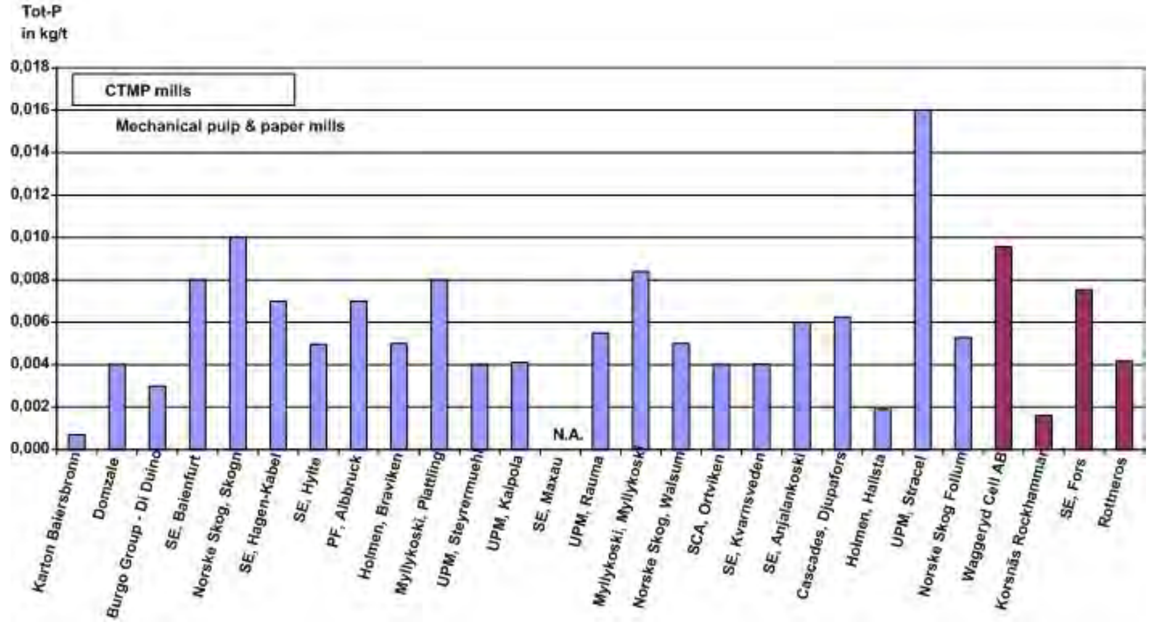
Source: EIPPCB data collection/questionnaires, data from 2006 and 2008, [Swedish Statistics 2008], [248, Hamm 2007]

Figure 5.11: Yearly averages of specific TSS loads from individual mechanical and chemimechanical pulp mills

Nutrients

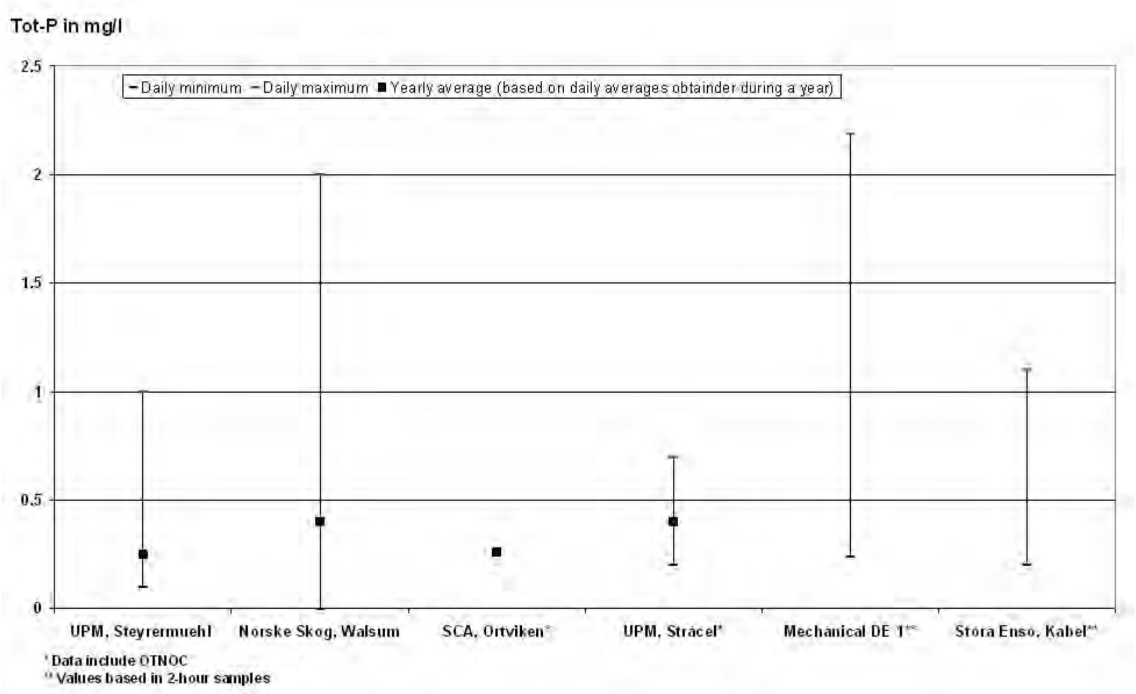
The discharge of nitrogen in mechanical pulping originates from the wood and chelating agents (e.g. EDTA, DTPA) used in bleaching. A dosage of 2 – 3 kg of EDTA/tonne of pulp results in an additional discharge of 150 – 220 g of nitrogen/tonne of pulp. The discharge of phosphorus depends on the wood. Emissions of nutrients (nitrogen and phosphorus) are low and not sufficient if the discharged water is to be treated in activated sludge processes. Therefore, nutrients (N and P) are normally added before such treatment.

Overviews of specific phosphorus and nitrogen loads for individual plants are given in Figure 5.12 and Figure 5.14, and short-term averages are given in Figure 5.13 and Figure 5.15. Loads reported for mechanical pulp and paper mills vary from 0.001 kg/ADt to 0.016 kg/ADt for total phosphorus and from 0.001 kg/ADt to 0.839 kg/ADt for total nitrogen. The values for CTMP plants vary from 0.002 kg/ADt to 0.010 kg/ADt for total phosphorus and from 0.145 kg/ADt to 0.184 kg/ADt for total nitrogen.



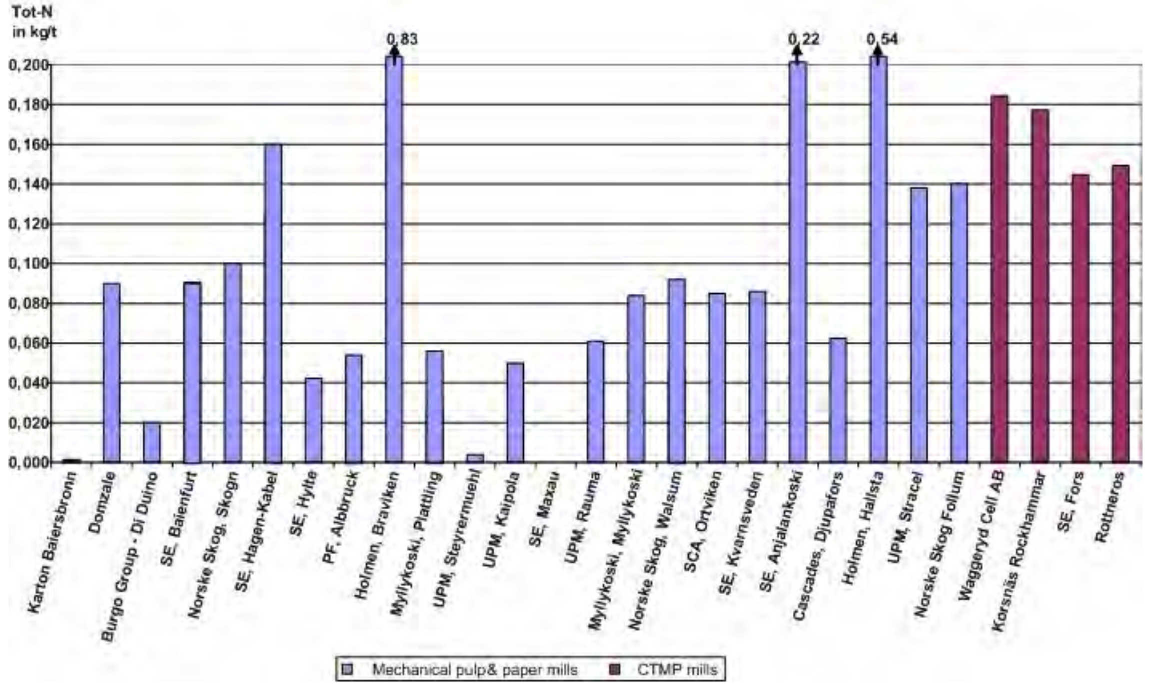
Source: EIPPCB data collection/questionnaires, data from 2006 and 2008, [Swedish Statistics 2008], [248, Hamm 2007]

Figure 5.12: **Yearly averages of tot-P loads from individual mechanical and chemimechanical pulp mills**



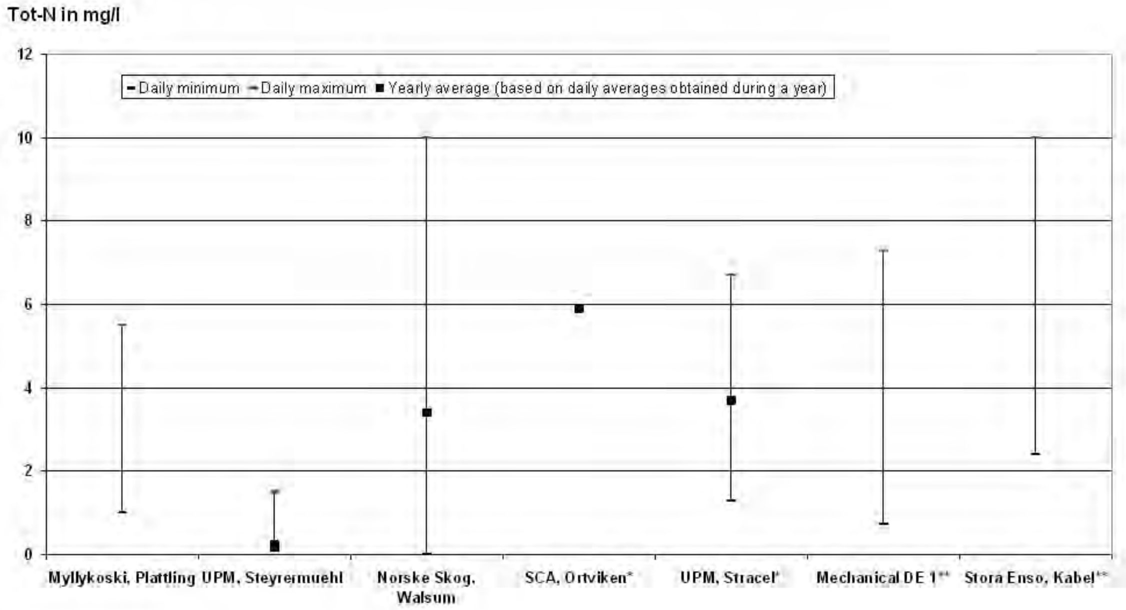
Source: EIPPCB questionnaires from 2007/2009

Figure 5.13: **Short-term averages of tot-P emissions from mechanical pulp mills**



Source: EIPPCB data collection/questionnaires, data from 2006 and 2008, [Swedish Statistics 2008], [248, Hamm 2007]

Figure 5.14: **Yearly averages of tot-N loads from individual mechanical and chemimechanical pulp mills**



* Data include OTNOC

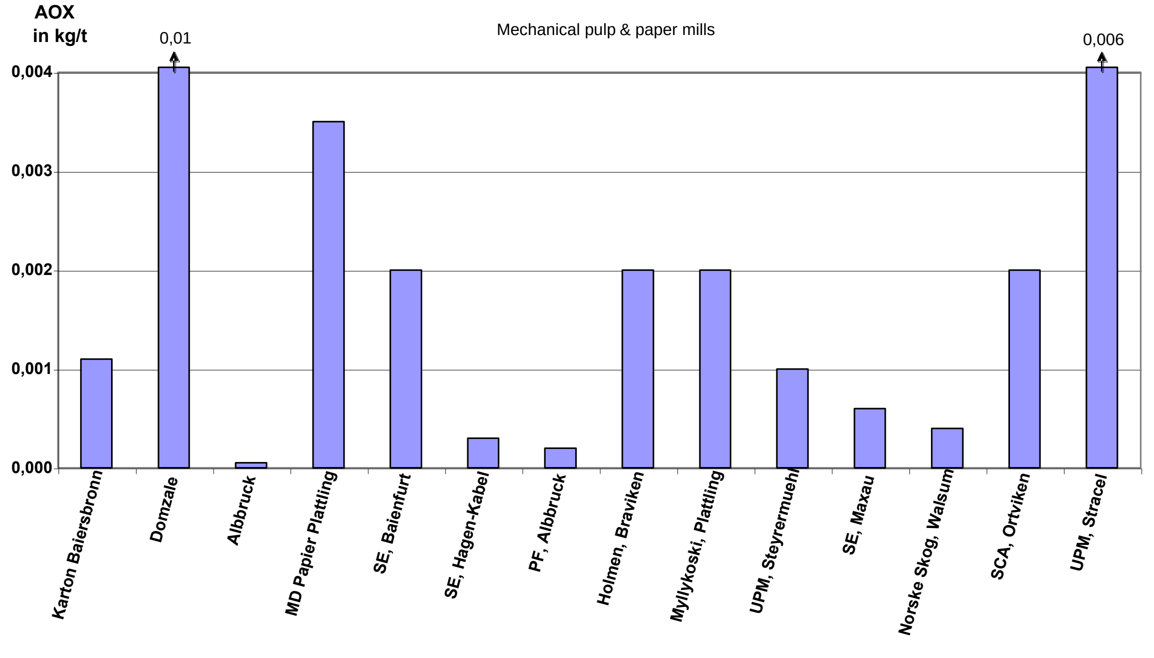
** Values based in 2-hour samples

Source: EIPPCB questionnaires from 2007/2009

Figure 5.15: **Short-term averages of tot-N emissions from mechanical pulp mills**

Chlorinated organic compounds (AOX)

An overview of specific AOX loads for individual plants is given in Figure 5.16. Reported loads vary from 0.000 2 kg/ADt to 0.010 kg/ADt for mechanical pulp and paper mills.



NB: Graph only presents data from mills that reported AOX. The rest of the mills are not presented

Source: EIPCCB data collection/questionnaires, data from 2006 and 2008, [Swedish Statistics 2008], [248, Hamm 2007]

Figure 5.16: Yearly averages of AOX loads from individual mechanical and chemimechanical pulp mills

5.2.2.4 Emissions to air

Volatile organic compounds (VOC)

Emissions to air from mechanical pulping are partially loaded with VOC. The VOC from mechanical pulp mills are totally natural, i.e. originating from wood. Their aroma is mainly that of fresh wood. The VOC stem from the part of the wood often called resins or extractives (and measured in percentage through extraction methods like DCM = dichloromethane). These compounds tend to evaporate or dissolve at high temperatures and/or dissolve through alkaline treatment. Fresh spruce contains 1 – 2 % DCM (of which <1 % is considered VOC); unbleached mechanical pulp: 0.3 – 0.5 %; bleached mechanical pulp/CTMP: <0.1 %; fresh pine: 3 – 5 % (up to 8 % in southern pine species). Studies on softwood have shown that 90 % of the terpenes are degraded at the wood yard and the chip pile. The terpenes escape to the atmosphere as diffuse emissions within 14 weeks of being stored. Sources of VOC emissions are the ventilation of air from chests from wood chip washing and other chests and from spray scrubbers, where vent steam from TMP heat recovery contaminated with volatile wood components is condensed.

VOC emissions depend on the wood species used, on the quality and freshness of the wood, on the storage time at the wood yard and on the pulping techniques applied for wood processing.

Depending on the type of raw material, the emitted substances originating from the wood include acetic acids, formic acids, methanol, pinenes and terpenes (the latter two originate from softwood).

A German TMP mill reported the concentrations of organic substances before external treatment given in Table 5.7.

Table 5.7: Emissions of volatile organic compounds from a German TMP mill before treatment

Process stage	Emission of organic substances
Spray scrubber (start-up scrubber)	- Total organic C: 6 000 mg/m^3 (highest individual value: 9 600 mg/m^3) - Pinenes (^{1}): 13 000 mg/m^3
Washing of wood chips	- Total organic C: 300 mg/m^3 - Pinenes (^{1}): 500 mg/m^3
Evacuation of air from other chests	- Total organic C: 150 mg/m^3 - Pinenes (^{1}): 50 mg/m^3
(^{1}) Mostly pinenes ($C_{10}H_{16}$) but also including other volatile organic substances of class III of the German Technical Instructions on Air Quality Control.	

The analysis of VOC from a TMP plant is very difficult because the exhausts contain steam and even water droplets. FID (flame ionisation detection) for example gives misleading results when measured as a total carbon. The component analysis FTIR will give more accurate information.

Depending on the applied pulping technology, VOC emitted from the fibre line can vary in a wide range. The amount of organic acids emitted from CTMP processes are a very small fraction of those coming from a TMP system, since the acids are mainly kept in the alkaline aqueous phase. For instance, a softwood CTMP mill reported 200 g of terpenes per tonne of pulp before treatment. In general for softwood fibre lines including a scrubber system, the emission of VOC is 1 kg/t of pulp. For hardwood applications approximately 0.4 kg of VOC per tonne of pulp can be expected (*source:* Andritz, 2009).

Some VOC may be released from waste water treatment. Most diffuse emissions occur from chip piles during storage.

An overview of the emissions to the atmosphere from a CTMP mill is shown in Figure 5.17.

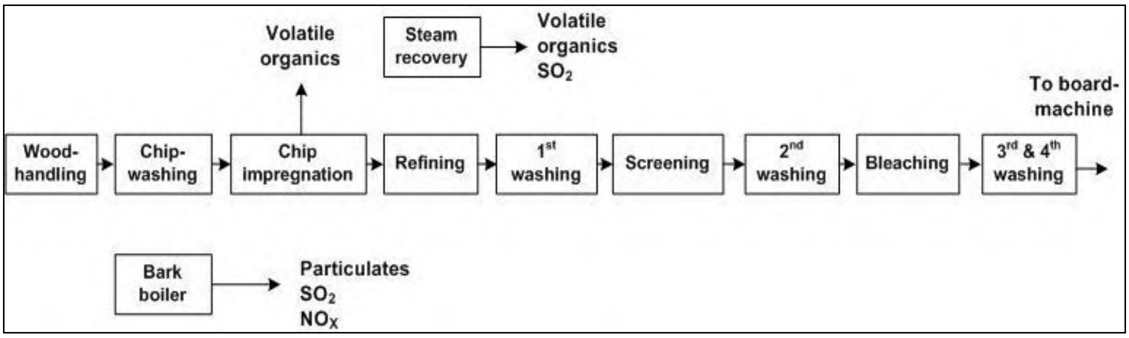


Figure 5.17: Emissions to the atmosphere from CTMP mills

The atmospheric emissions from the fibre line originate mainly from bleaching and steam recovery (VOC) and the bark boilers where wood residuals are burnt (particulates, SO_2, NO_X). (See Section 2.6.2).

There are different options to reduce the VOC emissions:

- the recovery of terpenes from contaminated condensates for incineration purposes;
- incineration of the exhaust gas in the on-site power plant or in a separate boiler.

In Europe, there is no known pulp or paper mill that reported on special control measures for their odours related to VOC emissions. Elsewhere, for example in UPM-Kymmene, Blandin Paper Mill and New Page, Duluth Paper Mill, a regenerative thermal oxidiser (RTO) controls

VOC from the main grinder stack (PGW mill) and the grinder chamber evacuation vent [188, Pöyry 2010]. No more specific data could be gathered.

Emissions from energy generation
Like in other pulp and paper mills, mechanical pulping generates emissions to air that are not process-related but are mainly related to energy generation by combustion of different types of biofuels and fossil fuels (see Section 2.6). In a typical integrated paper mill that uses mechanical pulp, high-pressure steam is generated in a power plant. The energy is partially transformed into electricity in a back-pressure turbo-generator and the rest is used in paper drying. The power plants burning solid fuels have electrostatic precipitators for the removal of particulates from the flue-gases. The emission of sulphur dioxide is limited by using selected fuels. Depending on the local conditions, there are paper mills in Europe using different amounts of energy from external supply.

Emissions from bark boilers
For refiner mechanical pulps, the removed bark is usually burnt in bark boilers. Together with the bark, parts of the rejects and sludge might be incinerated. There are some mechanical pulp mills that use no roundwood as raw material but wood chips from sawmills.

5.2.2.5 Solid waste generation

The solid waste/residues removed from the mechanical pulping processes consists of bark and wood residues from the debarking, washing and screening of chips (about 1.5 % rejects), fibre rejects (primary sludge), ash from energy production and excess sludge from external biological waste water treatment. The residues containing wood are usually burnt in the bark boiler. Ashes are usually disposed of or are used in the building material industry.

The largest waste fraction consists of different types of sludge, mainly fibre-containing primary sludge and excess sludge from biological waste water treatment. The amount (weight) of waste for disposal can be reduced and the value/cost of the sludge can be improved through optimised dewatering equipment. For transport or incineration purposes, the maximum amount of water should be removed. Usage of excess heat for drying adds further value/reduces cost. At a dryness of approximately >35 %, the sludge will have a net positive calorific content (see Section 2.9.6.1.4).

The options for further use depend on the quantities and qualities of the sludge produced. Primary sludge may be used as additional material in the brick industry or may be incinerated on or off site. For suitable solutions for the further treatment of sludge and fibre losses, it is reasonable to treat different types of sludge separately.

A chemical analysis of primary and secondary sludge from a German mechanical pulp and paper mill showed the results given in Table 5.8.

Table 5.8: **Composition of primary sludge from sedimentation tanks and composition of excess sludge from the activated sludge plant**

Parameter	Unit	Primary sludge	Excess sludge
DS content	%	47.9	31.7
Organic solids	% DS	33.2	48.3
TOC	% DS	19	23
Arsenic	mg/kg DS	1.6	2.3
Lead	mg/kg DS	41	22
Cadmium	mg/kg DS	<0.67	<0.67
$\text{Chromium}_{\text{total}}$	mg/kg DS	24	17
Copper	mg/kg DS	238	71
Nickel	mg/kg DS	5.7	7.5
Mercury	mg/kg DS	0.08	0.09
Zinc	mg/kg DS	141	135

Source: Report from a German mechanical pulp mill (GW & TMP).

A small amount of hazardous waste is generated in all mills. Such waste includes oil and grease residues, used hydraulic and transformer oils, waste batteries and other scrap electrical equipment, solvents, paints, biocide and chemical residues, etc.

5.2.2.6 Consumption of chemicals

The main chemicals used for mechanical pulping are bleaching chemicals and in the case of CTMP the chemicals used for impregnation of the wood chips.

If sodium dithionite bleaching is applied ($Na_2S_2O_4$), a maximum charge of sodium dithionite of about 8 to 12 kg per tonne of pulp is mixed to the pulp. In most mills a metal chelating agent (e.g. EDTA, DTPA) is added.

Oxidative bleaching with peroxide (H_2O_2) is carried out in the pH range of 10 – 10.5. The pH has to be adjusted with sodium hydroxide (NaOH). The maximum economical amount of peroxide is 3 – 4 % (50 % solution) of the amount of pulp. Sodium silicate is added (1.5 – 4 % of the amount of pulp) to buffer the pH and stabilise the peroxide. Chelating agents (e.g. EDTA, DTPA) are used to form complexes with heavy metals (Fe, Mn, Cu, Cr), which prevent the pulp from discolouring and the peroxide from decomposing. The dosage of chelating agents is up to 5 kg per tonne of pulp. EDTA and DTPA show low biodegradability and contain nitrogen, which will show up in the waste water. The bleached pulp is finally pH adjusted with sulphuric acid, sulphur dioxide or carbon dioxide.

In some mills, $Ca(OH)_2$ or $Mg(OH)_2$ substitute NaOH as the alkali in peroxide bleaching (e.g. SCA Laakirchen, MD Papier Plattling). The substitution of NaOH by $Ca(OH)_2$ leads to approximately 30% lower COD emission loads while achieving high brightness levels.

The ranges of chemicals used vary largely because they depend on the main process used for the bleaching of mechanical pulp. For instance, if reductive dithionite bleaching is used, H_2O_2, NaOH, Na_2SiO_3 and H_2SO_4/SO_2 are not used at all. Furthermore, the quality of the wood is an important factor. The pulping of sawmill chips may result in a lower initial pulp brightness (up to 5 % ISO brightness) than the pulping of wood chips from fresh roundwood. Therefore, the latter needs fewer bleaching chemicals to achieve a comparable brightness. For fresh pulpwood, less polluting reductive bleaching might be sufficient. Table 5.9 compiles data on the consumption of the main chemicals in kg/t for bleached grades of mechanical pulp.

Table 5.9: Consumption of main chemicals for bleached grades of mechanical pulp

Substances	Amount of chemicals used for GW and PGW (kg/t)	Amount of chemicals used for TMP (kg/t)	Amount of chemicals used for CTMP (kg/t)
$Na_2S_2O_4$	0 – 12	0 – 12	-
H_2O_2	0 – 40	0 – 50	0 – 40
NaOH (1)	5 – 30	0 – 40	0 – 60
Alternative alkali: e.g. $Mg(OH)_2$			
Na_2SiO_3	0 – 40	0 – 40	0 – 40
EDTA/DTPA	0 – 5	0 – 5	0 – 5
H_2SO_4/SO_2	NA	NA	0 – 10
Na_2SO_3	NA	NA	25 – 30

NB: NA= not applicable.

(1) Target for ISO brightness increase is decisive for the use of NaOH.

In integrated mechanical pulp mills, various chemical additives (process and product aids) may be used depending on the final paper product (see Section 6.2.2.3), e.g. pitch dispersant agents, retention aids, fixing agents, defoamers, biodispersion agents or biocides, optical brighteners, cleaning agents, etc.

5.2.2.7 Energy use

The specific energy consumption in mechanical pulping is dependent on the particular pulping process, the properties of the raw material (wood species) and, to a large extent, the quality requirements (freeness) of the pulp set by the end product. The freeness value (Canadian Standard Freeness = CSF) characterises the drainage properties of the pulp and is widely used for specifying the quality of the pulp. A low freeness value indicates a slow draining pulp with a high degree of fibrillation. For the manufacturing of a pulp with lower freeness (better strength) the energy input in the grinding or refining is increased. Besides the drainage properties, the distribution between long fibres and fine material in a specific pulp and the softness of the fibres are controlled by the energy input. The type of paper and board in which mechanical pulp is used and the share of mechanical pulp in the furnish determine the requirements for freeness, brightness and other properties. Wood-containing printing paper, e.g. LWC, SC magazine paper (freeness 20 – 60 ml CSF) and newsprint (freeness 80 – 150 ml CSF) are the most common products. The pulps are also used in paperboard (freeness 450 – 550 ml CSF), tissue (300 – 400 ml CSF) and fluff (500 – 550 ml CSF). The lower the freeness (CSF), the higher the electricity consumption.

Only a portion of the mechanical work put into the grinder or refiner is used to liberate the fibres in the wood. The rest of the applied energy is converted through friction into heat and some of this can be recovered as hot water or steam that can be used for the drying of the final product.

The greatest potential for energy recovery from mechanical pulping is from the processes carried out in pressurised refiners. The options to recover energy differ depending on the type of refiners and the design of the TMP plant. For instance, some systems involve secondary or tertiary refining at atmospheric pressure where heat recovery is more difficult. The potential for heat recovery is not a constant percentage of the total energy input over the range of freeness because lower CSF pulp requires more refining in pressurised refiners and thus leads to higher shares of recoverable energy. Typical ranges of energy consumption and recovery rates are shown in Table 5.10. There is a considerable variation for freeness and specific energy consumption. Data sources are old but the values are still correct and correspond to today's experience (*source*: UPM, 2010).

Table 5.10: Energy consumption and recovery of energy in mechanical pulping

Mechanical pulp and freeness (ml CSF)	Energy consumption (kWh/t of pulp)	Recoverable energy	
		As hot water (%)	As high-pressure steam (%)
GW 350 – 30	1 100 – 2 200	20	0
PGW 350 – 30	1 100 – 2 200	30	20
PGW-S 350 – 30	1 110 – 2 300	30	20
RMP 350 – 30	1 600 – 3 000	30	20
TMP 400 – 30	1 800 – 3 600	20	40 – 80
CTMP 700 – 30	1 000 – 4 300	20	40 – 45

NB: Energy consumption refers to oven dry (100 %) pulp. These figures are only indicative numbers, which may deviate ± 10 %, covering a large variety of pulp grades and end products. CSF = Canadian standard freeness.
Source: [TEKES, 1997]

The amount of applied grinding energy in mechanical pulping follows the quality requirements of the end product such as bulk, strength, opacity and surface smoothness. For instance, for groundwood, the energy consumption ranges from about 1 100 kWh/t at 350 ml CSF to about 2 200 kWh/t at 30 ml CSF with no energy recovery. The PGW variant consumes from about 1 100 kWh/t at 350 ml CSF to about 2 300 kWh/t at 30 ml CSF but up to 30 % of the gross energy input may be recovered as hot water by exchanging it against the hot pulp. Up to 30 % of the energy may be recovered as hot water with RMP and up to a total of 40 – 80 % for TMP as steam and an additional 10 – 20% as hot water. With TMP operating at about 6 bar pressure, the process produces up to 2 tonnes of steam per tonne of pulp or about one tonne of steam per MWh of the refiner. Generally, the amount of recovered steam depends on the specific energy consumed and is some 2 tonnes per tonne of pulp at a pressure of 2 to 4 bar.

Generally, more electrical energy is used in TMP pulping than in groundwood pulping. For instance, groundwood pulp used for SC paper and newsprint production consumes in total about 2 200 kWh/t and 1 600 kWh/t respectively, whereas TMP consumes about 3 600 kWh/t and 2 500 kWh/t respectively. However, higher heat recovery in TMP may normally lead to lower overall energy consumption than GW pulping. To compare the overall energy efficiency of the different pulping processes, heat recovery in TMP pulping and usage of reinforcement kraft pulp and filler material in the final product furnish must be considered.

The following simplified calculation shows how the choice of the furnish influences the electricity consumption of the manufacturing of LWC or MFC paper. The reader should bear in mind these aspects when comparing specific electricity consumption figures of integrated mechanical pulp and paper mills.

Examples of used furnishes of LWC/MFC paper are given in Table 5.11.

Table 5.11: Examples of used furnishes of LWC/MFC paper

Pulp grade	Furnish A (%)	Furnish B (%)	Furnish C (%)
Purchased chemical pulp	33	10	0
TMP	34	57	67
Fillers and coating pigments	33	33	33

Source: [169, Nilsson et al. 2007, p. 31]

From a comparison of the resulting electricity consumption shown in Table 5.12, it can be concluded that furnish C with the highest share of mechanical pulp results in significantly higher consumption of electricity per tonne of paper even though it is assumed that the refiners and paper machines in examples A – C are the same. For simplification, electricity-using mill subprocesses other than mechanical pulping and paper machine are not considered here.

Table 5.12: Electricity consumption for different furnishes

Process unit	Furnish A (%)	Furnish B (%)	Furnish C (%)
TMP	3 600 kWh/t TMP pulp	3 600 kWh/t TMP pulp	3 600 kWh/t TMP pulp
Paper machine	800 kWh/t paper	800 kWh/t paper	800 kWh/t paper
TMP and paper machine	2 000 kWh/t paper	2 900 kWh/t paper	3 200 kWh/t paper
Source: [169, Nilsson et al. 2007]			

Table 5.13 shows the energy consumption in the form of heat and electrical power in a Swedish TMP mill with a production of 500 000 t/yr of newsprint and Table 5.14 shows the energy balance for the same mill. The data source is 15 years old but is still considered valid. These data should only be taken as a rough indication of the energy situation and energy balance in an example TMP-based pulp and paper mill that manufactures mainly newsprint. Today heat recovery will often be higher and numerous mills use more energy-efficient refiner technology.

Table 5.13: Energy consumption in an integrated mill with a production capacity of 500 000 t/yr newsprint from TMP

Department	Process heat (MJ/ADt)	Electrical power (kWh/t)
Wood handling	150	50
Refining	0	2 110 (1)
Washing and screening	0	50
Bleaching	0	75
Bleach chemical preparation	0	5
Bleached stock screening	0	35
Power boiler	0	25
Total pulp mill	**150**	**2 350**
Stock preparation	0	235
Paper machine	5 300 (1)(2)	350
Total paper mill	**5 300**	**585**
Effluent treatment	**0**	**39**
Total per tonne of paper	**5 450**	**2 974**

(1) From a Finnish integrated TMP mill, a higher electricity consumption in the range of 2 400 kWh/t was reported for the refining stage (including reject refining) and a lower value of 4 800 MJ/ADt process heat consumption for the paper machine (Finnish comments).

(2) A Swedish newsprint mill reports a heat demand of about 4 GJ/t for drying paper, a need that will be reduced by about 10 % with a future shoe-press installation.

Source: [130, SEPA report 1997]

Table 5.14: Energy balance for an integrated Swedish mill manufacturing 500 000 t/yr of newsprint from TMP

Department	Heat (MJ/ADt)	Electric power (kWh/t)
Pulp mill		
Recovered steam, only for process use (1)	+1 500	
Power boiler, process steam (only own bark)	+1 500	
Turbine generator		+100
External supply	0	+2 289
Consumption	-150	-2 350
Effluent treatment	0	-39
Excess energy from pulp mill	**+2 850**	**0**
Paper mill		
Consumption	-5 300	-585
External supply 1)	+2 450	+585
Total external supply	**2 450**	**2 874**

(1) From the Finnish papermakers' point of view, the heat recovery of the TMP process is significantly higher. For an integrated 250 000 t/yr newsprint mill based on TMP a heat recovery value (recovered steam) of 3 450 MJ/ADt was reported. Thus, in this case there is no need for an external supply of heat (Finnish comments).

Source: [130, SEPA report 1997]

The energy balance and the degree of heat recovery depends, among other things, on the energy prices in the given country. If the energy from the grid is relatively cheap, mills may only run a small power plant for steam production (e.g. a bark boiler) that is needed for the paper machine and the TMP mill will be operated with purchased electricity. The recovered energy from the refiners will be sufficient to produce the heat needed for a second paper machine. Countries with comparatively higher prices for electricity tend to install larger power plants for power generation on site resulting in generation of a surplus of heat (less heat recovery).

In Table 5.15 the values for energy consumption of a Finnish non-integrated CTMP mill are compiled.

Table 5.15: Energy balance for a non-integrated Finnish CTMP mill (400 ml CSF)

Department	Heat (MJ/ADt)	Electrical power (kWh/t)
Pulp mill		
Recovered steam, only for process use	+2 700	
External supply	0	+1 650
Consumption	0	-1 600
Effluent treatment	0	-50
Excess energy from pulp mill	**+2 700**	**0**
Pulp dryer		
Consumption	-5 600	-150
Steam boiler (wood residuals & fuel oil)	+2 900	+150
Total external supply	**2 900**	**1 800**

Examples of specific energy consumption data of some integrated mechanical pulp and paper mills (coated and uncoated wood-containing papers) taken from questionnaires filled in by operators are given in Table 5.16. The data refer to whole mills, i.e. they include different types and shares of mechanical pulps, in some cases a share of RCF processing, the paper machine and supporting activities such as raw and waste water treatment. For these mills, it is not specified which energy-saving measures they have implemented.

Table 5.16: Examples of specific energy consumption of some integrated mechanical pulp and paper mills (reference years: 2006 and 2008)

Paper grade manufactured	Process heat (kWh/t) (1)	Electrical power (kWh/t)	Total energy (kWh/t)	Fibre furnish
MFC, LWC paper	1 534 (2)	2 642	4 175	100 % hydrogen peroxide bleached TMP (31 % fillers and pigments)
LWC paper	1 306	2 091	3 397	70 % mechanical pulp (GW, TMP), 30 % purchased chemical pulp
LWC paper	1 626	1 514	3 140	53 % mechanical pulp, 40 % purchased chemical pulp, 7 % paper for recycling
LWC paper	1 775	1 217	2 992	55 % mechanical pulp (GW, TMP), 45 % purchased chemical pulp
LWC, SC paper	1 025	1 375	2 400	50 % paper for recycling, 35 % mechanical pulp, 15 % purchased chemical pulp
Folding boxboard	1 495	1 197	2 692	65 % mechanical pulp (GW), 35 % purchased chemical pulp

NB: MFC = machine-finished coated paper; LWC = light-weight coated paper.

(1) Heat consumption figures exclude heat for electricity production. Energy consumption of chemical pulp production is also excluded. To convert (kWh) into (MJ) multiply (kWh) by 3.6.

(2) 1 182 kWh/t of the 1 534 kWh/t process heat used is recovered heat from TMP refiners (41 % recovery of generated thermal energy in the form of steam). The net heat input is thus only 352 kWh/t.

Sources: [248, Hamm 2007], [questionnaire 2009].

When interpreting these data, the reader should especially consider the aspects discussed in Section 2.5 and the fact that specific energy consumption is influenced significantly by the type of mechanical pulp (e.g. TMP or GW), the furnish used, i.e. the share of mechanical pulp, the share of purchased chemical pulp and of recycled fibres as pulp components, and the percentage of fillers and coating pigments.

There is a broad variation of both mechanical and purchased chemical pulp shares in the recipes of wood-containing paper depending on individual grade qualities. Furthermore, many paper products in the mechanical paper range contain recovered fibre too. For instance, the mechanical pulp share of total fibre furnish in UPM-Kymmene’s uncoated (newsprint, SC paper) and coated (MFC, LWC and MWC paper) wood-containing papers varies between 0 and 90 % and 34 % and 97 % respectively depending on paper grade and relative paper quality. The highest share of purchased chemical pulp of UPM SC paper is about 20 % and UPM MWC over 40 %.

Such a broad range of fibre composition necessarily leads to relevant variations in specific energy consumption in wood-containing paper production: power consumption for thermomechanical pulp (TMP) is normally higher than for pressurised/stone groundwood (PGW/SGW) and much higher than for paper for recycling (RCF) processing. In return, TMP has the benefit of steam recovery, substantially reducing the net heat demand of the subsequent integrated papermaking process.

To summarise, the indicative energy consumption levels for mechanical and chemimechanical pulping can be found in Table 5.17.

Table 5.17: Indicative energy consumption levels for heat and power for different types of integrated mechanical pulp and wood-containing paper and board mills

Type of paper and board mill (furnish)	Indicative energy consumption level for net process heat in kWh$_{th}$/t (1)	Indicative energy consumption level for electricity in kWh$_{e}$/t (1)(2)
Wood-containing SC, MFC, LWC paper (80–100 % TMP of fibre in final paper)	800 – 3 300 (3)	1 700 – 2 900
Wood-containing LWC paper (>50% mechanical pulp, varying share of purchased chemical pulp, deinked RCF, and fillers & coating pigments)	1 300 – 3 000	1 200 – 2 700
Wood-containing SC paper	300 – 1 700	1 900 – 2 600
Wood-containing newsprint (>50% mechanical pulp)	400 – 900	2 500 – 3 000
PGW-based grades	1 000 – 2 000	1 800 – 2 300
Wood-containing folding boxboard (>50% mechanical pulp)	1 500 – 3 000	1 200 – 2 600
CTMP (referred to tonne of pulp)	≈ 0 – 300	2 300 – 3 000

(1) Energy-saving techniques, furnish, pulping process, wood species and especially the quality requirements of the pulp have a significant influence on the specific energy consumption of mechanical pulp-based paper mills (the lower the freeness value CSF, the higher the electricity consumption).

(2) For mechanical pulp-based paper production, recycled fibres and purchased chemical pulp may also be used as pulp components. The higher the content of mechanical pulp, the higher the consumption of electricity per tonne of paper, a fact which is expressed by the upper end of the range.

(3) Figures do not consider the use of recovered secondary energy, such as recovered steam from TMP refiners. TMP heat recovery energy originates from electricity used for the TMP process. If for TMP-based pulp and paper mills the recovered steam from refiners would be offset against the actual heat consumption, the heat balance of the whole pulp and paper mill may result in significantly lower heat consumption of around 400 kWh/t (in case of a high share of TMP and advanced heat recovery).

The following system boundaries were considered for the indicative energy consumption levels given in Table 5.17 above:

(1) The energy consumption levels refer to entire mills' net production and include pumps, agitators and compressed air. Peripheral subsystems for raw and waste water, sludge and rejects such as dissolved air flotation, reject screw presses or sludge presses, and waste water treatment are also covered.
(2) The energy consumption figures consider the process heat and electricity consumption for both pulp and paper manufacturing (the amount of pulp considered is the one necessary for paper production at the site). If deinked recycled fibres are used and manufactured on site, the energy consumption of RCF processing is included. If some chemical pulp is used, the energy consumption of chemical pulp production is excluded.
(3) The values include all processes starting with the wood yard and the feed conveyor for slushing of purchased chemical pulp (if used) and ends after the last slitter winder, i.e. before converting.
(4) Values for specific energy consumption (SEC) relate to net process heat demand, i.e. the heat input is reduced by the recovered and reused heat (mainly relevant for TMP and CTMP refiners).
(5) The figures for power consumption do not consider the primary energy input of fuels for the generation of power but represent process heat and power used. Electric infrared (IR) dryers are part of the power consumption.
(6) For heat, the consumption values refer to the thermal capacity of the used steam and the lower calorific value for gas in the case of IR or air dryers. Gas infrared dryers are included in the heat consumption, if applied.

5.2.2.8 Noise

The debarking plant and, to a lesser extent, the paper machine and the refiners generate noise that can be controlled by carefully insulating the debarking house. Trucks and other vehicles used to transport the great amounts of raw materials and products can cause noise in the vicinity of the mill (see Section 2.9.13).

5.3 Techniques to consider in the determination of BAT

This section describes techniques (or combinations thereof), and associated monitoring, considered to have the potential for achieving a high level of environmental protection in the activities within the scope of this document. The techniques described will include both the technology used and the way in which the installations are designed, built, maintained, operated and decommissioned.

It covers environmental management systems, process-integrated techniques and end-of-pipe measures. Waste prevention and management, including waste minimisation and recycling procedures are also considered, as well as techniques that reduce the consumption of raw materials, water and energy by optimising use and reuse. The techniques described also cover measures used to prevent or to limit the environmental consequences of accidents and incidents, as well as site remediation measures. They also cover measures taken to prevent or reduce emissions under other than normal operating conditions (such as start-up and shutdown operations, leaks, malfunctions, momentary stoppages and the definitive cessation of operations).

Annex III to the Directive lists a number of criteria for determining BAT, and the information within this chapter will address these considerations. As far as possible, the standard structure in Table 5.18 is used to outline the information on each technique, to enable a comparison of techniques and the assessment against the definition of BAT in the Industrial Emissions Directive.

This section does not necessarily provide an exhaustive list of techniques which could be applied in the sector. Other techniques may exist, or may be developed, which could be considered in the determination of BAT for an individual installation.

Table 5.18: Information for each technique described in this chapter

Headings within the sections
Description
Technical description
Achieved environmental benefits
Environmental performance and operational data
Cross-media effects
Technical considerations relevant to applicability
Economics
Driving force for implementation
Example plants
Reference literature

In this section all relevant techniques which are commercially available at the time of writing (2013) for prevention or reduction of emissions/waste and reducing consumption of energy and raw materials, both for new and existing installations, are given. This list of techniques is not exhaustive and may be continued when reviewing this document. The techniques cover in-process measures and end-of-pipe techniques as well and represent possibilities for improvement to achieve integrated prevention and control of pollution.

5.3.1 Emission control from the wood yard

The wood logs used for mechanical pulping are normally sprinkled with water to prevent drying out. This may require water collection systems in the wood yard in order to prevent the uncontrolled release of organic substances measured as COD and toxicity (see Section 2.9.2.1).

5.3.2 Dry debarking

Refer to Section 2.9.2.2.

5.3.3 Minimisation of fibre losses when removing impurities from the mechanical pulping process

Description
The most common impurity in the mechanical pulping process is sand, which can wear out the process equipment if not removed and can disturb the papermaking process. Other possible impurities are in the wood material such as pieces of metal or improper wood material, e.g. rotten wood or wood with material properties which deviate significantly from the properties of the wood used in the pulping process.

The minimisation of reject losses starts from wood harvesting. Improper wood material should already be separated there. Wood and chips should be handled on paved wood yards in order to prevent the mixture of gravel and sand with the raw material going to the process. Pieces of metal must be removed in the chip manufacturing process. The sand that usually may enter the process to some degree is removed by using hydrocyclones. Hydrocyclones are also used to remove some fibre material with poor bonding ability.

The rejected material from the hydrocyclones consists of small stiff particles of fibre with a small specific surface called chops, and particles of sand, if any remain within the process.

The separation of contaminants from the pulp is normally carried out by use of centrifugal cleaners or centricleaners, where particles heavier than fibres are separated, or pressure screens equipped with holes or slots, where oversized material is separated.

The rejects from centricleaners also contain a large amount of fibre material. This material is recovered by adding several centricleaners in cascades. With this arrangement, considerable amounts of raw material can be saved and the suspended solids load sent to the effluent treatment can be reduced. Some mills today reconsider centricleaners in the pulp line and consider narrow slotted screen baskets with high fractionation efficiency as an alternative.

Achieved environmental benefits
Reduction of fibre losses through preventive measures and efficient cleaning stages.

Environmental performance and operational data
Good chip washing removes sand and other abrasive components from the chip flow because impurities wear out machines and especially refiner segments and cause extra costs for mills. Mills normally have magnetic traps for metals over the chip conveyors which catch metals from the chip flow but non-magnetic metals cannot be caught. Non-magnetic metals cause damage to machines and cause production shutdowns in mills.

The main drawback when using hydrocyclones is the low pulp consistency (0.5 – 0.7 %) which corresponds to water volumes of 150 – 200 m^3/ADt. Most of that water can be recirculated and used for other purposes in the pulp mill. Many mills use hydrocyclones in the pulping line and at the inlet to the paper machine headbox. There are also many mills which have hydrocyclones only at paper machines.

Cross-media effects
The reduction of fibre losses during the removal of impurities decreases the total power consumption per tonne of pulp.

Technical considerations relevant to applicability
The addition of cleaning stages can be applied at both new and existing mills.

Economics
No information provided.

Driving force for implementation
The driving force for adopting this measure is to increase raw material and energy efficiency and to protect machinery and equipment.

Example plants
Numerous plants in Europe.

Reference literature
[14, CEPI 1997].

5.3.4 Minimisation of the disposal of process residues and sludge to landfill by efficient dewatering and incineration with energy recovery

Description and achieved environmental benefits
Final cleaning rejects, fibre losses and sludge that are generated during pulp and paper manufacturing and water treatment must be dewatered before final disposal or further treatment. Dewatering is carried out by means of wire presses or screw presses. Dewatering aims at removing water from the sludge as much as possible. Different types of mechanical equipment are available for this operation:

- belt presses (twin wire presses)
- screw presses
- decanter centrifuges.

Many installations have installed belt presses which have a reliable function and produce a DS content of 40 – 50 % with fibre sludge and 25 – 40 % with mixed fibre/biological/chemical sludge.

Screw presses can be used in two ways: either to increase the DS content after the belt press dewatering, by which a DS increase of approximately 10 % can be obtained; or for direct dewatering as a higher DS content can be obtained by screw presses compared to dewatering with a belt press.

After dewatering, the sludge and rejects can be dried (see Section 2.9.6.1.4) in order to increase the heating value of the materials for energy recovery in incineration plants. Incineration further reduces the amount of wastes sent from mechanical pulping to landfill disposal and recovers the energy content of the waste fractions. Incineration of the bark is carried out in bark boilers or in co-combustion plants using mixed fuels. Particularly for rather low DS sludge, fluidised bed boilers are presently the best option (see Section 2.6.1.2.3). These fluidised bed boilers can be run with 100 % sludge although the use of a support fuel is more common (like coal or oil). The requirement for the support fuel depends on the DS and the ash content of the sludge. Generally, at least 35 – 40 % DS is required for spontaneous combustion.

For detailed discussion of incineration with energy recovery including emission control techniques, the reader is referred to Sections 2.6 and 2.9.7.

Environmental performance and operational data

The dewatering processes have been used in many pulp and paper mills. Incineration in bark boilers and other incinerators are common techniques in the sector (see Sections 2.6.1 and 2.9.7 and 5.3.10).

The heating value of rejects and sludge and the overall burning results can be improved by applying improved dewatering equipment such as screw presses. The dryness target should be 45 %, when the ash content is below 30 % and reaching for instance 65 – 70 % at 50 % ash content. However, the sludge mix and its material characteristics may vary significantly between mills and different sludges have different dewatering characteristics. For instance, excess sludge from biological treatment has relatively poor dewatering properties (18 – 22 % DS) if not mixed with other materials; by contrast, primary sludge from primary clarifiers is easier to dewater (35 – 55 % DS) but can also be mixed with other material for better dewatering.

When the amount of sludge is high and the proportionate amount of all the fuels is over 30 %, the shredding of sludge followed by palletising or briquetting can be economical in increasing its bulk density sufficiently to render combustion easier. The sludge and other solid fuels can be fed alternately or in addition through a preheating treatment. Indirect drying utilises low- or medium-pressure steam, generated at the mill, which at best could still be used elsewhere as lower pressure steam. The direct drying method uses the flue-gases as a heat source.

The improvement of the overall combustion is case-specific. It can be achieved by adding efficient fuel pre-demoisturisation for certain solid fuels, by mechanical dewatering of the combustion materials or by drying them with heat. In general, when the initial moisture content of the fuel is in the range of 45 – 50 %, a 10 – 15 % improvement in heat economy has been recorded by increasing the dryness to 55 – 60 %. The drying of sludge up to 80 % dryness is possible.

Cross-media effects

In sludge dewatering, water emissions are increased through the dewatering of the sludge and are usually treated effectively in the biological waste water treatment plant. If the dewatered or dried rejects and sludge are incinerated, the energy content is recovered. The usable energy value depends on the achieved DS content before incineration and the composition and mixture of the material to be burnt. Generally, the energy content of the rejects and sludge that exceeds the energy needed for evaporation of the moisture in the rejects is surplus energy. Usually only ash from incinerators remains as solid waste/residue that can either be landfilled or used for other purposes (e.g. the construction industry).

Technical considerations relevant to applicability

For economic and environmental reasons, the drying of rejects and sludge is applied only if excess heat is available and the added heat can be utilised for this purpose (see Section 2.9.6.1.4). The incineration of process residues and waste is applicable to new and existing mills.

Economics

No information provided.

Driving force for implementation

The driving force to adopt this measure is to reduce waste to be disposed of in landfills.

Example plants

Numerous plants in Europe.

For sludge dewatering, efficient presses are used increasingly in order to achieve high dryness levels. Incineration in bark boilers and other incinerators is common in the sector (see Sections 2.6.1 and 2.9.7 and 5.3.10).

Reference literature
[75, Pöyry 1997], [71, Pöyry 1992].

5.3.5 Efficient washing and process control

Description
The purpose of pulp washing by means of drum washers or wash presses is mainly to separate the organic material dissolved in refining from fibres. The washing process is in principle similar to washing in chemical pulping, but the efficiency requirements are less demanding. A washing stage before refining is also applied in some mills (mills pretreating softwood by combining pressurised preheating, high compression and impregnation to improve pulp properties).

Drum washers like the ones used in chemical pulping (e.g. displacement washers) cannot be used due to poor web formation on the drum. Instead, the dilution–extraction washing principle is used for mechanical pulps. The pulp is diluted with the wash water to low or medium consistency and then dewatered on efficient presses to a high consistency. This can be done either on screw presses, twin wire presses or twin roll presses. The washing efficiency is usually 65 – 70 % calculated from the recovered organic material. This corresponds typically to one washing stage. With improved washing, it is possible to increase the washing efficiency by up to 90 % by installing more washing equipment in series (*Source*: data from a supplier, 2009).

Achieved environmental benefits
With improved washing, it is possible to concentrate the organic material in a smaller volume of effluents and reduce the carry-over of COD to the paper or board machine. This improves the runnability of the paper/board machine and reduces the need for papermaking chemicals. This may also be an asset if the effluents are further treated separately from the paper or board effluents, e.g. in an anaerobic treatment.

Environmental performance and operational data
Washing has become a standard technique for most integrated mechanical pulp mills that have peroxide bleach plants. All market bleached CTMP mills have extensive multistage washing installed.

Cross-media effects
No major cross-media effects. Better washing will in most cases generate higher COD discharge before treatment.

Technical considerations relevant to applicability
Efficient washing is used both in integrated TMP and CTMP systems to reduce the carry-over of detrimental substances to the paper/board machine, but is also required for market chemithermomechanical pulps.

Economics
No information provided.

Driving force for implementation
The improved washing improves the runnability of the paper/board machine, reduces sheet breaks, increases intervals for the cleaning of wires, felts and rolls on the paper machine and reduces the need for papermaking chemicals. It may also create better circumstances for an anaerobic treatment of the CTMP effluent stream. Quality aspects of finished board and paper and reducing operating costs are another reason for the consideration of this technique.

Example plants
A few plants in Europe and in North America.

Reference literature
[14, CEPI 1997], [75, Pöyry 1997].

5.3.6 Water recirculation in pulp and paper mills

Description
The degree of recirculating water within the pulping process is highly dependent on the suitability of a specific water stream for reuse and the level of contaminants that are allowed to accumulate in the process. In any case there must be bleedout points for sewering and disposal of contaminants in an effluent treatment system. Normal water make-up is done in non-integrated mills with fresh water. In integrated mills, paper machine white water covers most of the process water needs of the pulp mill.

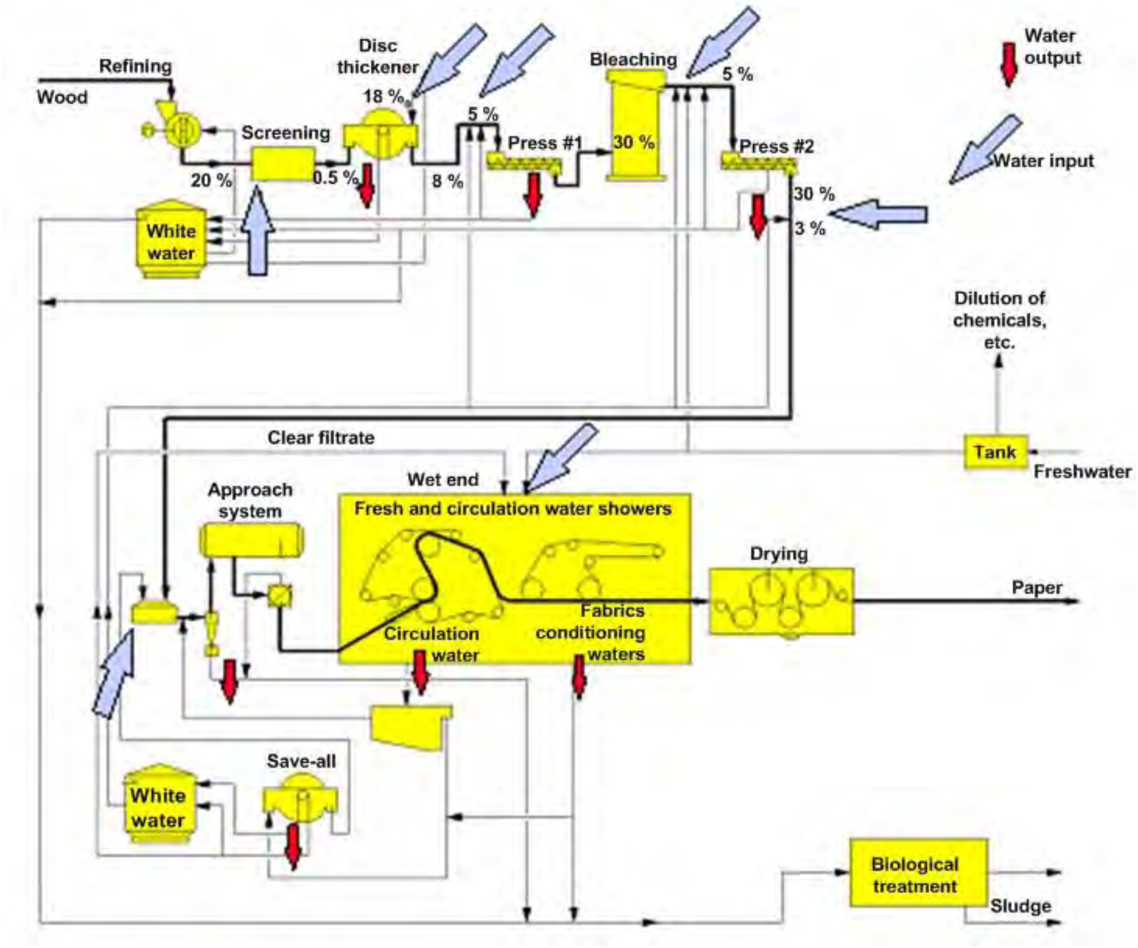
Inside the mechanical pulping process the recycle stream candidates are various filtrates, pressates or similar from chip or pulp handling and cloudy or clear white water generated by fibre save-all equipment. These streams are fed to specific uses according to their availability and suitability. Many factors influence the degree to which water recycling is suitable in pulping. Undesired compounds are generated during wood or chip pretreatment, refining and bleaching and some are brought in to integrated mills with the counter-current flow of paper machine white water used in the pulping department.

At the process points where dissolved materials are formed, there must also be dilution to effectively carry away the undesirable compounds from the wood material or pulp. Otherwise they are carried to the succeeding process stages with adverse effects. Additionally, in the recycling and discharging of waters, a trade-off may be necessary to reach an economical balance. For instance, discharging water from the pulping process by sewering more clear water instead of cloudy white water better captures fibre material in the pulp, but also retains more unwanted resinous compounds in it. In general terms, the proper selection of water reuse has to consider aspects such as the colour of the process water, the pH, the dissolved and suspended solids content including residuals of used pulping chemicals that can cause unwanted chemical reactions or even increased pulping chemical consumption.

Items forming the basis of water use reduction and recycling in pulping are:

- use of the counter-current water flow principle and separation of water loops (e.g. separation between mechanical pulp mill, peroxide bleaching and paper machine);
- use of disc filters for filtration of paper machine white water and for mechanical pulp mill process water;
- improved fibre recovery by sewering clear instead of cloudy white water and in integrated mills by using excess white water from the paper mill in pulping;
- rebalancing of tank volumes, especially white water volumes for coping with process fluctuations, start-ups and shutdowns;
- high-consistency thickening of pulp prior to feed to drying (or paper machine), which is effective both for non-integrated and integrated mills;
- clear white water usage in equipment cleaning showers and if acceptable, as flushing water.

In Figure 5.18 the main water sources (water input) and sinks (water output) in an integrated mechanical pulp and paper mill are given. Fresh water is introduced in the papermaking process mainly through the paper machine forming section and the press section showers, after which it is fed upstream to various washing and diluting processes. Water loops are clearly separated by thickening steps before stock is diluted with some fresh water to adjust consistency (the percentages given in Figure 5.18 refer to consistency) and to dilute the stock with clean water before it enters the approach system.



Source: [26, Edelmann et al. 1997]

Figure 5.18: Main water sources and sinks in an integrated mechanical pulp and paper mill

Achieved environmental benefits

With advanced closure of the water circuits, the effluent discharge and fibre losses to the sewer are reduced. The degree of water reduction depends on the paper/board grade. In integrated mills, efficient water management includes the counter-current reuse of paper machine white water.

Environmental performance and operational data

The principles discussed can be used with no significant impact on the pulping process. Table 5.19 shows the achieved levels of water use of some example mills for different pulp and paper grades. Specific measures to control the water system are only indicated if provided.

Table 5.19: Achieved levels of water use of some example mills that manufacture wood-containing paper with different fibre furnishes

Example mills	Type of pulping and mix of raw materials used	Paper grade(s) produced	Water consumption (m^3/ADt) (1)	Applied measures for water management
SCA Ortviken, SE	100 % TMP pulp	Coated paper, improved newsprint (NP), NP	15	Internal cleaning of white water and recycling of process water
Holmen Hallsta, SE	79 % TMP, 12 % GWP, 9 % DIP	Magazine, SC paper, book paper & newsprint	11	No information provided
UPM Stracel, FR	100 % TMP pulp	MFC+LWC paper	13.8	
Myllykoski Plattling, DE	33 % GW, 21 % purchased chemical pulp, 7 % DIP, 39 % fillers & pigments	LWC paper	12.5	Two water loops with DAF for process water in the deinking plant
SE Maxau, DE	TMP, PGWP, GWP, deinked RCF	SC-A, SC-B paper, newsprint	9.8	No information provided
UPM Augsburg, DE	35 % GW pulp, 50 % RCF deinked, 15 % purchased chemical pulp	LWC, SC paper	9.0	No information provided

(1) The values for water consumption include both pulping and papermaking.

For more existing data on the water use of integrated mechanical pulp and paper mills, the reader is referred to Section 5.2.2.2 and especially to Figure 5.7 which also includes information on water flows of CTMP mills.

Mechanical pulp mills are, with few exceptions, integrated with paper production. This means that water for the pulp mill usually comes from the paper machine and the effluents from the pulp mill are directed to the sewer, where waste water from both the pulp mill and paper machine is mixed and subsequently treated together.

Achievable specific volumes for water use for integrated mechanical pulp and paper mills are based on graphic paper: 9 – 15 m^3/t of paper (e.g. MFC, LWC, newsprint paper, SC-A and SC-B paper). The reasonable extent of water circuit closure also depends on local conditions. Factors such as climate, availability, source and quality of fresh water and the type, quality and sensitivity of the receiving watercourse may influence technical solutions.

Mechanical pulp mills that also run a DIP line to cover a certain share of the fibre furnish may have a slightly lower fresh water demand than purely mechanical pulp and paper production.

The on-line monitoring of combined pulp mill effluent flow rate and the lab monitoring of suspended and dissolved solids, pH, temperature and organic content as COD are recommended. Also on-line suspended solids or turbidity meters can be used.

Cross-media effects

More dissolved or colloidal matter can be retained with pulp as a result of efficient water reuse in pulping. This must be compensated in the paper machine to avoid for instance an increase in paper web breaks, changes in wet-end paper web retention or sheet drainage.

Technical considerations relevant to applicability

The degree of water reduction depends on the paper/board grade. The suitability of specific process water stream(s) for reuse or recycling must be assessed to avoid adverse effects on the process itself and the product. Existing mills may need to rebalance their filtrate, white water and pulp tank capacities in order to keep fresh water make-up and effluent bleedout to a minimum.

Water and energy balances are often carried out simultaneously because the water temperature in the pulping rises along with the degree of water loop closure.

Economics
Because most mechanical pulp mills are integrated with paper production, the measures to improve water reuse are typically linked to water use reduction in both pulping and papermaking.

The investment required for an integrated mill, with 700 ADt/yr production and aiming at a reduction of fresh water consumption from 20 m^3/t to 10 m^3/t, is about EUR 10 – 12 million.

Driving force for implementation
Reduction of hydraulic load and suspended solids load is the driving force for implementation. More concentrated waste water can be treated more effectively with a lower investment and lower operating costs.

Example plants
Numerous modern mills apply efficient water recirculation. Many old mills have also carried out the listed measures.

Reference literature
[14, CEPI 1997], [26, Edelmann et al. 1997].

5.3.7 Substitution of NaOH by $Ca(OH)_2$ or $Mg(OH)_2$ as the alkali in peroxide bleaching

Description
The substitution of NaOH by $Ca(OH)_2$ or $Mg(OH)_2$ as the alkali in peroxide bleaching.

Achieved environmental benefits
Reduction of COD emissions.

Environmental performance and operational data
The technique is used by some mills (e.g. SCA Laakirchen, MD Papier Plattling). It can lead to approximately 30% lower COD emission loads.

Cross-media effects
No information provided.

Technical considerations relevant to applicability
Applicability for highest brightness levels may be restricted.

Economics
No information provided.

5.3.8 CTMP mill effluent treatment – closing up the water circuits by use of evaporation and burning of the concentrates

Description and achieved environmental benefits

There are a few alternatives of how to treat the waste water from CTMP plants and they are described below.

- Activated sludge treatment in one or two stages with or without chemical treatment (see Section 5.3.12). At the time of writing (2013) the activated sludge method is the most common one and, if correctly designed, very effective. A BOD reduction of 98 % and a COD reduction of 85 % can easily be reached. A drawback using this method is the fairly high concentrations of nutrients in the effluent. Therefore, some CTMP plants have had to complete the treatment with an additional chemical treatment (see Section 3.3.14).
- Internal chemical treatment of the white water of the first washing stage plus activated sludge treatment of the rest. There is one CTMP plant treating this white water with a chemical, which makes it possible to remove extractives and fines in a subsequent flotation stage. At the same time a 40 – 50 % COD reduction was reported. A drawback of this method is the fairly high chemical costs.
- Combination of an anaerobic and aerobic treatment of the waste water. There was only one plant in Sweden (SCA, Östrand) using this technique. SCA Östrand abandoned the anaerobic treatment. Instead the waste water from the softwood CTMP plant has been treated together with kraft pulp effluent aerobically since 2004. Evaporation of the most contaminated waste water and burning of the concentrate plus activated sludge treatment of the rest is another option. Worldwide, new evaporation techniques have been successfully implemented in a few mills which have the possibility to send the concentrates to a kraft pulp mill recovery system. In this case, the concentrate is burnt in a recovery boiler of an adjacent kraft pulp mill. The evaporation alternative is most suitable in such a case, when the pulp capacity has to be increased and the biological treatment plant is becoming too small. The clean condensate from such an evaporation plant can be used in the CTMP plant as process water, lowering the fresh water consumption considerably. Evaporation is also an alternative if tertiary treatment is considered necessary, i.e. in such cases where the nutrient concentrations in the effluent have to be lowered.
- Evaporation of all the effluents and incineration of the concentrates in a recovery boiler. This results in zero discharge of liquid effluents. The former Millar Western Pulp mill (Meadow Lake), in Saskatchewan, Canada, now produces up to 325 000 air dry tonnes (ADt) of bleached CTMP annually, well above its initial design capacity of 240 000 ADt. The mill commenced operations in 1992. The problem of effluent discharge to waterways was decisively dealt with by construction of a zero liquid effluent discharge facility. All of the process waste water is treated and 80 % is recycled as distilled water for reuse in the process. The remaining 20 % of the water is lost in the drying of the final pulp product, and by evaporation from effluent and treated water holding ponds. The effluent treatment system uses conventional evaporation, concentration and incineration unit operations. The CTMP mill converts aspen hardwood using the alkaline peroxide pulping (APP) process into the finest tissue and writing grade market pulp. Their zero effluent system is described below because it contains a number of innovations, which are of general interest for the sector. It has opened the door for use in other industrial applications where the receiving water body cannot effectively assimilate an industrial discharge.

The Meadow Lake water recycling system consists of the six unit operations which are shown in Figure 5.19 and Figure 5.20:

- suspended solids removal (Krofta clarifiers including an option to use settling ponds);
- mechanical vapour recompression evaporation (1.5 times more capacity than the design flow rate to provide flexibility and catch up ability);
- steam-driven concentration;
- concentrate incineration;

- distillate polishing for general mill usage;
- treatment of lake water make-up.

As shown in Figure 5.19, the only water that needs replacing is that which is lost through evaporation and is about 2 m^3/ADt.

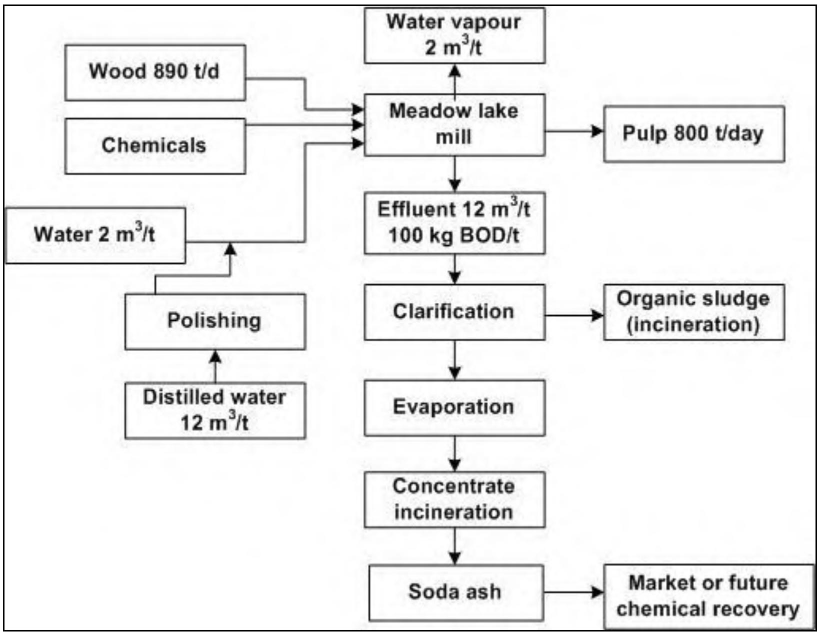
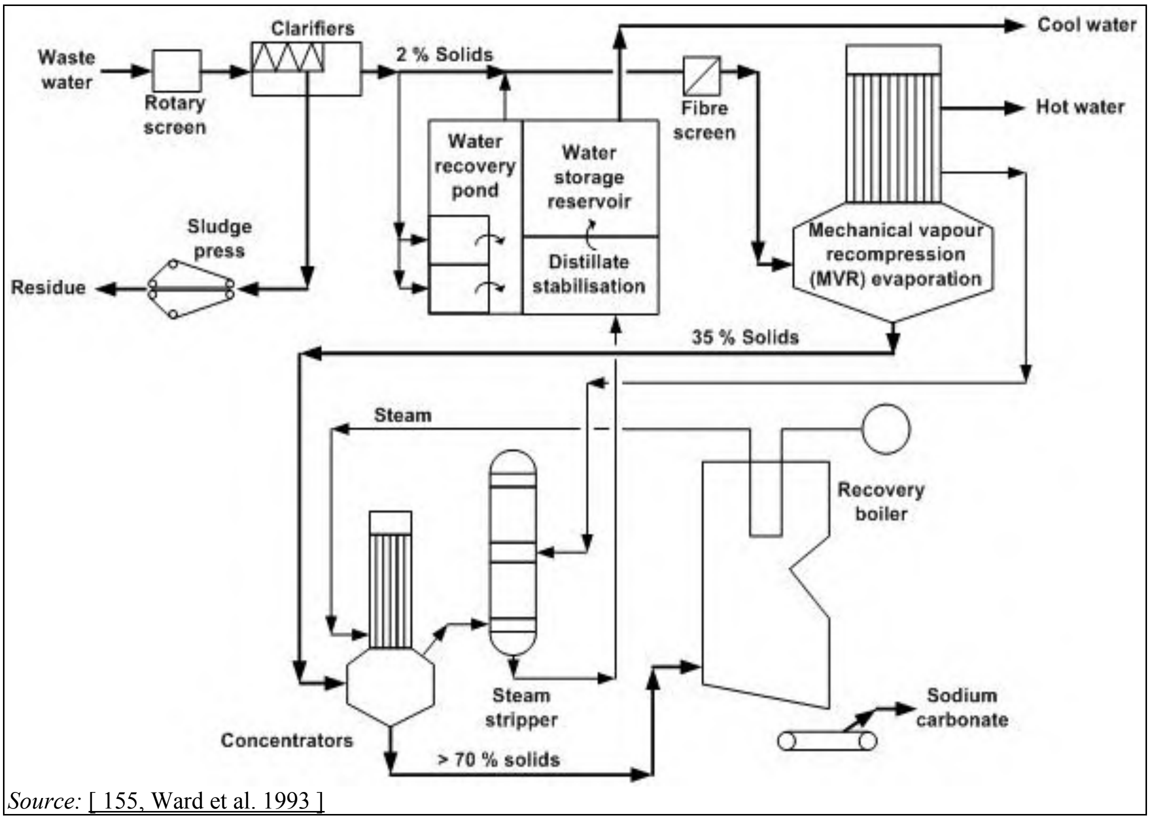


Figure 5.19: Water recycling system at the Meadow Lake BCTMP mill

Evaporation technology is used to close the water loop and achieve zero effluent status [44, Evans 1992].

Figure 5.20 shows the effluent process concept including major flows of the water through the various treatment steps.



Source: [155, Ward et al. 1993]

Figure 5.20: **Zero liquid effluent process concept at the Meadow Lake BCTMP mill**

All process water streams are pumped to the primary treatment, which serves to remove suspended solids. Captured solids are dewatered and incinerated. Clarified water can be stored in outside ponds that provide reserve capacity between the pulp mill and the evaporators.

Clarified water is delivered to the mechanical vapour recompression (MVR) evaporators where the concentration of total solids is increased from 2.5 % to 35 %. The distillate from the MVR evaporators is segregated into fractions internally to prevent contamination of the clean distillate, which account for 85 % of the distillate produced. The distillate fraction which has most of the VOC is stripped of most of those organics in a steam stripper for incineration in the recovery boiler. Most of the evaporator distillate can be used directly in the pulp mill at 65 °C. However, some demands exist for water at 20 – 30 °C. To provide this, some of the distillate is cooled and the small fractions of volatile organics are removed in a biological stabilisation pond.

The solids level of the concentrate from the MVR evaporators is increased to 70 % DS in two steam-driven concentrators and incinerated in a chemical recovery boiler. The smelt from the recovery furnace is cooled and solidified on a conveyor then deposited in a bunker.

Environmental performance and operational data
The water recycling system causes no losses in pulp production and has no negative impact on pulp quality. The company has developed some unique methods of employee involvement in management decisions. Training was crucial to the successful start-up at Meadow Lake. New employees were given a minimum of three months of instruction in their positions before start-up was attempted. Ongoing coaching for skill development has kept the workforce at the cutting edge of technology and work practices. Safety at all costs has led to employee commitment to this essential programme that keeps morale high and insurance premiums low. Small teams are formed regularly and have the ability and authority to make changes to the process where benefits from such changes can be demonstrated.

The monitoring of the processes and the equipment is of the utmost importance in a zero effluent facility. Different testing programmes are running, such as the dynamic monitoring of fouling rates and corrosion and an ISO 9002 certified quality management system. These are supplemented by an analytical lab to keep a careful watch on the facility. One example is the metals monitoring programme which tracks ions in the system and permits proactive work to take place on corrosion, fouling and scaling.

Cross-media effects
Information on the energy balance compared to a conventional system was not available. The solid waste loop is not yet closed but in conventional systems it is not closed either. No other cross-media effects are known.

Technical considerations relevant to applicability
Closing up the CTMP plant is possible for both new and existing mills. The limitation is the high capital cost of evaporation and the recovery boiler (as in Meadow Lake). The described concept was built for a greenfield mill in 1992 and requires a lot of space, which existing mills often do not have. The solution will depend on local conditions and is often different for market CTMP mills compared to integrated CTMP manufacturing. When using evaporators, the bleaching of CTMP has to be modified. For instance no sodium silicates can be used because of scaling.

Economics
The system has operating costs that are competitive with conventional bleached CTMP water and secondary effluent treatment systems. After the optimisation period, the effluent treatment operating costs at Meadow Lake are now below the cost of conventional secondary treatment. However, high investment costs for oversized evaporation and liberal sizing of the recovery plant and storage capacity for effluents (for three days) arose at the start-up phase. The attractiveness of the zero liquid discharge approach is augmented by potential chemical and energy recovery that can be used to reduce the cost of production and amortise capital costs. Data on specific costs are not available. Changes in aqueous effluent regulations do not effect zero effluent mills, which is an economic advantage.

Driving force for implementation
At the Meadow Lake site water is scarce and the possible receiving water body is small. A conventional effluent treatment system would have necessitated the drilling of wells tapping into an underground aquifer to provide enough dilution water to thin the effluent discharge and keep the river flowing year round. This option was not acceptable to the owners of the company and the decision was made to pursue zero effluent technology.

The zero effluent concept may receive more acceptance in those cases where more strict effluent discharge limits have to be met. Besides solving the COD discharge problem, evaporation /incineration will allow a considerable reduction of fresh water use by the reuse of evaporator condensate, with the option to recover caustic when a causticising plant is added. The closing up of the chemical cycle will not only reduce the inorganic salts discharged to the receiving water body, but will also contribute to the reduction of operating costs.

Example plants
Examples are the BCTMP pulp mill in Meadow Lake and the Tembec Chetwynd BCTMP pulp mill in Canada, Stora Enso Fors (Sweden), M-Real Joutseno and Kaskinen (Finland), Klabin (Brazil), and Sun Paper Yanzhou (China).

Reference literature
[43, Evans 1991], [44, Evans 1992], [45, Evans et al. 1993], [53, Fromson et al. 1993], [136, Sweet et al. 1993], [155, Ward et al. 1993].

5.3.9 Extensive recovery of secondary heat from TMP and CTMP refiners and reuse of recovered steam in paper or pulp drying

Description

The working efficiency of a TMP refiner is relatively poor. Nearly all electrical energy put into the refining process is transformed into heat. The majority of the energy is bound in the plate gap containing a specific latent heat for the vaporisation of water (the generation of steam). Heat is also bound to heated water and heated fibre material.

'Heat recovery' means the reuse of all of the heat which is created in a TMP process. A TMP plant consists of main line refiners, which might be just one main line refiner (e.g. RTS process) or two or three in series, and reject refiners, which usually number one or two.

From the heat recovery point of view, the various refiner types can be divided into two groups:

- refiners which have higher pressure at the outlet than at the inlet: single disc (SD) and conical disc (CD) refiners;
- refiners which have the same pressure at the inlet and at the outlet: twin and double disc (DD) refiners.

Figure 5.21 shows the energy and mass flows in a SD or CD refiner where the incoming wood chips and water are transformed into mechanical pulp and thermal energy by using electrical power. The generated heat can be recovered as high-pressure steam, blowback steam that can be recovered as low-pressure steam and heated water. Also, the heat losses are indicated in the figure in a schematic way. The amount of blowback steam depends on pressures at the inlet and in housing as well as on the type of segments used in the refiner. Typical pressures in SD and CD refiners are at the infeed 1 bar and in the housing 4 bar.

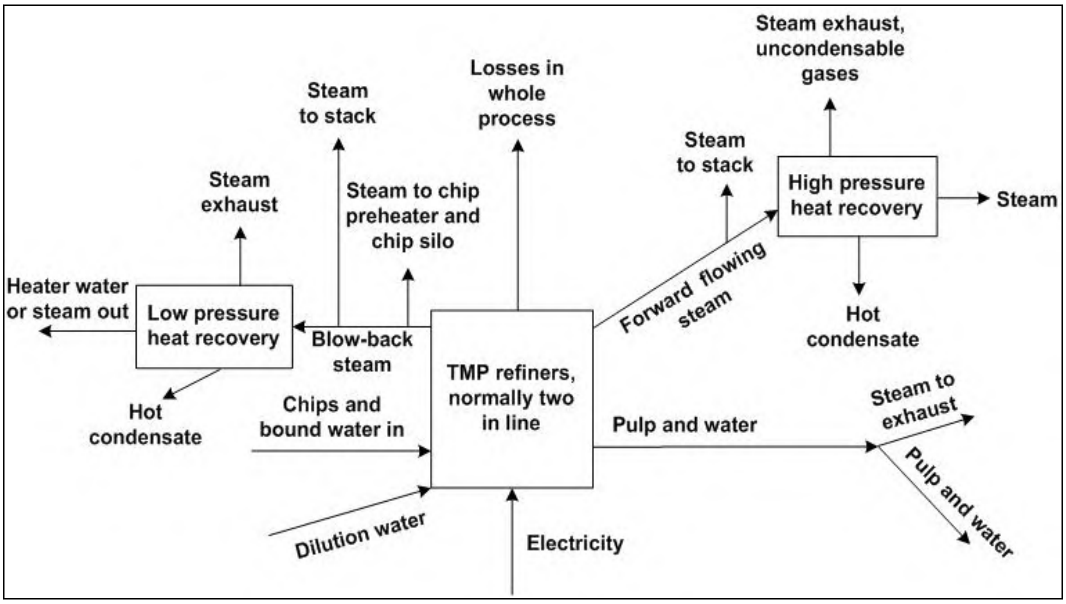


Figure 5.21: **Energy and mass flows as well as energy flows bound to mass flows in a SD or CD refiner**

Figure 5.22 shows the same principles for twin or DD refiners. It can be seen that there is no blow-back steam and no low-pressure heat recovery.

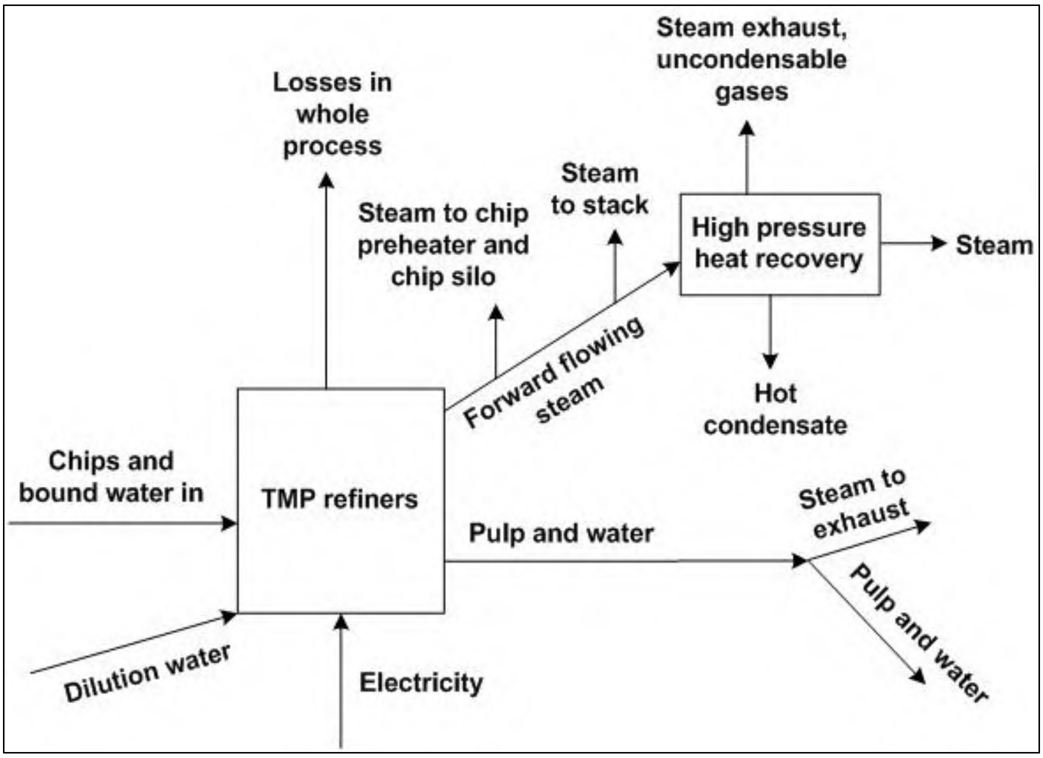


Figure 5.22: **Energy and mass flows as well as energy flows bound to mass flows in a twin or DD refiner**

The typical infeed and housing pressure in twin and DD refiners is 4 bar. Typically in the refiner main line, energy from 1.7 MWh/t to 2.5 MWh/t is used.

Typical theoretical maximum values for recoverable energy flows are shown in Table 5.20. For the definitions of the sources of energy recovery, the reader is referred to Figure 5.21 and Figure 5.22.

Table 5.20: **Estimated relative distribution of recovered heat and steam from applied refiner power in a refiner main line**

Source of energy recovery	SD and CD refiner (values in %)	Twin and DD refiner (values in %)
High-pressure steam recovery	61	79
High-pressure steam condensate	11	15
Low-pressure heat recovery	20	NA
Low-pressure condensate	2	NA
Irrecoverable heat (e.g. low value heat in fibre and water, motor cooling losses, radiation losses)	6	6

NB: For an unambiguous definition of heat recovery efficiency, one must define which heat flows are covered by the calculation and what reference temperature for the energy content is used for the calculation.

The percentage of relative heat recovery refers to the ratio of recovered energy without considering the exergy level.

NA=not applicable.

Source: annex 1 of [169, Nilsson et al. 2007]

In a modern mill, reject refiners run pressurised. The reject ratio is typically 40 % and the energy used in reject refining is typically 1 MWh/t. Typical recoverable energy in a reject refiner is 16 – 24 % compared to those in the main line. The high-pressure steam generated in TMP refiners is separated from the fibres in cyclones or in mechanical separators and is then condensed in a reboiler against vaporising clean steam. Contaminated condensates can be used as dilution water for the refiner to increase the steam production or for heating circulation waters. The low-pressure steam is used in the surface condenser to heat the circulation waters and contaminated condensate is fed to chip washing or to the unrefined reject tank in TMP.

The need for the different types of recoverable energy (steam at low and high pressures, water at various temperature levels) varies from mill to mill. The most significant is the high-pressure steam recovery. Usually the recovered high-pressure steam is used in the dryer section of the paper machine. Usability of high-pressure heat recovery is limited by the required cleaning of the heat exchangers and starts and stops in the TMP plant as well as at the paper machines. Therefore, for the best long period average, the figure for high-pressure steam recovery is less than 5 % below the maximum value presented in Table 5.20.

Achieved environmental benefits

Recovery of heat from the refiners and reuse in the process saves resources (fuels for energy generation) and reduces associated emissions and waste from the steam boilers (SO_2, NO_X, dust, CO_2).

Environmental performance and operational data

Heat recovery systems are standard applications for new TMP plant installations. When starting up a TMP plant, the dirty steam has an excessive fibre carry-over. In that case the steam must be sent to an atmospheric scrubber.

Cross-media effects

No negative effects. Energy recovery is cost efficient.

Technical considerations relevant to applicability

This technique can be applied to both new and existing plants. For older TMP refiners it may not be possible to pressurise them for using the dirty steam in a reboiler. A high refining pressure may cause losses in brightness, when exceeding a certain temperature due to the creation of colour-forming structure units in the lignin. The relatively complex heat recovery system has to be integrated into the existing control system (DCS) to supervise the performance and safety. Preventive maintenance prevents unnecessary and expensive shutdowns and performance losses due to blocking or corrosion damage of the reboiler.

Economics

Especially for heat recovery, economic efficiency is to be assessed for each situation. Depending on the energy prices, the payback time for the investment is around one year.

Driving force for implementation

Cost reduction by energy savings (steam). Increasing the capacity of the steam generation can be achieved.

Example plants

This technique is standard practice in all new and recently rebuilt plants (only a few plants in Europe have not installed them).

Reference literature

Annex 1 of [169, Nilsson et al. 2007], [249, Blum et al. 2007]

5.3.10 Emission-optimised incineration of solid waste and energy recovery

Description

In mechanical paper mills, mostly ones also integrated with paper mills, there are a variety of solid wastes – bark, wood residues, pulp waste sludge and screening rejects – that must be treated or disposed of. The bark is readily used as fuel in the mill's auxiliary boiler but sludge is more difficult to handle. A viable option is the incineration of this sludge. Because sludge represents waste that often has a lower heat value than solid fuels (such as bark or wood waste), its incineration in a boiler designated solely for sludge is rare.

In practice, mills that use bark, wood, peat or coal as fuel for steam and power generation obtain cost efficiency by burning the pulping and paper sludges in the same boiler with solid fuels of high heat value (see Section 2.6.1). This is also emphasised by the fact that sludge, unless at over 50 % consistency and low in ash, would in any case require support fuel to dispose of it properly by burning.

The environmentally sound technology most suitable for pulp sludge and reject incineration is the same as for wood, bark and peat. However, certain specific features in the preparation of sludge or burning can differ.

The boilers provide steam to be used directly as process steam for heating and drying, but in an increasing number of cases they are also used for electric power production (see Section 2.6.1.2). However, when the boiler is small and its main purpose is to dispose of sludge with a minimum amount of support fuel, the boilers cannot economically produce anything else but low-pressure steam for heating in the process or buildings.

In the incineration of pulp and paper mill sludge, the environmental ends can be met by application of a proper boiler and, as sometimes needed, a series of fuel pretreatments (see Section 2.6.1.1).

In paper and reject sludge incineration, both conventional grate-fired boilers and fluidised bed boilers can be used. The fluidised bed technology, however, is more versatile with its better flexibility, higher efficiency and low emissions. Bubbling and circulating fluidised bed boilers (BFBC and CFBC) are used in the pulp and paper industry (see Section 2.6.1.2.3).

The heating value of bark from wet debarking or peat at 40 – 60 % moisture is 4.5 – 10.5 MJ/kg. In contrast, the mechanically dewatered pulp sludges have a lower heat value amounting to 2.5 – 6.0 MJ/kg due to their often higher moisture and ash content. The heat value of dry pulp waste can reach over 20 MJ/kg. The higher the humidity of the fuel, the lower the overall economy of the boiler and also the more difficult the operability unless efficient technology is applied. A fluidised bed boiler is less sensitive to fuel humidity than a grate-fired boiler. Because some paper sludges often reach 20 – 30 % ash content, and at worst with deinking waste 60 %, operational problems such as grate plugging due to ash is very likely in grate-fired boilers.

The sludge heat value and the overall burning results can be improved by applying improved dewatering and drying (see Section 5.3.4).

The emissions from fluidised bed boilers can better meet the requirements than the grate-fired boilers. The fluidised bed systems provide in situ SO_2 and NO_X emission control in addition to being simpler and more effective than the grate-fired ones.

For information on available primary and secondary measures for reducing the emissions of SO_2, NO_X, CO and particulate matter and achieved emissions, the reader is referred to Section 2.9.7.

Achieved environmental benefits

Emissions from modern fluidised bed boilers burning pulping and reject sludge with support fuels can be efficiently controlled and optimised.

Environmental performance and operational data

For data on achieved emission levels from operational plants using emission control techniques (including any reference conditions and monitoring methods used) the reader is referred to Section 2.9.7.

When a major portion of the boiler fuel is sludge, the net heat economy is low. In mills where other solid fuels are also used for steam or electricity production, a better process efficiency is obtained by burning the sludge as minority fuel with them.

Continuous emission monitoring with on-line gaseous compound meters is available. Because of their improved reliability and lower cost, they have become more common. Multi-point temperature and oxygen monitoring of the boiler is also beneficial.

Cross-media effects

The reduction of the waste volume by incineration increases emissions to the atmosphere. However, these emissions are controlled by applying environmentally sound incineration and emission control techniques that minimise emissions of particulate, SO_2 and NO_X emissions.

Technical considerations relevant to applicability

The implementation or improvement of fluidised bed boilers for the burning of wood residues or solids disposal can be applied to both new and existing mills. The controllability of the burning process and the flexibility in terms of the use of other solid fuel and its quality variations are superior to that of grate-fired boilers.

Improvements in grate-fired boilers coupled with the upgrading of heat recovery and external flue-gas cleaning can improve their economic and environmental performance, but not to the level of fluidised bed systems.

Economics

The modification of an existing bark boiler for sludge and reject incineration costs EUR 0.5 – 0.7 million at a 700 ADt/d integrated mill, provided that the boiler already has extra capacity to burn these wastes. The additional operating cost for the residue incineration is EUR 250 000 – 350 000 per year.

A separate sludge and reject boiler for a mill of the same size costs EUR 5 – 7 million and its operating costs are EUR 500 000 – 600 000 per year.

Driving force for implementation

The main driving force is the reduction of the disposal of organic material to landfills.

Example plants

Numerous mills in northern and western Europe.

Reference literature

[1, Finnish BAT Report 1997], [14, CEPI 1997], [104, Paper and Timber 1993].

5.3.11 Use of sufficiently large buffer tanks for the storage of concentrated or hot liquids from the process

Description

The use of large buffer tanks for hot liquids in groundwood (GW) or thermomechanical pulp (TMP) production is not relevant in most cases because these pulps are produced almost solely in integrated mills. Typically much of the process water used in these pulping processes is received as excess white water from a paper or board machine. GW and TMP water consumption is low in comparison to papermaking so there is commonly continuous bleedout of excess contaminated water from the pulping line to the sewer. Instead of large buffer tanks, GW and TMP mills often use equalisation basins before the biological waste water treatment in order to reduce the hydraulic and organic peak loads and equalise as much as possible the inflow to the biological waste water treatment plant.

Chemithermomechanical pulp (CTMP) production has a more mixed situation, because a number of mills are non-integrated and produce market pulp. As with other mechanical pulping, different white water grades are produced and recycled inside the pulping process. In integrated mills, the paper or board machine excess white water is fed as replenishment to the CTMP water system, in non-integrated mills fresh water is consumed. When bleaching is applied, water recycling by using bleaching filtrate for instance in chip impregnation improves water reuse. Excess contaminated water is sewered for example from chip washing and as excess white water or sometimes also from intermediate washing in pulp refining.

In CTMP pulping, as opposed to chemical pulping, there are fewer reasons for very large water storage tanks. By the implementation of the typical counter-current water flow principle to reach a low fresh water consumption, the balance still needs to be sewered. Nevertheless, the process tank capacities need to have sufficient volume to supply water during flow peaks, especially in pulp dilution and washing. These occur mainly when a pulping line is started up, during short-term fluctuations in the balance between pulp and paper production, or for instance when unbleached pulping is shut down but bleaching is still in operation.

The CTMP effluent is, due to chemical chip treatment, more contaminated than GW and TMP effluents, calling for more careful tank level management to minimise peak loads from entering the effluent treatment. The conversion of the electrical energy in TMP and CTMP refining to energy in steam decreases the accumulation of heat to the water in the pulping system. In mills where steam is efficiently used for water heating or pulp or paper drying, the need for occasional steam blow-out could be decreased. In other mills the need for the cooling of steam with water and sewering this hot fraction can be decreased by maintaining a larger water volume in the production.

Achieved environmental benefits

Buffer tanks and equalisation basins reduce peaks flows and loads and spillages of concentrated effluent streams. Intermediate containment and storage and gradual release to the biological waste water treatment maintain and improve the performance of the external treatment plant.

Environmental performance and operational data

By the improved water circuit closure the control of contaminated and warm or hot streams into the sewers has become more pronounced. In-mill optimisation to handle concentrated or hot streams can be carried out by refinement or change in operating procedures and/or increased volumes in liquid storage facilities.

To control undesired spillages, level probes for key water chests are required, especially for overflow control.

Cross-media effects

No major effects.

Technical considerations relevant to applicability
The evaluation and optimisation of necessary tank volumes can be carried out in both new and existing mills. For existing mills, operating data from different production situations help in determining proper tank management procedures and the need for tank volume increases.

Economics
The investment required is very case-specific. When estimating a need for 2 000 m^3 of extra water or stock volume and some additional tanks, piping, electrification and instrumentation, the additional investment required is EUR 100 000 – 250 000. The operating costs are low, comprising mainly maintenance and control costs.

Driving force for implementation
These measures are applied because they allow a better control of the fluctuations in the pulping process and prevent the biological waste water treatment plant from being disturbed or damaged. Legal requirements are another motivation.

Example plants
Numerous modern mills around the world.

Reference literature
[14, CEPI 1997].

5.3.12 Aerobic biological waste water treatment

Description
See Section 2.9.11.2.1.

Achieved environmental benefits
Reduction of emissions of organic matter (COD, BOD), AOX, phosphorus, nitrogen and chelating agents to water.

Environmental performance and operational data
The dominating process for treatment of waste water from mechanical pulp mills is the activated sludge process. Preferably the two-stage process is used. Some mills apply pure oxygen in a first stage, followed by a 'normal' aerated second stage. Some mills use a high-loaded first stage followed by a lower-loaded second aeration tank. Moving bed biofilm reactors are also used for this type of waste water. One mill has reported a biofiltration stage after a two-stage activated sludge system. In principle, effluent from mechanical pulp mills can also be treated efficiently anaerobically because the concentrations in waste water are often above 2 000 mg COD/l. However, in most cases, pulp and paper mill effluents are treated with aerobic methods, with the exception of CTMP mills or other concentrated effluent streams for which anaerobic treatment has sometimes been applied (see Section 5.3.8).

The efficiency of the treatment plants vary to a certain extent depending on the type of effluents treated and the design, operation, maintenance and control of the treatment plant. Typical values are within the ranges of 95 – 98 % for BOD removal (normally 95+ %) and 80 – 90 % for COD removal. At well designed and operated plants, TSS emissions are between 10 mg/l and 20 mg/l and BOD between 5 mg/l and 15 mg/l (close to the detection limit) both as an annual average value (see Table 5.21).

Table 5.21 compiles the achieved emission levels to water after biological treatment of a selection of well performing mechanical pulp and paper mills in Europe and demonstrates the different treatment concepts realised. The mills operate with different process conditions and water system configurations. Where data were available, the fibre mix used, the pulping or bleaching techniques, the products manufactured (e.g. % ISO brightness to be achieved) and the waste water treatment system applied are indicated. Example paper mills include newsprint, printing paper and board mills.

These mills have implemented internal water management and apply an effective biological treatment. The treatment efficiency of these examples is >80 – 90 % for COD. The biological treatment plants are designed and operated mostly as low-loaded activated sludge plants or comparable systems such as moving bed biofilm reactors sometimes followed by an activated sludge stage. The list of mills is a selection of mills where data were available or provided and is therefore not intended to be complete. The method of analysis is the one used in the respective country but mostly standard methods are applied. In Sweden and Finland the values for BOD are given as BOD_7. All values are yearly average values. Figures in Table 5.21 given within brackets are concentration values (mg/l). A few mills measure total organic carbon (TOC) as a substitute for the parameter COD or in addition to it. Where available, these TOC values are presented in the table in square brackets.

Table 5.21: Annual average of emissions to water after biological treatment of mechanical pulp mills in Europe

Example mills (data source)	COD [TOC] in kg/ADt and (mg/l)	BOD$_{5\text{ or }7}$ in kg/ADt and (mg/l)	TSS GF/A in kg/ADt and (mg/l)	AOX in kg/ADt and (mg/l)	Tot-N in g/ADt and (mg/l)	Tot-P in g/ADt and (mg/l)	Flow in m^3/ADt	Type of treatment	Remarks
Integrated mechanical pulp and paper mills									
UPM-Kymmene Austria, Steyrermühl (Questionnaire 2009)	2.74 [1.03] (155 [58])	0.1 (5)	0.16 (9.2)	0.001 (0.06)	4 (0.23)	4 (0.25)	16	Single-stage activated sludge	23 % TMP, 61 % DIP, rest: fillers/pigments; 38 % SC-B and 62 % newsprint; initial COD load: 19.1 kg COD/t; COD removal: 85 %
MD Albbruck (Questionnaire 2009)	1.24 (99)	0.08 (6.5)	0.1 (8)	0.000 5 (0.04)	21 (1.68)	5.8 (0.46)	12.5	Trickling filter, moving bed reactor, single-stage activated sludge;	70:30 GWP:PGWP; chemical pulp; 36 % fillers/pigments; ULWC, LWC, MWC, HWC paper (80 % ISO); COD removal: 88 %
Braviken (Environmental report)	2.4 (160)	ND	0.4 (27)	ND	75 (5)	5 (0.33)	15	ND	Mainly newsprint, TMP/RCF deinked
SE Hagen Kabel (Questionnaire 2007)	2.3 (190)	0.1 (6)	ND	0.000 3 (0.02)	80 (5.3)	7 (0.5)	15	Anaerobic, trickling filter, activated sludge	55 % Mechanical pulp (GW, TMP), 45 % purchased chemical pulp, LWC paper
SE Baienfurt (Questionnaire 2007)	2.0 (83)	0.11 (5)	0.3 (14)	0.002 (0.08)	45 (2.3)	8 (0.4)	17.5	Activated sludge	65 % Mechanical pulp (GW), 35 % purchased chemical pulp, folding boxboard
MD Paper Plattling (Questionnaire 2009)	2.5 (72 – 305)	0.23 (4 – 23)	0.19 (1 – 57)	0.02 (0.1 – 0.4)	28 (1 – 5.5)	8 (0.1 – 2.2)	12.5	Moving bed reactor + single-stage activated sludge	33 % GW, 7 % DIP, chemical pulp, 39 % fillers and pigments; LWC paper; COD removal: 82 %
Stora Enso, Anjalankoski (Questionnaire 2009 and Finnish statistical data 2008)	4.8 (ND)	0.1 (ND)	0.4 (ND)	ND	220 (Chemical additives)	6 (ND)	19.8	Moving bed reactors (MBR)	77 % PGW and 23 % TMP, high brightness papers and board (max. 93 % ISO, 2 – 3 stages); COD removal: no data
Norske Skog Walsum (Questionnaire 2009)	3.8 (277)	0.18 (13)	0.16 (12)	0.0004 (<0.03)	46 (3.4)	5 (0.4)	13.6	Moving bed reactors + single-stage activated sludge	~ 40 % TMP, chemical pulp; ~ 40 % fillers/pigments; 100 % LWC paper; COD removal: 88 %
Norske Skog Skogn (Questionnaire 2009)	2.2 (190)	ND	0.5 (15)	ND	100 (5)	10 (0.5)	12.7	Single-stage activated sludge	70 % TMP, 30 % DIP; newsprint; COD removal: 90 %
Myllykoski Paper Oy (Questionnaire 2009 and Finnish statistical data 2008)	3.4 (ND)	0.14 (ND)	0.4 (ND)	ND	80 (ND)	8 (ND)	16.1	Single-stage activated sludge	100 % GW and PGW, chemical pulp; fillers/pigments; 62 %, SC-A, 38 % MWC (78 – 80 % ISO); COD removal: no data

Example mills (data source)	COD [TOC] in kg/ADt and (mg/l)	BOD$_{5 \text{ or } 7}$ in kg/ADt and (mg/l)	TSS GF/A in kg/ADt and (mg/l)	AOX in kg/ADt and (mg/l)	Tot-N in g/ADt and (mg/l)	Tot-P in g/ADt and (mg/l)	Flow in m^3/ADt	Type of treatment	Remarks
Sappi Kirkniemi mill (statistical data 2009)	1.4 (145)	0.06 (6)	0.6 (6)	ND	31 (3.5)	1.6 (0.2)	9.8	Activated sludge + chemical stage with flotation	GW and PGW 31 %, chemical pulp 21 %, fillers/pigments 39 %; COD removal 89 %
SCA Ortviken, SCA Graphic Sundsvall AB (Questionnaire 2009)	4.1 (280)	0.15 (10)	0.29 (20)	0.002 (0.12)	85 (5.9)	4 (0.26)	14.6	Moving bed reactors + single-stage activated sludge	100 % TMP; some chemical pulp, fillers/pigments; newsprint (28 %), improved newsprint (15 %), LWC (57 %); COD removal: 91 %
CTMP mills (for integrated production the specific emission load refer to the manufactured pulp only)									
Rottneros AB, Rockhammars Bruk (Swedish statistics 2007)	12 (ND)	ND	0.5 (ND)	ND	182 (ND)	2 (ND)	15	ND (market CTMP)	ND
Waggeryd Cell AB (Swedish statistics 2007)	13 (ND)	ND	0.9 (ND)	ND	117 (ND)	8 (ND)	9	ND (market CTMP)	ND
Stora Enso, Fors Bruk (Swedish statistics 2007)	15 (ND)	ND	0.9 (ND)	0.001 (ND)	133 (ND)	8 (ND)	27	ND (integrated production)	ND

NB: ND = no data.

Sources: [244, Pulp and Paper TWG 2007], [248, Hamm 2007], [138, PP TWG 2009], [TWG comments 2010], [Statistical data Swedish EPA 2008].

Magazine paper production based upon intensively peroxide bleached TMP with a low degree of kraft pulp blend (e.g. some LWC paper mills) has an effect on the final discharge of organic substances (measured as COD) for TMP. Increased market demands for brightness and new enhanced paper products will create a higher lignin-based COD load to the waste water treatment plant. Despite high efficiency waste water treatment plants, the COD load after treatment may reach 5 – 6 kg/t in a few cases. In the case of highly bleached mechanical pulp (70 – 100 % of fibre in final paper), COD levels of up to 8 kg/t may occur.

Cross-media effects
Aerobic biological waste water treatment consumes energy (e.g. for aerators and pumps) and generates sludge that normally requires treatment before utilisation or disposal.

Technical considerations relevant to applicability
The process can be applied at both new and existing mechanical pulp (and paper) mills.

Aerobic waste water treatment plants have been used for many years in all types of mechanical pulp and paper mills with good results.

Economics
The investment required for a completely new activated sludge treatment plant is approximately EUR 10 – 12 million for a new 700 ADt/d integrated mechanical pulp mill. These costs also include the necessary primary treatment and sludge handling. The corresponding operating costs are EUR 0.9 – 1.2 million/year.

In existing mills, measures to reduce water flow should preferably be carried out before building a new waste water treatment plant in order to reduce the investment costs.

Driving force for implementation
The activated sludge process is preferably used when high or very high treatment efficiencies are required.

Example plants
Numerous plants all over the world for all types of effluents.

Reference literature
[1, Finnish BAT Report 1997], [14, CEPI 1997], [131, SEPA report 1997].

5.4 Emerging techniques

5.4.1 New energy-efficient TMP processes

Description

As there is a strong correlation between the energy applied and the pulp quality obtained, a reduction in the specific energy consumption (SEC) in TMP manufacturing always means some loss of pulp quality such as fibre length, tear and tensile strength. Therefore, when comparing low-energy design concepts, the optimum TMP process in terms of specific energy savings cannot be defined without simultaneously defining the quality requirements.

The main factors affecting the energy consumption in TMP manufacturing are how the refining forces are applied on the wood and fibres, and how the wood and fibres react to these forces. The energy-saving TMP processes make use of increased refining intensity, chip pretreatment, utilisation of third-stage post-refining, low-consistency refining (LCR), new plate patterns and optimised process conditions. Some examples for energy-efficient development in TMP pulping are given below:

a) High-speed and high-intensity TMP refining

An example is the RTS refiner that usually operates at up to 2 300 revolutions per minute (rpm) and 5.5 bar overpressure. The first RTS installation was at Perlen Papier AG, Switzerland, in 1996. Specific energy savings in the order of 15 % are possible at acceptable pulp quality. References include Norske Skog Walsum (DE), Norske Skog Golbey (FR), Holmen Halstavik (SE), Iggesund Paperboard, UK), UPM-Kymmene Stracel (FR) and Norske Skog Follum (NO).

b) Chip pretreatment

Andritz has developed the RT Pressafiner pretreatment for chips to be treated before main line refining. For instance, in the RT TMP process the chips are first macerated in a pressurised RT Pressafiner chip press before entering the main line refiners. RT treatment is used for example at Holmen Braviken, SE, before single-stage DD refining, and in North America combined with RTS twin SD refiners. The reduction in SEC is about 10 %, i.e. 100 – 180 kWh/t. TMP mills that use this chip pretreatment may reduce their waste water load by inserting a washing stage (plug screw) before refining and bleaching which reduces COD and the extract content (measured as DCM) in the pulp by around 30 %. The low volume but highly concentrated pressate may undergo a specific waste water treatment.

Status of development

Almost all new TMP lines installed are low-energy designs. Double disc (DD) refining is used in some Swedish and Norwegian mills. DD refiners will consume 300 kWh/t less refining energy than normal SD (single disc) refining, but the pulp properties will also change (opacity, strength).

Environmental implications

Full-scale experience with high-intensity (speed) and high-temperature refining suggests that an energy reduction in the order of 15 % compared to conventional TMP is possible (e.g. RTS process) if product requirements allow a different fibre quality. For another energy-efficient TMP process, energy savings of 10 – 20 % have been reported (e.g. thermopulp process) to a given quality level.

Economic considerations

No data available. Energy savings must be balanced with investment costs. It can be expected that the new technology will only be implemented gradually due to the remaining lifetime of present equipment and plants.

Reference literature

Papermaking Science and Technology, Book 5, Mechanical Pulping, 2009, edited by Bruno Lönnberg, Chapter 7, Thermomechanical Pulping, pp. 214-221, Paperi ja Puu Oy.

For chip pretreatment
'Review: reduction of energy consumption in refining through mechanical pretreatment of wood chips', Gorski, D., Engstrand, P., Hill, J., Johansson, L., International Mechanical Pulping Conference, Sundsvall (2009).

5.4.2 New energy-efficient bleached CTMP processes

Description
Also for CTMP pulping, the main research work focused on energy reduction in refining. The production of conventional aspen CTMP at 250 ml CSF still requires 1 350 – 1 500 kWh/ADt. Caustic application ahead of the primary refiner decreases the applied specific refining energy and develops the strength properties.

Different to the conventional CTMP, the P-RC APMP process (mild **P**reconditioning of the chips, **R**efiner **C**hemical **A**lkaline **P**eroxide **M**echanical **P**ulping) uses alkaline peroxide solutions ahead of refining, which allows higher alkali charges before refining, resulting in a drop of refining energy down to 1 050 – 1 200 kWh/ADt at the same freeness. In addition, the efficient chip pretreatment yields well-impregnated flexible fibres which can be refined to the required freeness level with low-consistency refiners in the second stage and in the reject refining stage, which lowers the specific energy consumption by another 100 – 150 kWh/ADt without compromising strength properties.

Status of development
Most of the recent hardwood bleached CTMP installations apply the P-RC APMP technology, which demonstrates the energy savings potential. Also, low-consistency refining in the second stage and in the reject refining stage has been implemented in industrial operations with the expected results.

Reference literature
Enhancing fibre development at reduced energy consumption using TMP subprocesses and targeted chemical application – pilot and commercial scale results, Jan Hill, Marc Sabourin, Lars Johansson, Johann Aichinger – published at IMPC 2009.

Minimizing TMP Energy Consumption using a Combination of Chip Pretreatment, RTS and Multiple Stage Low Consistency Refining, Marc Sabourin IMPC 2007.

5.4.3 Use of enzymes during the refining of TMP

Description
The addition of enzymes (e.g. cellulase) to the wood chips between the first and secondary refiner can hydrolyse the hemicellulose and improve the fibre freeness of the cellulose fibres. This would allow the necessary time in the secondary refiner to be shortened.

Status of development
So far, this technique has been tested in several laboratory tests and on a pilot plant scale. Also, short-term tests (1 – 2 weeks) have been carried out in the TMP line of UPM-Kymmene/Rauma mill.

Environmental implications
The main environmental benefit derived from the application of the technique would be the reduction of electricity consumption in the second refiner, due to the shorter refining time. Trials carried out so far point out that energy savings in the reject refiners of up to 10 – 15 % could be possible.

In order to allow enough contact time (e.g. 2 hours) between the enzyme and the wood chips, it would be necessary to have facilities that provide the necessary retention time for the pulp flow between the primary and the secondary refiner.

Reference literature
[211, Technical University of Denmark and Novozymes 2007]

6 PROCESSING OF PAPER FOR RECYCLING

Recovered fibre has become an indispensable raw material for the paper manufacturing industry, accounting for more than 40 % of the total raw materials, because of the favourable price of recovered fibres in comparison to the corresponding grades of market pulp and because of the promotion of waste paper recycling by many European countries. In Europe the average utilisation rate of paper for recycling is around 50 % (i.e. the percentage of paper for recycling utilisation compared to the total paper production). The maintenance of the fibre cycle relies on the feed of a certain amount of primary fibres to ensure the strength and other properties of the paper to be produced.

6.1 Applied processes and techniques

The system for processing paper for recycling varies according to the paper grade and the type of furnish used. Generally, the processing of recycled fibres (RCF) can be divided into two main categories:

- processes using exclusively mechanical cleaning, i.e. without deinking, comprising products like Testliner, corrugating medium, uncoated board and cartonboard;
- processes using mechanical cleaning and deinking comprising products like newsprint, tissue, printing and copy paper, magazine papers (SC/LWC), coated board and cartonboard or market DIP.

All process systems aim at defibration, deflaking and the removal of impurities, i.e. efficient separation of fibrous material and impurities and contaminants. Recycled fibre plants consist of similar 'building blocks' designed for the specific task. These typical stages of recycled fibre processing are described below.

6.1.1 Sorting, handling and storage of paper for recycling

Sources and types of paper for recycling
Paper is recovered mainly from three sources: (i) process cuttings and other waste paper from industrial sources; (ii) commercial sources of packaging such as supermarkets, department stores, industrial plants or printed paper (unsold magazines and newspapers and printing paper from public and private offices); (iii) paper from households, and small businesses.

Used paper and board are collected for recycling by municipal or private organisations, and delivered to collection yards in most cases. Collection yards sort paper into grades and can be independent or located in the immediate vicinity of paper mills. Non-paper elements, such as plastics and paper and board detrimental to production, e.g. wet strength papers, are removed as much as possible before delivery to paper mills.

In order to facilitate its trade and effectively organise its collection, sorting, and use as feedstock in papermaking, the European paper industry published in 2000 a list of standard grades, the 'European List of Standard Grades of Recovered Paper and Board', later transformed into a European Standard [28, CEN 643 2001]. This list gives a general description of 57 standard grades for paper for recycling by defining qualitatively what paper type they mainly contain or do not contain, and to a limited extent the impurities allowed.

Paper for recycling traceability
In 2008, the paper for recycling chain introduced the European Recovered Paper Identification System to demonstrate and improve the traceability of paper for recycling throughout the supply chain. Many suppliers of paper for recycling have registered on the European Recovered Paper Identification website to get a unique identification code for their companies and their paper for recycling depots. The supplier code identifies paper for recycling with its supplier, who in turn knows his supplier and so forth. Full traceability is therefore ensured from the sources of paper for recycling to the pulpers of the paper mills.

Paper for recycling storage and on-site sorting
Paper for recycling is normally delivered to the paper mill either in the form of bales that are kept together by metal or plastic wires or straps, or as loose paper. The bales are opened by cutting the wires or straps which are collected and sold as metal waste or recovered plastics respectively. Paper for recycling is also delivered to many mills as loose material in large containers or by bulk dumping. The paper for recycling is stored in paper for recycling yards or in buildings that are integrated in the paper mill.

If paper for recycling is delivered to the paper mills as loose paper, manual sorting can be carried out at the mill. Besides an inclined conveyor and a speed-adjustable sorting belt that is usually installed at a higher level, no further mechanical auxiliary equipment is necessary. Several persons work at this sorting belt to remove unusable materials manually which are thus converted into residues. These residues include non-paper components such as wood, metal, glass, plastic, and paper and board products that are detrimental to production. The workers throw these items into containers provided for this purpose below the sorting belt. The further use and disposal of these waste materials is the responsibility of the operator of the paper mill.

Better collection and sorting will lead to a better quality of paper for recycling. This will allow savings of energy, water and auxiliary materials as well as reduced waste generation during the processing of paper for recycling.

6.1.2 Major processes

Repulping of the dry paper for recycling

The paper for recycling is put into a pulper together with hot water, white water or process water, and pulped with mechanical and hydraulic agitation resulting in its disintegration into fibres. After repulping, the paper for recycling has a pulping consistency for subsequent treatment. For processes with deinking, such as newsprint, tissue, printing and copy paper, magazine paper, market DIP, some chemicals such as NaOH are added as pulping additives. Usually, the detachment of inks already begins in the repulping stage. Different technical solutions are available for various types of raw materials and products. There are three types of pulper: low consistency (LC: 4 – 6 % DS), high consistency (HC: 15 – 20 % DS) and drum pulpers. There are batch and continuous pulpers. Contaminants and clusters can be removed continuously during operation by a dirt trap (e.g. screen plate, ragger) and then sent to a reject conveyor, in order to prevent the contaminants from breaking into small pieces or accumulating in the pulper. There is an increasing use of secondary pulpers for further defibration, deflaking and cleaning from heavy-weight (HW) and light-weight (LW) dirt. The installations trade under different names but are based on similar functioning. Drum pulpers, which are the most common pulpers, are followed by a drum screening as a first cleaning step.

Normally, the water for disintegration is totally recirculated process water that comes from the paper machine (in many cases as white water), the stock preparation or the deinking loop.

Mechanical removal of impurities

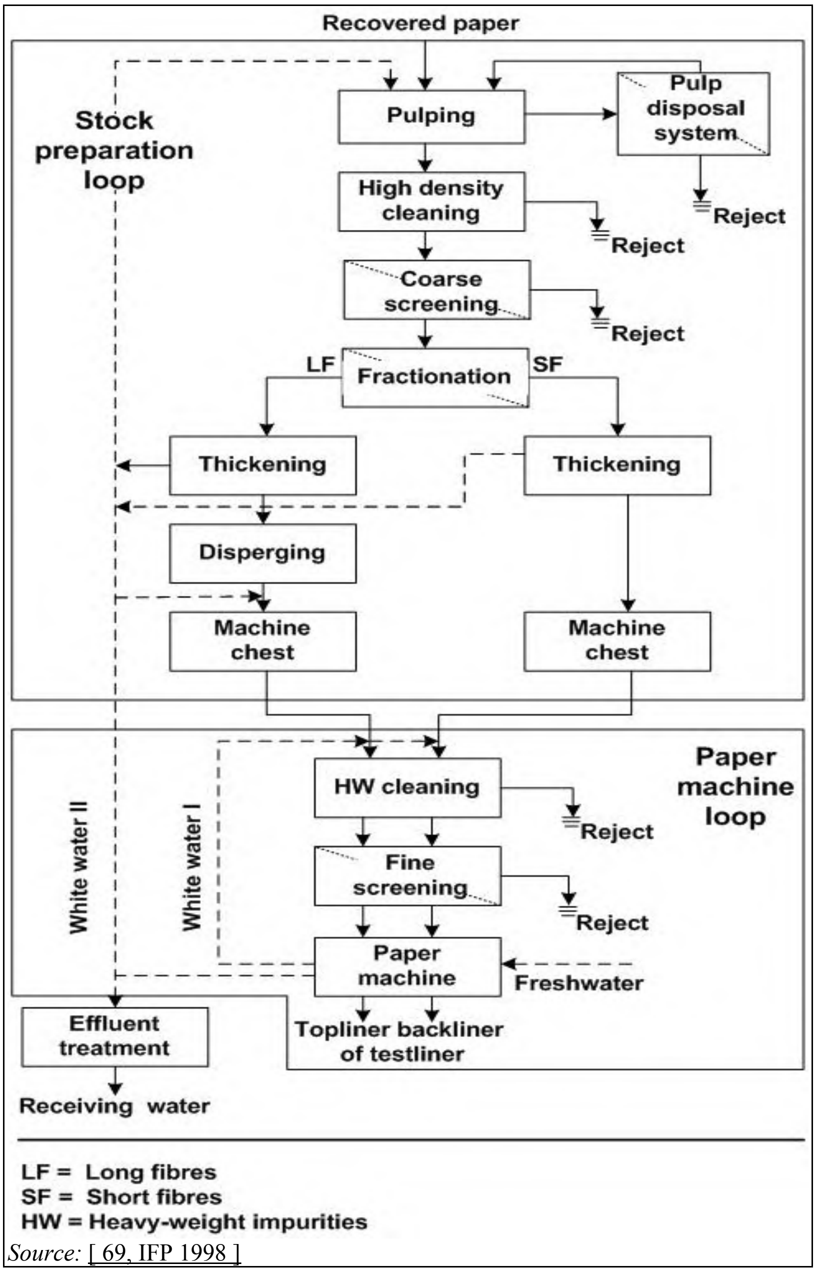
The removal of mechanical impurities is based on the differences in physical properties between fibres and contaminants, such as size, and specific gravity compared to fibres and water. Basically there is screen-type equipment with different dimensions of screen opening (holes and slots) and optionally various types of hydrocyclones (high consistency cleaners, centrifugal cleaners, etc.).

The partially cleaned pulp slurry is pumped from the pulper to hydrocyclones (high density cleaners) in which centrifugal forces remove smaller heavy-weight particles. The heavy rejects of these cleaners and the pulper disposal system usually have to be disposed of by landfilling (high inorganic material content). Ragger and pulper rejects are often submitted to shredding before separation of metals. The organic material is often burnt in an incinerator to utilise the calorific value of the rejects.

The next process stage is screening to separate contraries, which are larger than the openings of the perforated baskets of the pressurised screens. The selection of screen type depends on the end product and the quality of the fibre furnish used. Coarse screening (3 – 4 % consistency) for the removal of coarse contaminants during stock preparation can be distinguished from fine screening (1 % consistency) in the approach flow of the paper machine. The applied devices function in a similar way but differ in the fineness of the separating optimum. Generally, screening at a lower consistency is more efficient, but it requires extended machinery installation and consumes more energy. The reject has to be disposed of or incinerated.

Depending on the furnish quality to be achieved, the stock preparation plant for processing paper for recycling has to be equipped with additional machines such as fractionators, dispersers or refiners. A fractionator separates the pulp into two fractions, making it possible to treat short and long fibres of the pulp slurry in different manners. The energy-intensive process of dispersing can be performed in order to disperse specks and to reduce visible dirty specks in size. It can also slightly improve the fibre-to-fibre bonding (better strength characteristics) in the paper produced. A stock preparation plant for the processing of paper for recycling can optionally be equipped with refiners to improve the optical and strength characteristics of the paper. Refining is associated with a substantial energy demand.

A possible arrangement of RCF processes with mechanical cleaning for the production of case-making materials (here: Testliner) is shown in Figure 6.1. It should be pointed out that, in practice, each plant is individually equipped with machines of one or several suppliers, depending on the grades of paper for recycling used, the demands of the final product quality, the runnability of the paper machine and on local conditions regarding environmental issues.



Source: [69, IFP 1998]

Figure 6.1: Flowsheet of an example stock preparation plant for processing paper for recycling for case-making material (two-ply Testliner)

The preparation of paper for recycling for the manufacturing of Testliner and corrugated medium is applied by about 150 mills in Europe. It is the first market in tonnage for paperboard in Europe (case materials account for 26 % of the total paper and board production using a share of 86 % of recycled pulp as a European average).

Processes with flotation deinking (optional)
Ink removal is necessary in plants manufacturing paper grades where brightness is important, e.g. for newsprint, printing and writing paper, tissue or light topliner of paper for recycling-based cartonboards. The main objectives of deinking are to increase brightness and cleanliness and to reduce stickies. It should be noted that the difference between deinked and non-deinked grades is in the process and not in the product itself. Also, in a few paper mills that manufacture white cartonboard, a deinking line for the production of the white layer is operated.

A complete deinking plant also includes the above-mentioned basic unit operations, repulping, screening and cleaning for the removal of coarse contaminants (non-paper items such as stones, sand, metal, string, glass, textiles, wood, plastic foils, and paper clips). In addition to mechanical cleaning of the furnish, a chemical pretreatment in the pulper and the removal of printing inks in flotation cells are carried out. A prerequisite for successful deinking is that the ink particles are released from the fibres and kept in dispersion. To support ink detachment and to keep the ink dispersed, NaOH and sodium silicate are added (in some cases, e.g. office paper or tissue, NaOH might not be added). Soaps or fatty acids are normally used as surfactants, making ink particles hydrophobic. Hydrogen peroxide and chelating agents are also sometimes added to the pulping sequence (usually there is no need for the use of chelating agents in the bleaching of paper for recycling). The dispersed ink particles are then separated from the fibre slurry by means of (multistage) flotation techniques. The operation principles of flotation deinking are the following: air is introduced to incoming pulp in fine bubbles; ink particles adhere to the ascending air bubbles due to surface charge; ink-laden froth is skimmed out from the surface. Depending on the cell size and construction, there may be several cells in series to achieve a proper dwell time for ink removal. In order to reduce fibre loss with deinking sludge, the foam from primary cells is often treated with secondary cells in cascade mode. Ink froth and rejects are dewatered separately on a gravity wire table followed by wire or screw pressing with up to 60 % DS. Deinking sludge is incinerated or prepared for other recovery routes.

After deinking, the pulp is thickened and sometimes washed using sieve belt presses, (disc) thickeners, screw presses, and washers. After these cleaning steps, the pulp may still contain small residual impurities, such as the remains of printing ink particles, wax and stickies, which originate from pressure sensitive adhesives (PSAs) for example. These impurities can be dispersed so finely with a disperser that the particles are invisible to the naked eye. Before dispersion, the DS content of the pulp has to be increased from around 5 – 12 % to 25 – 30 % because dispersion requires strong friction forces and higher temperatures. The dispergers themselves are a similar device to refiners as described in Section 5.1.3. After dispersion the stock is diluted again.

The order of the operation may vary from mill to mill and some of the steps may be repeated.

A deinking plant concept with flotation deinking for the preparation of RCF for newsprint is shown in Figure 6.3.

Processes with wash deinking and ash removal (optional)
Flotation deinking is efficient for particle sizes ranging from 10 to 250 µm. Ink particles which are smaller than the optimum range for flotation deinking can be removed by wash deinking which is basically multistage dewatering. Besides inks, fillers and fines are removed by washing. Coated papers are especially sensitive to impurities in the uncoated base paper and require very clean RCF pulps. Therefore, a modern deinking plant for preparation of paper for recycling to LWC paper often includes two flotation stages and may also include a wash deinking stage.

If ash removal is required, as for tissue paper or for market DIP for RCP tissue paper, the system always includes a washing stage as shown in Figure 6.4.

Bleaching (optional)

Before entering a storage tower, the pulp is often bleached by use of bleaching chemicals. Generally hydrogen peroxide (P), hydrosulphite (Y) or formamidine sulphinic acid (FAS) are used as bleaching agents. Oxidative bleaching with hydrogen peroxide may already be started in the pulping. Normally, the bleaching chemicals are added directly in the disperger to maintain or increase the brightness. The reaction itself takes place in a bleaching tower ensuring a sufficient dwell time. Any possible increase in brightness depends on the raw material and on the pretreatment of the stock. Hydrogen peroxide bleaching is carried out in the presence of NaOH, sodium silicate and sometimes chelating agents. For almost wood-free secondary fibre stock, 'unconventional' bleaching chemicals such as oxygen or ozone can be used. Finally, the pulp is pumped to the storage chests or mixing chests. These chests serve as a buffer between the stock preparation and the actual paper machine, to promote process continuity. In the mixing chests the required additives are added and the correct fibre consistency is adjusted for proper sheet-forming in the paper machine.

Process water purification

Water from the dewatering stages may be clarified in a micro-flotation unit. The process water is then reused in the process. The micro-flotation unit gives a sludge that is thickened together with other sludge, recovered for other uses or incinerated. In the case of wash deinking, the total water usage is reduced by recycling the wash water as well. In this case, suspended solids are removed from the washing filtrate by a separate flotation unit.

Final cleaning and dewatering

Different types of fine screens and cleaners remove residual contaminants before the highly diluted pulp slurry is fed to the paper machine.

Dewatering/thickening may be done by disc filters, wire presses and screw presses to achieve the pulp consistency needed as well as to keep the white water loops separated.

Reject and sludge handling

In the processing of paper for recycling, various types of rejects and sludge in varying quantities are collected and have to be handled. These are treated in the sludge and reject system. The highest possible fibre recovery also contributes to minimising the quantity of residues.

6.1.3 Examples of systems for processing paper for recycling

Various product characteristics require different cleanliness and brightness properties from the RCF pulps and the process concepts vary accordingly. For example, deinking is not required in many board grades. On the contrary, a very efficient multistage process is required for high-speed paper machines, thin paper or for grades where brightness is important. The degree of sophistication of the whole process depends on the furnish used and the paper grade to be manufactured. Therefore, it is not reasonable to describe 'one typical' system for processing paper for recycling.

The main systems for processing paper for recycling that can be distinguished are discussed in more detail below:

- RCF stock preparation for packaging paper and paperboards (Testliner and corrugated medium);
- RCF stock preparation for newsprint and simple printing and writing papers;
- RCF stock preparation for LWC/SC papers and high-grade printing and writing paper;
- RCF stock preparation for tissue and market deinked pulp (DIP).

The systems for processing paper for recycling may differ from each other by using different types of furnish and they have different impacts on the environment with respect to energy and fresh water demand, effluents and residues.

6.1.3.1 Packaging paper and board

For the production of packaging paper or board from paper for recycling, i.e. Testliner and corrugated medium, only mechanical cleaning is applied, i.e. no deinking process is needed. For these paper grades, supermarket and mixed paper for recycling grades are commonly used. Figure 6.2 shows a system for the preparation of secondary fibre Testliner. For the preparation of Testliner stock, there are more complex two-loop systems (Figure 6.2) and lower cost single loop systems in operation. The two-loop system allows easier control of the process, resulting in improved paper machine efficiency, and operates with a screening stage at the approach flow purely as a safeguard measure (police function). During pulping, coarse rejects are separated and the flake (flock) size is pre-calibrated. The following multistage cleaning and screening system removes heavy particles (e.g. sand), flat disturbing components, stickies, fine sand and leads to deflaking of the stock with good optical homogeneity. For Testliner and fluting systems, some mills are operating with totally closed water loops. Other mills have reopened the closed water loops because of operational difficulties and odour problems. Closed water loops operate satisfactorily from the point of view of manageable plant conditions and good product quality if around 3 – 4 m^3 of process water per tonne finished stock are treated in an integrated biological clarification plant (see Sections 6.3.4 and 2.9.14).

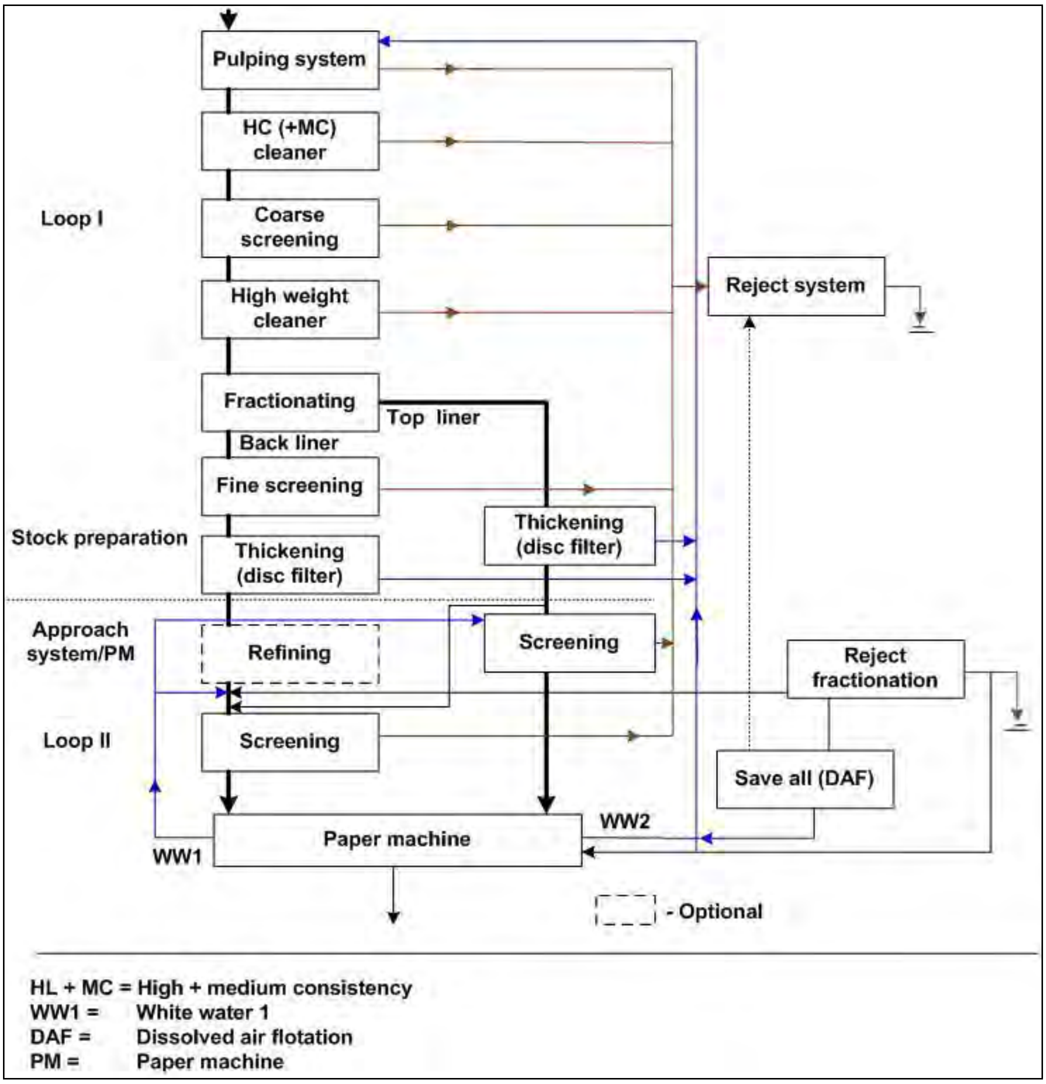


Figure 6.2: Example of an overall plant concept for Testliner (two-loop system)

The processing of paper for recycling tends to be similar for the different grades of packaging paper. High-grade folding boxboard usually requires more process equipment than Testliner; and Testliner manufacturing usually requires more than fluting.

6.1.3.2 Newsprint and simple writing and printing paper

The system shown in Figure 6.3 represents an example of a possible layout for the production of stock for newsprint. The raw material used for typical deinked pulp consists of a 50:50 mixture of newspapers and magazines. However, the ratio of old newsprint (ONP) and old magazines (OMG) in paper for recycling for deinking may vary depending on geographical location. For example, for Central Europe an OMG:ONP ratio of ~ 60:40 is common; in contrast, in Scandinavia and the UK an OMG:ONP ratio of 30:70 to 40:60 is typical.

The system shown in Figure 6.3 is characterised by a two-stage flotation step (pre-flotation in loop I and post-flotation in loop II) and a two-stage bleaching step combined with an intermediate dispersion. Oxidative bleaching (hydrogen peroxide) brightens the fibre stock and reduces the fibre mottling effect. For upgraded newsprint qualities with higher demands on brightness, a reductive stage with hydrosulphite and formamidine sulphinic acid (FAS) may follow thickening. For the production of graphic papers from paper for recycling, water loop design and water clarification are important. There are also other approaches to newsprint line process configurations. Figure 6.3 shows internal water loops only. Waste water is mainly purged with the removal of deinking sludge from flotation I and II which is dewatered in the sludge treatment together with the solids from cleaners and screening. The filtrate is sent to the biological treatment plant, which is not shown in the figure.

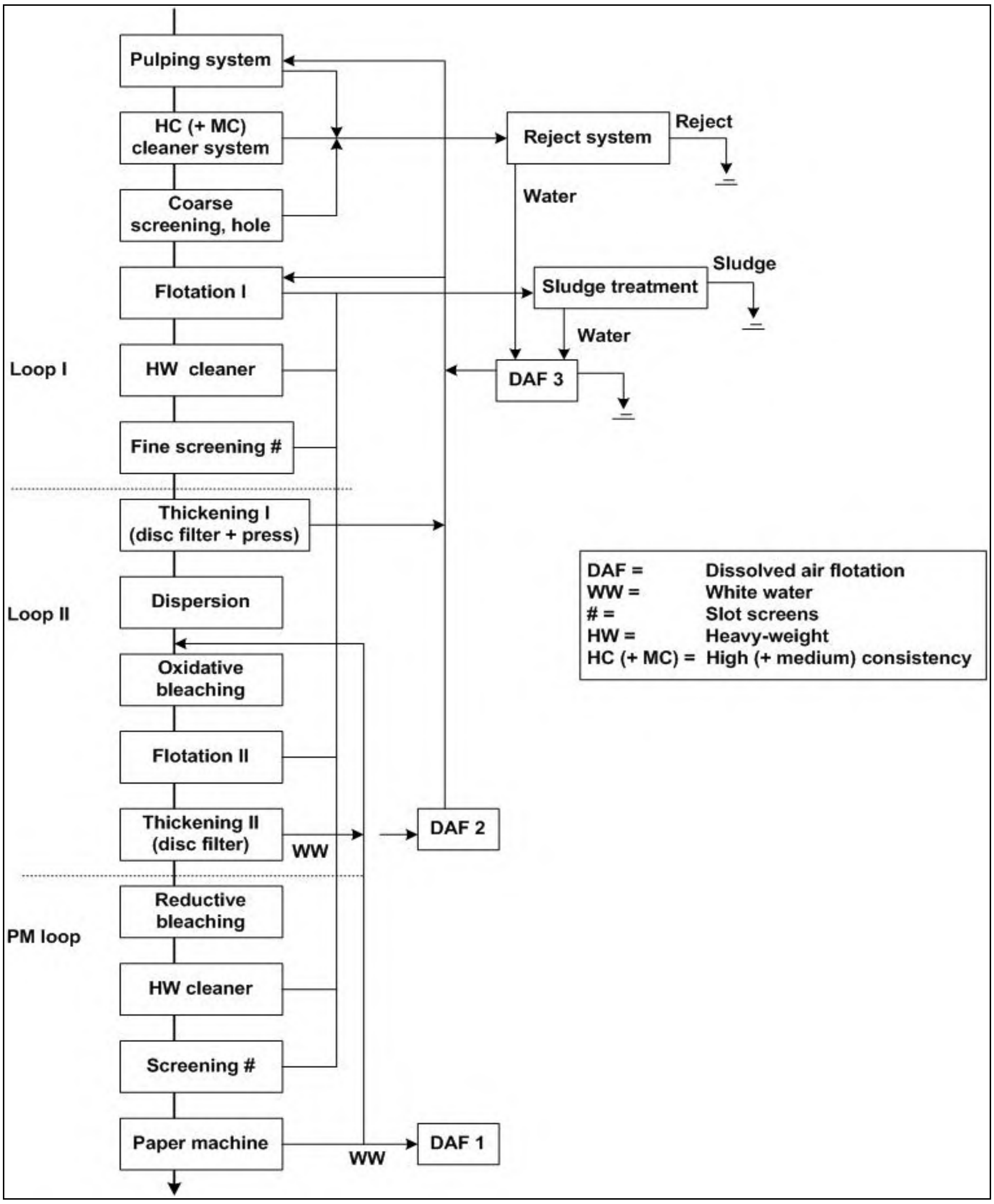


Figure 6.3: **Example of an overall plant concept for (improved) newsprint, SC or LWC paper**

A systematic separation of the individual water loops based on the counter-current principle is essential. Deinking lines can consist of various configurations and there can be two, three or in some cases four loops. In Figure 6.3, a two-loop system in the stock preparation system with a separate paper machine loop is shown. Internal clarification of the water circuits which are separated by thickening stages is carried out by dissolved air flotation (DAF) in order to control the loads of colloidal and anionic substances in process water and to maintain the fines and ashes at a controllable level in the process water loops. Sludge from the production line and from the flotation units is fed to sludge treatment. The coarse rejects separated in the production line are thickened in the reject system.

Upgraded newsprint is usually manufactured in two-loop systems achieving about 63 % ISO brightness (since reductive bleaching), low dirt counts (since post-flotation II), and a low amount of stickies (since additional slot screening). In contrast, standard newsprint can be produced in a one-loop system, i.e. without a post-flotation stage. As a consequence, the brightness is lower (approximately 58 % ISO), the amount of specks is higher and the ash content is higher as well. If paper for recycling grades that are difficult to deink are used, e.g.

flexo printed papers, two-loop flotation and a bleaching stage may be required to reach higher brightness targets.

Recovered fibres are also used for lower grades of printing and writing paper manufacturing. These recycled grades normally contain wood and are intended for office use as copy paper or stationary products. As a process system for those paper grades, a similar flotation-based system to upgraded newsprint to that shown in Figure 6.3 can be utilised.

6.1.3.3 LWC/SC paper

When processing household paper for recycling into market DIP stock for higher grade graphic papers containing wood such as SC and LWC grades, exact requirements have to be met. This includes the need for a low level of disturbing components, high surface quality (i.e. free of shives and fibre bundles to ensure a smooth surface) and demanding optical requirements (e.g. brightness, cleanliness) of the finished product.

The furnish normally consists of a mixture of recovered newsprint and magazines, with a high amount of magazines. SC papers are printing papers produced on high-speed machines on a large scale. One of the main criteria for processing household paper for recycling (deinking furnish) into printing papers is constant quality. Therefore, the screening, cleaning and disperging stages are very important. Because of the high optical requirements concerning brightness and cleanliness, a two-loop system with flotation in each of the loops and two-stage bleaching (HC tower bleaching plus reductive post-bleaching) is necessary. Optical brighteners are also used in these processes.

An overall plant concept could look similar to the one presented for improved newsprint as shown in Figure 6.3. In this stock preparation concept, the problem of disturbing components (colloidal contaminants, anionic waste) which may disturb the sensitive retention mechanism on the paper machine is solved by an appropriate water circuit/water clarification design in stock preparation. The system has clearly distinctive water loops, the first of which is normally alkaline and extends from the pulper to the thickening stage prior to disperging. The second loop ends at the thickening stage prior to secondary bleaching. Thickening stages with strict water loop separation ensures the reduction of contaminants in process water. The separated loop concept is based on the principle that disturbing contaminants cannot travel through the whole process water system. The 'filtrates containing anionic trash and colloidal contaminants from thickening are clarified by micro-flotation based on the flocculation and precipitation principle.

The necessary surface characteristics can be achieved by an additional refining stage for reduction of the large, long TMP fibres occurring in household paper for recycling. Refining may improve the smoothness and printability of the paper. The refiner can be placed after the reductive bleaching stage in a similar concept to that shown in Figure 6.3.

If the ash content of the finished stock is permitted to exceed 8 – 10 %, there is no need for a washer. The use of a washer leads to relatively high losses. Therefore, for economic reasons it is preferably avoided.

6.1.3.4 Tissue paper

Tissue has to meet different requirements to other paper grades and as a result requires different properties. The principle requirements are:

a) high absorbency and softness;
b) free from odour;
c) may need to respect 'food contact regulations' and 'cosmetics regulations';

d) high levels of cleanliness and brightness.

Therefore the processing of paper for recycling of tissue can be different to other grades.

Absorbency and softness

In order to achieve high absorbency and softness, the fibres have to be free from ash and fines. The content of fines and ash of paper for recycling (grades 2.05 + 2.06) can be up to 35 – 45 %. These components have to be washed out. Consequently, the yield during processing paper for recycling goes down to 53 – 58 % (including losses due to coarse impurities) and a relatively high amount of waste has to be handled and treated in these mills. However, there are examples (e.g. Niederbipp mill, Switzerland) where all rejects, including sludge, are incinerated on site, generating steam for mill consumer points, resulting in a reduction of residues to ash which is used as an aggregate in the building industry (cement). Also, the reuse as fibre/filler material at other paper mills is carried out in a few mills. The direct impact of the ash content on the amount of solid waste generated during processing paper for recycling should be considered when comparing figures on the amount of solid waste. De-ashing requires careful design of the process and especially of the water loops. The loading of organics and solids in the water loops is proportional to the quality of the paper used for recycling.

Odour

To get odour-free tissue, the water of the paper machine loop has to be free of organic acids, sulphides and other odour-causing substances. The use of more fresh water in the paper machine loop may be required. This loop then flows counter-current to the fibre flow, i.e. towards the pulping system.

Food contact and cosmetics regulations

To meet the requirements for food contact and for cosmetics, high levels of cleanliness are required and there may be limits on the types of chemicals that can be used and on chemical residues left in the final product, especially those which may migrate onto food or skin.

Optical cleanliness and brightness

Maintaining high levels of cleanliness and brightness requires clean water in the later stages of the process. This may somewhat increase the fresh water consumption of the mill.

Figure 6.4 shows a simplified diagram of the preparation plant for paper for recycling. The main features of the system are the following: a high consistency pulper with a dumping system where coarse contaminants are held back by a perforated screen plate and immediately removed. The rejects are then post-treated in a perforated drum screen and finally thickened in a reject screw press. The accepted material is treated in high consistency cleaners followed by a low consistency screening and cleaner as a second stage removing mainly metallic trash such as paper clips and staples. The stock is further processed in multistage screening and cleaning systems. As in all stock preparation plants, for processing paper for recycling the basic principle in pulping, cleaning and screening is to ensure the early discharge of rejects and contaminants.

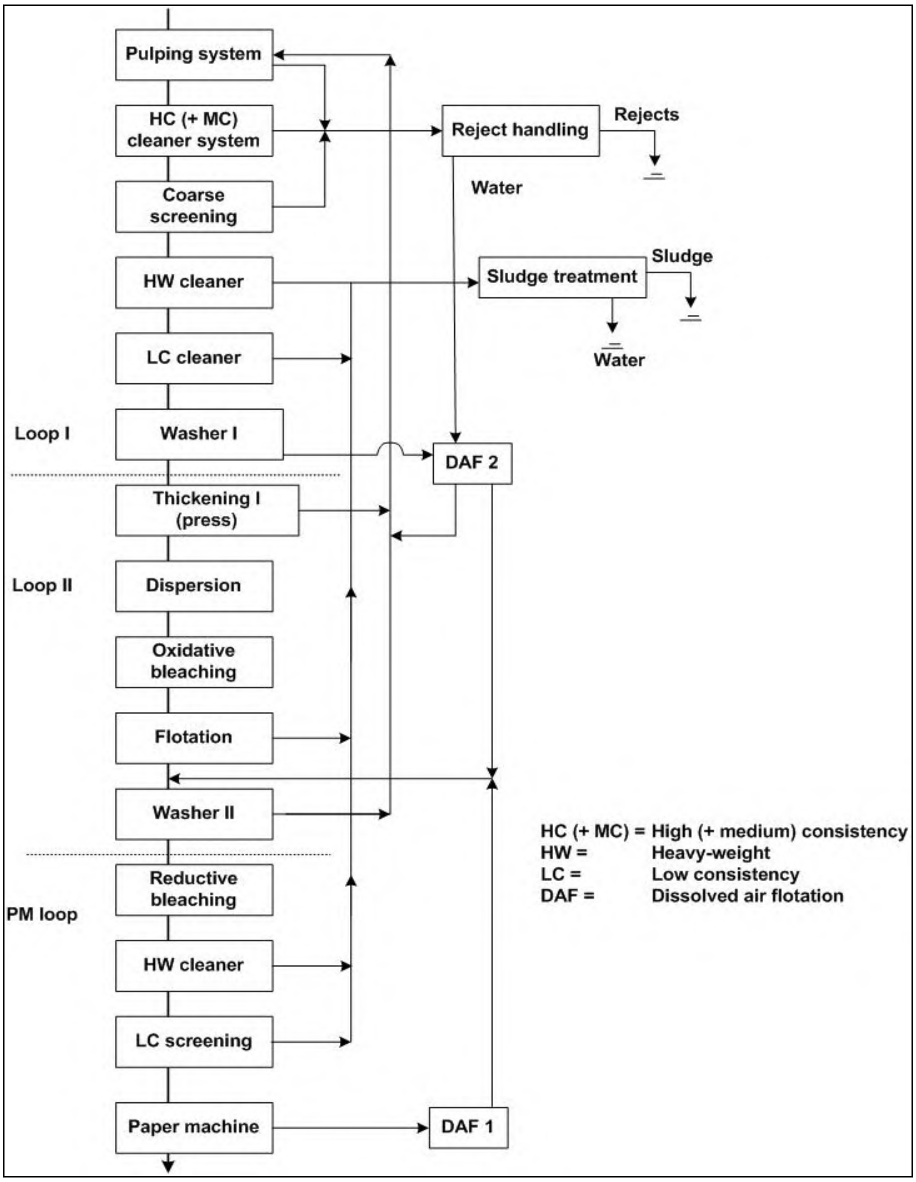


Figure 6.4: **Example of an overall plant concept for a paper for recycling preparation plant for tissue paper**

Washing is carried out at a low pulp consistency and it involves efficient use and recirculation of washing water. The circulating water has to be cleaned and the washing water ink and other solids have to be removed by dissolved air flotation or other efficient water cleaning techniques. Washer I serves for the removal of ash, fines and fine ink particles and is followed by a wire press for thickening the stock to about 30 %. The washing filtrate is cleaned in the dissolved air flotation (DAF) unit with the addition of cationic flocculants. Ash and fines are removed and the water is returned to the system. The stock is heated by means of a heating screw and treated in a disperger that separates any ink still adhering to the fibres and simultaneously mixes in the bleaching additives (oxidative or reductive bleaching is applied here). The flotation stage removes the ink particles separated by disperging as well as dirt specks and stickies. Secondary bleaching may follow washer II and the stock is then sent either to the storage tower or a final screening and cleaning in the approach flow of the paper machine. The handling of rejects and sludge is a crucial point for RCF tissue mills because of the relatively high amount of sludge from different sources (paper for recycling preparation, DAF, tissue machine, biological waste water treatment plant) with an organic carbon content of around 50 %.

Additional information on tissue manufactured from virgin fibres can be found in Section 7.1.11.3.

6.2 Current consumption and emission levels of RCF-based paper mills

6.2.1 Overview of input/output for the production of RCF paper

An overview of raw material and energy input and the output of products, residues for further utilisation and major releases (emissions, waste, etc.) of RCF-based paper mills is presented in Figure 6.5. The presence of some of the substances depends mainly on the paper grade and paper properties to be achieved and the type of energy supply.

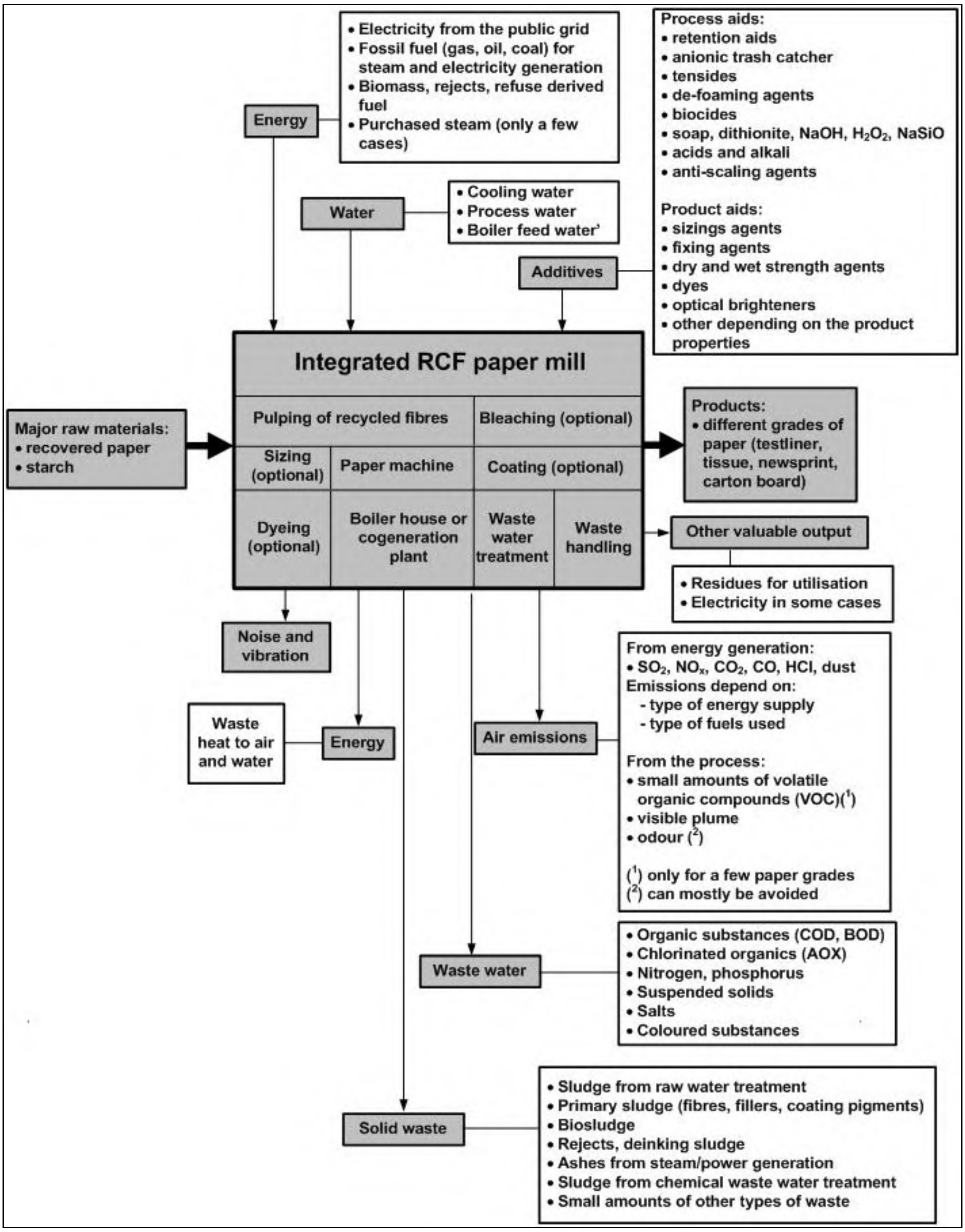


Figure 6.5: Mass stream overview of an integrated mill for processing paper for recycling

As shown in Figure 6.5, the raw materials for RCF-based paper production consist mainly of energy (electricity, fossil and other fuels), paper for recycling, water and some chemical additives. Large quantities of water are used as process water and cooling water. Various additives are applied during paper manufacturing as processing aids and to improve the product properties (paper auxiliaries). The environmental impact of processing paper for recycling basically comprises emissions to water, solid waste generation and atmospheric emissions that are mainly related to energy generation by combustion of fossil or other fuels in steam boilers or combined heat and power plants.

Paper manufacturing in RCF-based paper mills can be subdivided into three parts: stock preparation, approach flow/paper machine, and upgrading of manufactured paper. The stock preparation and the paper machine are closely connected with each other via the process water system (see Section 6.2.2.2).

Table 6.1 gives typical consumption and emission levels for stock preparation of different paper grades. Although the data are taken from real cases, they should be taken as examples only. Large differences in the composition of paper for recycling can be found in Europe, which have an impact on the stock preparation concept. The figures compiled in Table 6.1 refer exclusively to the stock preparation, i.e. the subsequent paper machine is not covered by the data. An exception is the water flows that always refer to the whole mill. This is because water flows between the stock preparation and the paper machine are normally so closely linked that it makes no sense to separate the flows.

Table 6.1: Consumption and emission levels for stock preparation of different paper grades

Consumption of raw material and emissions to water, waste	Packaging paper	Newsprint	LWC/SC paper	Tissue paper and market pulp
Main paper for recycling (depends on availability and price of paper for recycling and quality of the end product)	Mixed paper for recycling and boards, paper for recycling and packaging from stores and supermarkets	Deinkable paper for recycling (old newsprint and old magazines)	Deinkable paper for recycling (old newsprint and old magazines)	Deinkable paper for recycling (old newsprint + magazines); wood-free office paper for recycling
Energy consumption (1) - Electricity - Thermal energy (e.g. steam)	150 – 250 kWh/t 0 MJ/t (if dispersing is applied heating is required)	300 – 420 kWh/t 450 – 900 MJ/t (=0.2 – 0.4 t_{steam}/t)	400 – 600 kWh/t 650 – 1 200 MJ/t (=0.3 – 0.5 t_{steam}/t)	400 – 500 kWh/t 650 – 1 100 MJ/t (=0.3 – 0.5 t_{steam}/t)
Chemicals (2) - Repulping	Biocide	0.5 – 1.0 % H_2O_2 0.5 – 1.0 % NaOH 1 – 2 % Na_2SiO_3	0.5 – 1.0 % H_2O_2 0.5 – 1.2 % NaOH 1 – 2 % Na_2SiO_3	0.0 – 1.0 % H_2O_2
- Flotation I	–	0.3 – 0.6 % soap	0.3 – 0.6 % soap	0.3 – 0.6 % soap
- Flotation II	–	0.2 – 0.4 % soap (NaOH+fatty acids)	0.2 – 0.4 % soap (NaOH+fatty acids)	–
- Bleaching	–	1 – 2 % H_2O_2 0.5 – 1.2 % NaOH 1 – 1.8 % Na_2SiO_3 0.4 – 1 % Dithionite up to 0.2 % NaOH	1 – 2.5 % H_2O_2 0.5 – 1.5 % NaOH 1 – 2 % Na_2SiO_3 0.4 – 1 % Dithionite Up to 0.2 % NaOH	1 – 2 % H_2O_2 0.5 – 1.2 % NaOH 1 – 1.8 % Na_2SiO_3 0.4 – 1 % Dithionite up to 0.2 % NaOH
- Flocculants used for internal clarification of process water and sludge treatment (3)	0 kg/t (internal clarification in the paper machine loop (WW II)	Flocculation auxiliary agents: 0.5 – 1 kg/t	Flocculation auxiliary agents: 1.6 – 2.6 kg/t Flocculants.: 1.5 – 2.5kg/t	Flocculation auxiliary agents: 1.8 – 2.8 kg/t
Water - Water flow (4) - Emissions **before** biological WWTP	0 –30 m^3/t_{paper} TSS (5): usually below 200 mg/l COD: 27 – 36 kg/t (6 750 – 9 000 mg/l) AOX: <4 g/t (= 1 mg/l)	8 – 20 m^3/t_{paper} TSS (5): usually below 200 mg/l COD: 17 – 27 kg/t (1 700 – 2 700 mg/l) AOX: <10 g/t (= 1 mg/l)	8 – 30 m^3/t_{paper} TSS (5): usually below 200 mg/l COD: 17 – 27 kg/t (1 700 – 2 700 mg/l) AOX: <10 g/t (= 1 mg/l)	8 – 50 m^3/t_{paper} TSS (5): usually below 200 mg/l COD: 26 – 45 kg/t (2 600 – 4500 mg/l) AOX: <10 g/t (= 1 mg/l)
Waste - solid wastes (dry) (6) - organic content	50 – 100 kg/t_{paper} 70 – 80 %	15 - 25 % losses 170 – 190 kg/t_{paper} 35 – 45 %	20 - 35 % losses 450 – 550 kg/t_{paper} 20 – 40 %	500 – 600 kg/t_{paper} 40 – 50 %

(1) An essential factor for variations in energy consumption is the use of a disperger which consumes 60 – 100 kWh/t. Furthermore, the losses should be considered: processes with higher losses require machines with higher capacities and higher specific energy. The number of process stages in stock preparation/machines also has an influence on variations. If high-quality graphic grades are manufactured, energy consumption might be higher compared to standard grades.

(2) All chemicals consumption is expressed as 100 % effective chemicals and not as commercial solutions containing various amounts of water except for Na_2SiO_3 which is expressed as a commercial solution. The ranges can be explained by differences in the quality of paper used for recycling, inks to be removed and product quality to be achieved.

(3) The use of flocculants depends mainly on the number of micro-flotation units for process water clarification and on the amount of sludge to be dewatered. Water flows from washers are high and need a relatively high amount of flocculants if they are to be treated.

(4) The data for water flow refer to the water used in the whole mill, i.e. stock preparation + paper machine. The water flow means outgoing water from biological treatment and excludes sealing water.

(5) Usually there is a micro-flotation unit installed before discharging the effluents to the waste water treatment. This results in a relief of the primary treatment or makes it possible to do without primary treatment. Without a micro-flotation unit, the TSS content depends on the facilities for dewatering of sludge and rejects.

(6) Including sludge from process water treatment (micro-flotation units).

Source: operational experiences provided by a supplier, 1998, and amendments based on comments from operators, 2010.

Paper mills often manufacture paper products consisting of a mixture of different fibre types. Integrated RCF-based mills are often partially integrated, i.e. part of pulp is manufactured on site and the rest is purchased pulp. In Europe, nearly all RCF-based mills are integrated except two mills that produce market deinked pulp (Greenfield SAS, FR). A couple of integrated mills have excess processing capacity for paper for recycling for supplying market deinked pulp.

The raw material consumption and releases to the environment of processing paper for recycling are discussed one by one below.

6.2.2 Consumption and emission levels arising from individual process units

The following aspects associated with paper manufacturing based on recovered fibre processing are of concern:

- consumption of paper for recycling;
- water use;
- use of chemical additives;
- energy demand;
- waste water emissions;
- solid waste generation from stock preparation, process water clarification and waste water treatment;
- air emissions from energy generation;
- air emissions from sludge and residue incineration (optional);
- noise and vibration from paper machines (local);
- odour from vapours and from waste water treatment plants (local).

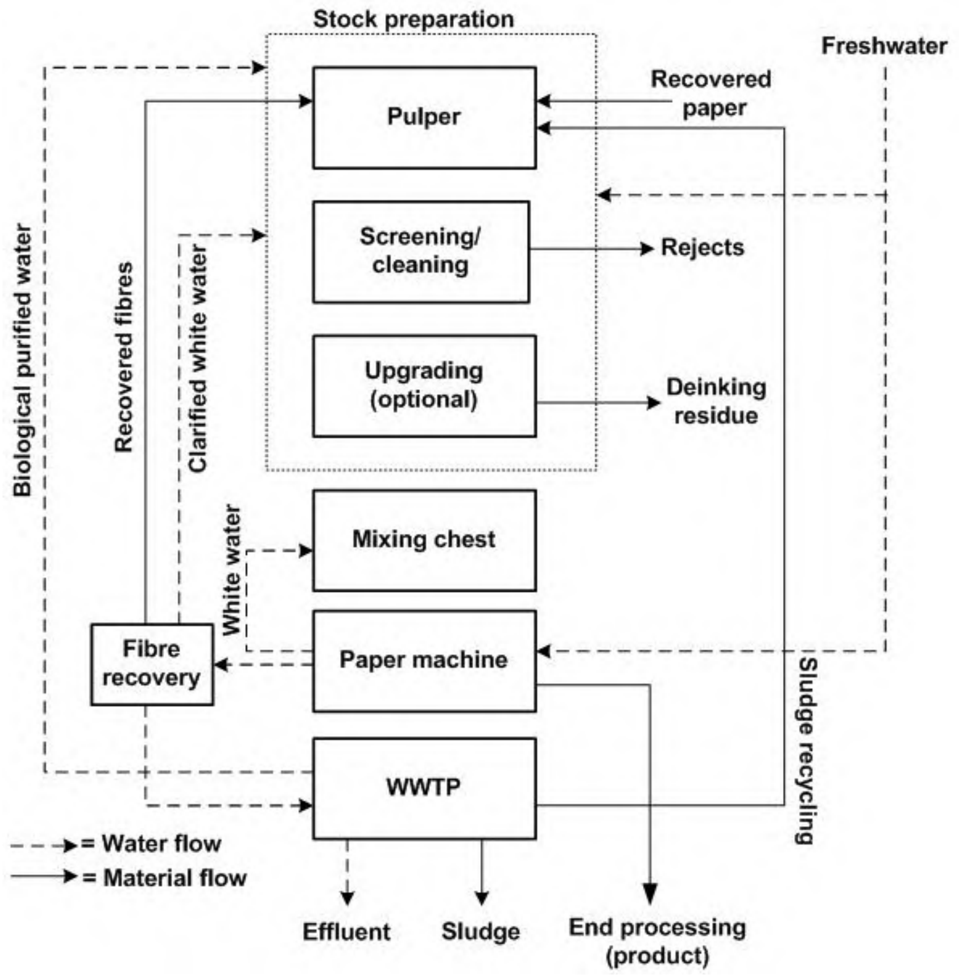
6.2.2.1 Consumption of paper for recycling

For the manufacturing of different types of papers such as 'brown' packaging papers or 'white' graphic papers, different amounts and qualities of secondary fibres are used. For instance, for the production of one tonne of paper, for case-making material (for corrugated medium) around 1 100 kg are used, for newsprint 1 200 – 1 350 kg are used, and for tissue and market DIP around 2 000 kg paper for recycling are used. According to the list of European standard qualities of paper for recycling [28, CEN 643 2001], paper for recycling is roughly classified into four groups, corresponding to ordinary, medium, high and kraft qualities which are further subclassified. Lower grade paper for recycling contains more impurities and must be cleaned more intensively to fulfil the product requirements compared to higher grade paper for recycling. Higher grades are mainly used for the processing of graphic papers or tissue whereas lower qualities of paper for recycling are commonly used as raw materials for the manufacturing of packaging paper. Since uniformity is important for pulp furnishes, the quantitative and qualitative variations of impurities and contaminants should be as small as possible. Thus, the collection and sorting methods are as important as the technical efforts to develop new processes for recovered fibre processing.

The percentage of impurities in paper for recycling has increased over the last decade because of the continuous increase in the recycling rate, the trend towards more multi-component packaging, easy to handle plastic packed advertising in magazines, and a combined collection of paper for recycling together with other waste fractions. The trend to use more fillers and pigments in paper production has generally caused higher calcium carbonate concentrations in the closed process water circuits of RCF mills, an undesired effect that in some cases needed to be controlled by decarbonisation techniques (see Section 6.3.5 on the removal of calcium from process waters). The increasing amount of impurities in paper for recycling will lead to increasing efforts in processing paper for recycling, such as cleaning and bleaching. It also results in increasing solid wastes at RCF paper mills.

6.2.2.2 Water use and waste water flow

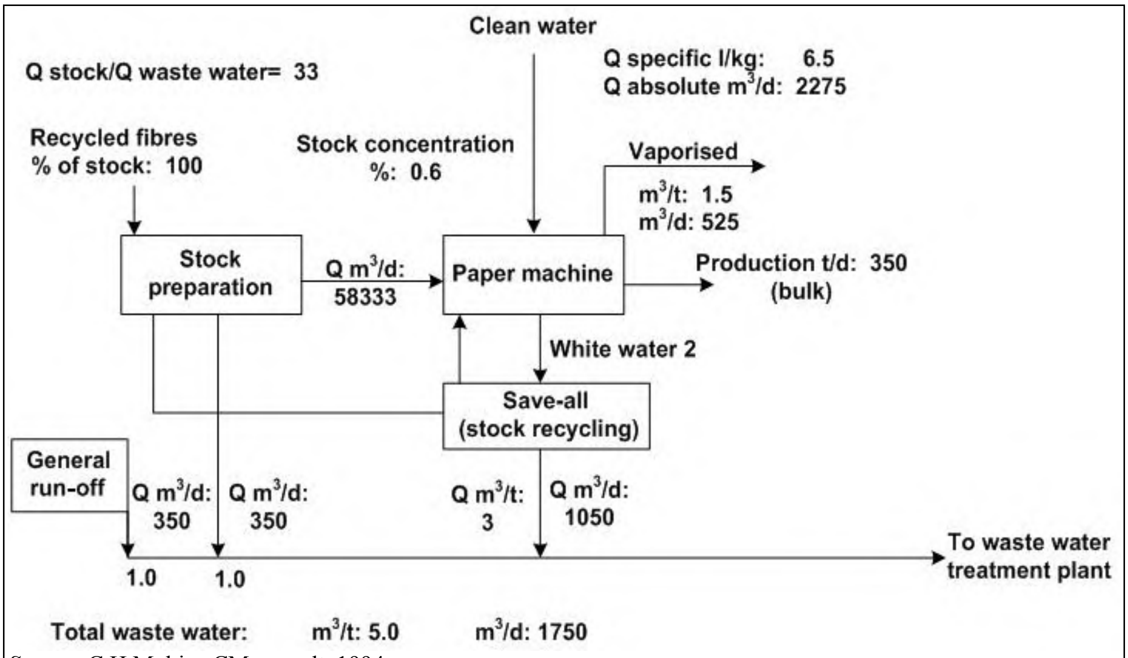
Paper and board mills commonly use large quantities of water. On the other hand, in most RCF-based paper mills a large amount of water is reused and recirculated back into the processes and thus reduces the specific water volume used for paper manufacturing. In Europe, both groundwater and surface water are used in paper mills. Depending on the paper grade, the water is pretreated in order to fulfil the requirements set for process water. If necessary, iron, manganese and sometimes algae and turbidity have to be removed by means of flocculation, complexation and/or filtration (see Section 2.4.1). Water has various functions in the paper industry: it is used as process water, cooling water and boiler feedwater (for further details see Section 7.1.3, water circuits and fibre recovery). As shown in Figure 6.6, process water is extensively recycled in the production process.



Source: [23, Dutch Notes on BAT 1996]

Figure 6.6: Basic flow chart of the paper and board production processing paper for recycling

All paper and board mills recycle drainage water from the wire section (white water). White water is recycled untreated as a diluent to the mixing chest (short circuit) or it is reused after clarification in the fibre recovery unit at specific locations in the process where higher water quality requirements are to be met. Excess flow from the fibre recovery unit of the stock preparation is discharged to keep the water balance and to purge unwanted substances that should not enter the approach flow of the paper machine. The possible rate of recycling depends on the quality requirements of production and on the quality of the treated process/waste water. In addition, the process design of the water circuits strongly influences the limit of water reuse without disadvantages for production and product quality. In Figure 6.7 and Figure 6.8 examples of stock water systems, water circuits and water balances for integrated RCF-based mills for brown and white paper grades are given.

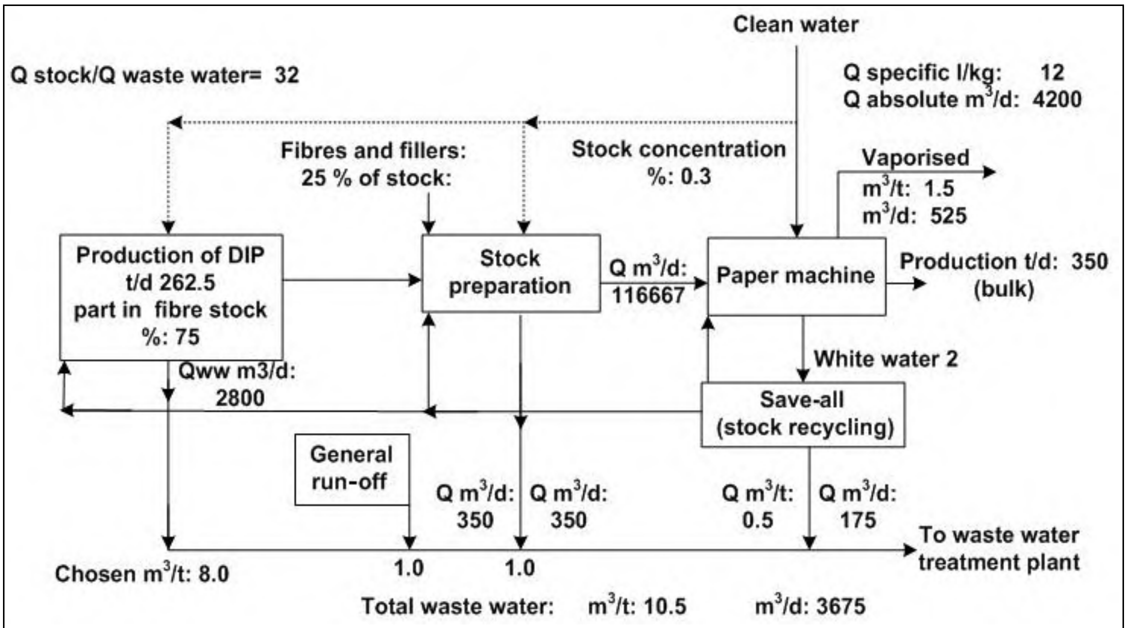


Source: C.H.Möbius CM consult, 1994

Figure 6.7: **Example of water circuits for an integrated RCF mill for corrugated medium without deinking**

The example for an almost closed circuit in the production of non-deinked paper from recovered fibres shows that fresh water is only used at the paper machine side (and minor quantities for the preparation of chemical additives and for boiler feedwater). The white water is recycled back to the stock preparation and used for slushing of the paper for recycling and different steps of mechanical cleaning of the pulp. A partial stream is discharged to the waste water treatment plant. About 1.5 m^3/t of paper is vaporised in the dryer section of the paper machine. In the example in Figure 6.7, the water is used 33 times in the process before being discharged.

In Figure 6.8, an example of an almost closed water circuit in integrated production of paper with a high content of market deinked pulp (DIP) is shown.



Source: C.H.Möbius CM consult, 1994

Figure 6.8: **Example of an optimised stock-water system for the integrated production of deinked pulp**

Process water flows counter-current to the materials flow, i.e. white water is recycled to the deinking plant and the stock preparation. Excess flows from different parts of the mill are discharged in order to protect the approach flow of the paper machine, where higher water quality is required, from disturbing substances and to balance the amount of water used in the system. At the paper machine, clean water is used to ensure the high water quality requirements at this part of the paper manufacturing process. The ratio between the fibre suspension fed to the paper machine and the discharged waste water is 32:1, i.e. water is used 32 times within the circuit. To avoid any drawbacks related to water reuse, the whole fibre-water-additive system of the mill has to be analysed and optimised. In some mills (partial) removal of impurities inside the process to a desired level is applied in order to fulfil the process water quality requirements set for a specific paper grade or process unit.

Table 6.2 summarises the specific water use of different mills processing paper for recycling.

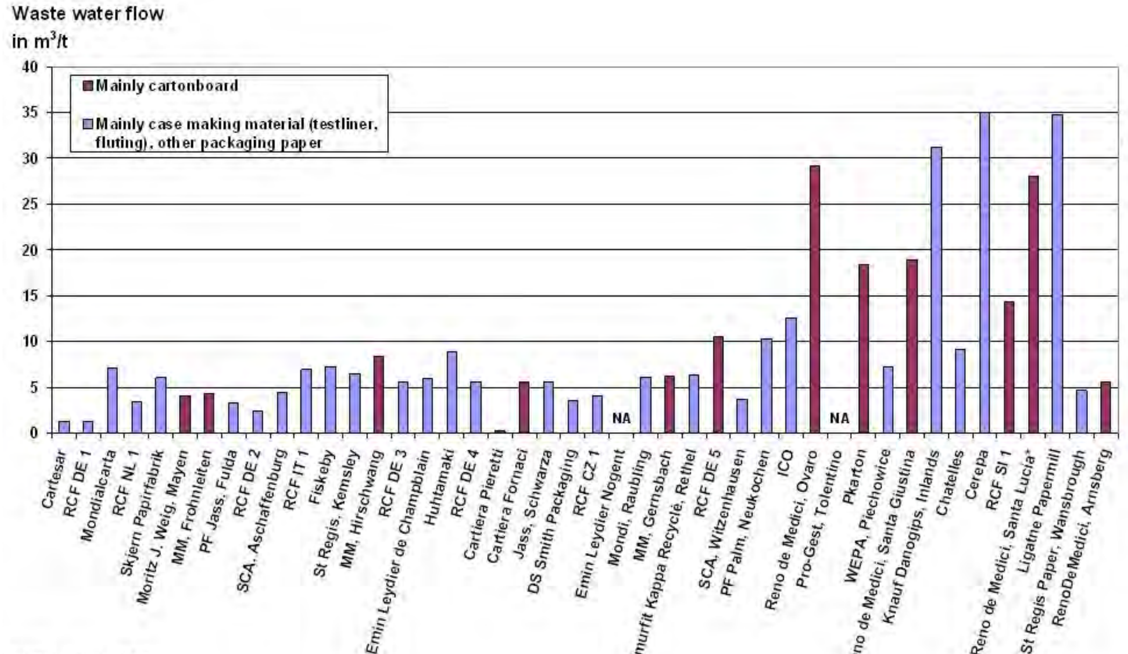
Table 6.2: Water use in RCF-based paper and board production

Product type	Specific water use (m^3/t) (1)
Coated and uncoated folding boxboard	5 – 30
Corrugated medium and packaging paper	1.5 – 35
Newsprint	9 – 20
Tissue	9.5 – 50
Writing and printing paper	9.5 – 55

(1) About 1.5 m^3 water per tonne of paper is vaporised in the dryer section of the paper machine, i.e. it does not appear as waste water.

Source: EIPPCB questionnaires filled in by operators of pulp and paper mills (reference years: 2006 and 2008

Figure 6.9 shows the specific waste water flow of mills processing paper for recycling **without** deinking. Of the mills that took part in the survey, most paper mills that manufacture mainly case-making materials discharge less than 10 m^3/t; many mills (11 mills) discharge even less than 5 m^3/t. Only a few have waste water flows of >10 m^3/t. In this group of mills, some paper mills also operate with a totally closed water system and zero effluent (approximately 10 mills) but did not however fill in the questionnaire and are therefore not shown in the figure.



* Mill produces WLC

Data source: EIPPCB questionnaires filled in by operators of pulp and paper mills, reference years: 2006 and 2008

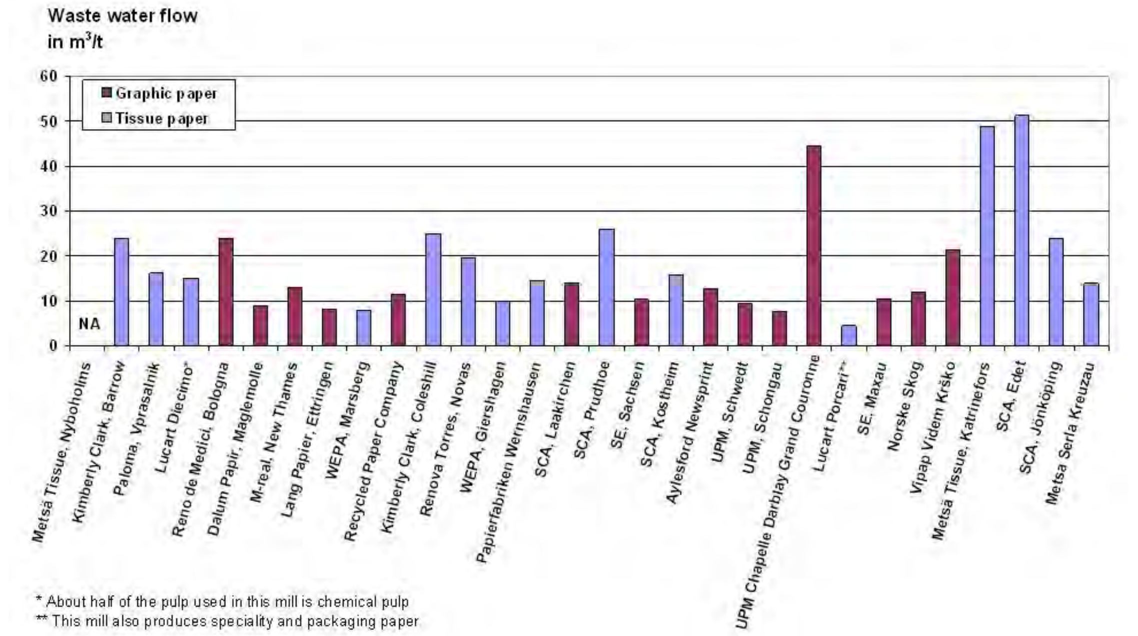
Figure 6.9: **Specific waste water flow of European RCF paper mills without deinking**

The producers of non-deinked cartonboard discharge mostly between 4 m^3/t and 10 m^3/t (with five exceptions).

Figure 6.10 shows the specific waste water flow of a large number of mills processing paper for recycling **with** deinking. The lowest reported waste water flow of mills using 100 % RCF is 8 m^3/t, both for graphic paper and tissue.

The majority of RCF-based graphic paper producers discharge less than 15 m^3/t, with only a few mills reporting higher and significantly higher discharge flows (three mills). Only one mill has a waste water flow of >25 m^3/t.

Of RCF-based tissue producers, the majority of the reporting mills reported flows below 25 m^3/t (only three exceptions), 50 m^3/t being the highest reported waste water flow (indirect discharger). Regarding the specific waste water volume, a distinction must be made between graphic RCF-processing mills and RCF-processing mills manufacturing tissue. With some exceptions, in tissue production the specific waste water amount is slightly higher than in manufacturing RCF-based graphic paper (mainly because of lower basic weights of paper produced – down to 12 g/m^2 –, higher cleanliness of the product, more frequent changes of grade or colours, and the often lower speeds of the paper machines).



* About half of the pulp used in this mill is chemical pulp
** This mill also produces speciality and packaging paper

Data source: EIPPCB questionnaires filled in by operators of pulp and paper mills, reference years: 2006 and 2008

Figure 6.10: Specific waste water flow of European RCF paper mills with deinking

6.2.2.3 Use of chemical additives

To improve the product properties, various chemical additives are applied in the paper and board industry. The amount and types of additives vary with the paper grade and the installed equipment. The chemical additives applied by the paper industry can be classified into product aids which are applied to optimise the specific properties of the paper according to the customer's requirements and process aids. The latter facilitate the operation of paper processing in order to enhance the runnability of the process. For further details on the use of chemical additives and examples of the main additives and their application, the reader is referred to Section 2.3.2 on the storage and handlings of chemicals and Section 7.2.2.3 on the use of chemicals.

Substances used for deinking are shown in Table 6.3 Deinking chemicals have little retention to cellulose and can be expected to be present in the deinking sludge.

Table 6.3: Typical chemical doses in the deinking process including bleaching

Chemical additives	Use (kg/t of deinked stock)
Sodium hydroxide	2 – 10
Sodium silicate	12 – 25
Soap	3 – 8
Talc	0 – 15
Hydrogen peroxide	5 – 25
Chelating agent (DTPA) (1)	0 – 3
Sodium dithionite	6 – 10
Sulphuric acid	8 – 10
Bentonite (2)	0 – 4
Enzymes	NA

(1) Usually there is no need for the use of chelating agents in processing paper for recycling/bleaching unless there are excessive concentrations of Fe and Mn ions.
(2) May be used for sticky-fighting, pitch control, additives in water circuit treatment (flotation) or as a retention aid.
Source: [1, Finnish BAT Report 1997], [comments from Stora Enso, 2010].

Chemical additives are often not completely used up during the process or not completely retained on the paper sheets especially as far as process aids are concerned. A certain amount is discharged via waste water. Excess additives also leave the system via rejects and sludge (refer to Figure 2.8). Some of these additives can have a negative influence on the practical functioning of the waste water treatment plant and/or the quality of the receiving water if they are not degraded or eliminated in the waste water treatment plant. In some Member States, water quality authorities require insight into the quantities and nature of the applied additives. In the Netherlands, for example, companies have to submit relevant information on the nature and composition of the chemical additives. This information is then used in an assessment methodology [121, RIZA 1997] which determines the impact of additives on the aquatic environment. Additives may only be applied if they have passed the assessment methodology with a positive score or are retained by a suitable technique.

6.2.2.4 Energy demand

RCF paper and board mills require substantial amounts of steam for the heating of water, pulp, air and chemical additives to the required process temperature and above all for drying the paper. Besides, large quantities of electricity are required for driving the machinery, pumping, vacuum, ventilation and waste water treatment. In paper mills, energy is usually the main factor in operating costs. Because the secondary fibres have already passed through stock preparation equipment when the original paper was made, RCF pulping requires comparatively less total energy for processing than is needed for chemical and especially for mechanical pulping.

In RCF paper mills, steam is normally produced on site by each company. Electricity can also be purchased from the public grid. Paper mills commonly have a need for both steam and electricity which favours running combined heat and power plants (CHP) (see Section 2.6.1.2.2). The CHP plants of paper mills sometimes produce more electricity than is actually needed for the production process. This excess electricity may be supplied to the public grid.

In Table 6.4 some detailed figures on energy consumption required for the stock preparation of paper for recycling used for tissue and newsprint are compiled. The figures include the stock preparation only and not the paper machine. For the latter, the reader is referred to Section 7.2.2.4 on energy demand. All data are related to equipment from the year 1998 and stock preparation concepts designed for high-quality systems. The values stand for existing examples of stock preparation concepts (*Source*: Valmet, today Metso). Normally, the process concepts chosen vary from mill to mill to a certain extent. However, the major building blocks of the systems are required by every RCF-processing mill. Hence they can give an indication of the range of energy demand that can be expected for these types of RCF paper mills. Further reported data can be found in Table 6.4 which gives wider ranges for the power consumption of newsprint and tissue.

Table 6.4: Existing examples of the energy consumption in the production of tissue and newsprint from paper for recycling

Technical parameters	Tissue DIP line (200 t/d)	Newsprint DIP line (1 000/d)
Raw material	Old magazines/mixed office waste	Old newsprint/old magazines
Yield (amount of paper product divided by the raw material input)	55 – 60 %	80 %
Total specific power (estimated)	230 kWh/t of DIP (1) Another mill reported 380 kWh/t for the tissue DIP line	300 kWh/t of DIP (2)
Total specific low-pressure steam	0.3 t steam/t of DIP	0.3 t steam/t of DIP
Specific energy demand for major unit processes		
Feed conveyor	1 kWh/t of DIP	0.4 kWh/t
High consistency pulping (1)	39 kWh/t of DIP (CHD pulping including coarse screening)	16 kWh/t (drum pulper)
Coarse screening	Not required	18.5 kWh/t
MC Cleaner	Pumping energy	Pumping energy
Sand removal (cleaner)	Pumping energy	Pumping energy
Fine screening	17 kWh/t of DIP	22 kWh/t
Flotation I	18 kWh/t of DIP	33 kWh/t
Washer I	8 kWh/t of DIP	No washing
Disc filter (thickening)	Not required	1 kWh/t
Dispersion (including thickener)	55 kWh/t of DIP (2)	67 kWh/t (2)
Dissolved air flotation	No data (difficult to calculate in kWh/t DIP)	No data (difficult to calculate in kWh/t DIP)
Flotation II	5 kWh/t of DIP	19 kWh/t
Washer II	10 kWh/t of DIP	No washing
Sludge press	No data (not main equipment)	No data (not main equipment)
All pumps	Not included (3)	91 kWh/t (4)

NB: Normally the values are presented as installed KW. When specific energy consumption is derived from these figures, an approximation to the real situation has to be made.

(1) CHD pulping = Continuous high density pulping. In many mills, standard batch HD which has a higher energy demand is applied.

(2) These values represent figures rather below average. For the best qualities, a consumption of up to 70 – 80 kWh/t is not uncommon in some mills. Normally for thickening and dispersion, an electricity demand between 85 – 90 kWh/t is reported (see figures further below).

(3) For the tissue stock preparation equipment, no pumps and agitators are included.

(4) Apart from the pumps for the flotation system, all pumps and agitators are included.

The energy consumption depends on the raw materials used, the stock preparation layout, the installed equipment, and the product properties to be achieved (for other, more typical examples, the reader is referred to Table 6.1 and below in this section).

When figures on energy consumption are compared, the aspects listed below should be kept in mind (see also Section 2.5.1).

- The yield of the process varies mainly according to the raw materials used and the final product to be manufactured.
- The country and the area where paper for recycling is collected significantly affect the raw material quality.
- Because of lower quality paper for recycling some mills may have to make additional efforts in the stock preparation.
- Usually, when energy consumption data are presented, only the main equipment is included, i.e. pumps and agitators are not always part of the system considered. These process components are nevertheless relevant in terms of the electricity demand.
- The contribution of pumps and agitators to the total installed power may vary from 20 % to 30 %. From the energy point of view, process concepts that decrease the amount of

pumps are therefore counterproductive. In the example for RCF newsprint in Table 6.4, the share of pumps in the total energy demand is 30 %.

- Peripheral subsystems for water, sludge and rejects such as DAF, reject screw presses, or sludge presses are also not included because they are not considered main equipment. Their energy demand has to be added to the figures.
- There is a difference between installed power (main equipment) and the average power that is actually used. As a rule of thumb, the true consumed power is 70 – 75 % of the installed power. This ratio varies according to the process stage and equipment supplier.
- Converting into the finished product is often integrated with tissue production. Many tissue mills therefore include the energy consumption of converting as part of their total energy consumption.

For further detailed figures on the specific energy demand of unit processes in the stock preparation plant for the processing of paper for recycling without deinking (two-ply Testliner), the reader is referred to Section 6.3.10.3 on the upgrading of stock preparation plants.

In Table 6.5 and Table 6.6 for a newsprint mill based on 100 % recycled fibres, values are given for the specific energy consumption (SEC) and the energy balance. The energy consumption is divided into heat and electrical power. The example refers to a Swedish mill with a production capacity of 500 000 t/yr newsprint.

Table 6.5: Specific energy consumption in an integrated Swedish mill with a production capacity of 500 000 t/yr of newsprint from deinked pulp (in 1995)

Process unit	Process heat (MJ/ADt)	Electrical power (kWh/ADt)
Pulp mill		
Deinking	200	175
Washing and screening	0	50
Bleaching	0	75
Total pulp mill	**200**	**300**
Stock preparation	0	235
Paper machine	5 300	350
Total paper mill	**5 300**	**585**
Effluent treatment	**0**	**32**
Total pulp and paper mill	**5 500**	**917**
Source: [130, SEPA report 1997]		

In Table 6.6, figures for the energy balance for the same mill are presented.

Table 6.6: Energy balances of two integrated RCF newsprint mills with a production capacity of 500 000 t/yr and 250 000 t/yr

Department	Heat (MJ/ADt)	Electric power (kWh/ADt)
Pulp mill		
Turbine generator	0	0
External supply	+ 200	+ 332
Consumption	- 200	- 300
Effluent treatment	0	- 32
Excess energy from pulp mill	**0**	**0**
Paper mill		
Consumption	- 5 300	- 585
External supply	+ 5 300	+ 585
Total external supply	**5 500**	**917**
Source: [130, SEPA report 1997]		

Achieved specific energy consumption data for whole RCF mills from questionnaires filled in by operators of German RCF mills are given in Table 6.7 and Table 6.8. The data refer to the whole mill, i.e. they include processing paper for recycling, the paper machine and supporting activities such as raw and waste water treatment. For these mills, it is not specified which energy-saving measures they have implemented. When interpreting these data, the reader should especially consider the aspects discussed in Section 2.5. Besides the applied measures for energy savings, the energy consumption also depends on the fibre furnish used and the products and product qualities manufactured, which make it more difficult to interpret specific energy consumption values for whole RCF paper mills.

Table 6.7: Specific energy consumption data for German RCF paper mills without deinking (reference year: 2006)

Paper grade manufactured	Process heat (kWh/t) (¹)	Electrical power (kWh/t)	Total energy (kWh/t)	Fibre supply
Folding boxboard	1 447	420	1 867	100 % RCF
Folding boxboard	1 492	468	1 960	85 % RCF, 10 % mechanical pulp, 5 % purchased chemical pulp
Folding boxboard	1 535	490	2 025	94 % RCF, 4 % mechanical pulp, 2 % purchased chemical pulp
Corrugated medium, Testliner, cardboard	1 223	372	1 595	100 % RCF
Corrugated medium, Board	1 667 2 676	366 660	2 033 3 336	98 % RCF, 2 % purchased chemical pulp
Folding boxboard	1 140	545	1 685	100 % RCF
Testliner	1 414	355	1 769	100 % RCF
Corrugated medium	1 214	461	1 675	100 % RCF
Testliner, corrugated medium	1 758	500	2 258	100 % RCF
Testliner, corrugated medium	1 184	432	1 616	100 % RCF
Testliner, corrugated medium	1 566	399	1 965	100 % RCF

(¹) Heat consumption figures exclude heat for electricity production. To convert from (kWh) into (MJ) multiply (kWh) by 3.6.

Source: [248, Hamm 2007]

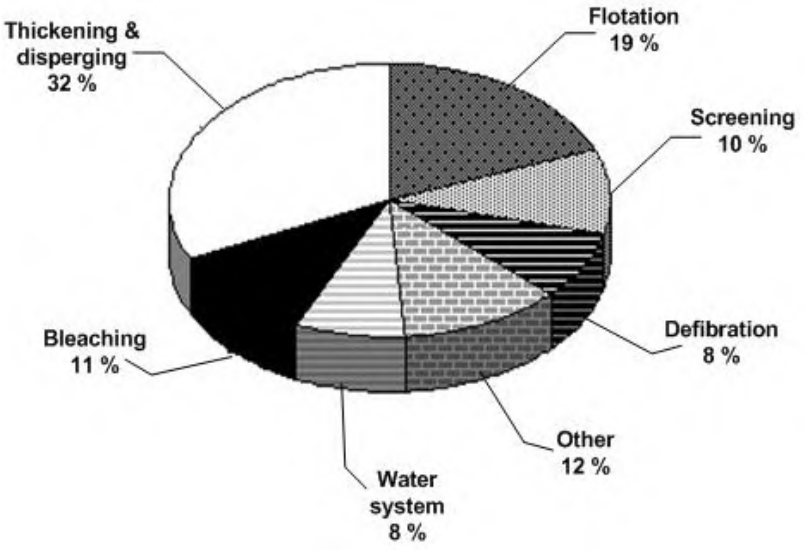
Table 6.8: Specific energy consumption data for German RCF paper mills with deinking (reference year: 2006; reference year for mainly newsprint row: 2011)

Paper grade manufactured	Process heat (kWh/t) (2)	Electrical power (kWh/t)	Total energy (kWh/t)	Fibre supply
Newsprint, SC paper	1 146	927	2 073	100 % RCF
Mainly newsprint	1232	959	2191	100 % RCF
Newsprint	1 113	1 285	2 398 (1)	85 % RCF, 15 % GW
Newsprint, SC paper	1 400	1 430	2 830 (1)	52 % RCF, 42 RMP, 6 % purchased chemical pulp
Tissue	1 600	1 000	2 600	75 % RCF, 25 % purchased chemical pulp
Tissue	2 793	1 377	4 170	Unknown share of RCF and purchased chemical pulp
Tissue	1 942	758	2 700	Unknown share of RCF and purchased chemical pulp
Tissue	2 589	1 158	3 747	Unknown share of RCF and purchased chemical pulp

(1) For RCF paper mills it should be noted that the specific energy consumption is directly proportional to the share and type of mechanical pulp in the furnish. Power consumption for RMP (refiner mechanical pulp) and GW (groundwood) is significantly higher than for RCF processing.
(2) Heat consumption figures exclude heat for electricity production. To convert from (kWh) into (MJ) multiply (kWh) by 3.6.
Source: [248, Hamm 2007]

In principle, energy consumption in recovered fibre processing depends to a large extent on the design, type and amount of process steps involved to achieve a certain product quality. The increase of brightness and the decrease of specks in particular are linked to increasing energy input. For example, whereas standard deinked stock for newsprint consumes about 300 – 350 kWh/t electrical energy, high-grade deinked pulp with higher ISO brightness requires 400 – 500 kWh/t. This significantly increased energy demand is caused by a new peroxide bleaching step with a disperger and an additional secondary flotation for the manufacturing of upgraded newsprint instead of standard grades.

Figure 6.11 shows the contribution of the major process units to the specific energy consumption of a newsprint mill for the processing of paper for recycling. Flotation includes two stages, screening includes prescreening and secondary screening, 'others' includes ventilation, the dryer for a part of the DIP stock, water clarification systems, etc., water system does not include water clarification. Bleaching is conducted in a disperger.



Source: [86, Merkel 1997]

Figure 6.11: Specific energy consumption of a newsprint mill for processing paper for recycling

The figure on energy consumption of the major process stages shows that about one third is consumed by thickening and disperging. For some process units, the following energy consumption values have been reported: conventional pulper 25 – 80 kWh/t, drum pulper 15 – 20 kWh/t, secondary pulper 15 – 40 kWh/t [UBA, 19/1994]. Thickening before disperging consumes about 30 kWh/t. Heating the furnish up to 90 °C and operating the disperger requires about 60 – 100 kWh/t. Flotation needs about 27 – 33 kWh/t. The energy consumption for flotation depends on the amount of flotation cells, the design of the piping in the mill and the types of air injectors applied. Wire presses and screw presses for dewatering require about 10 kWh/t.

Converting activities are normally excluded from the electrical consumption data. However, some tissue mills include converting in their reported energy consumption values because converting into finished products is mostly integrated with the tissue production. Therefore, for tissue mills it is often not clear whether or not the energy consumption of converting processes are part of the reported energy data, which makes it more difficult to interpret these data. In other paper mills, converting is always excluded from the reported energy data.

6.2.2.5 Waste water emissions

The contamination of waste water from RCF-based paper mills is related to the quality of the raw materials used (paper for recycling), the product requirements to be achieved, and the applied waste water treatment system. Chemical additives used, internal process management, good housekeeping and the technical status of the installation also have an effect on the emissions levels achieved.

Waste water from a RCF paper mill arises as an overflow of water from the paper machine or the stock preparation area. It is common practice to withdraw waste water at locations where the process water is mostly polluted (e.g. filtrate from the dewatering of deinking sludge). The process water is contaminated during cleaning, deinking and fibre recovery. Therefore, waste water from RCF-based paper mills consists of:

- water from reject separation by screens and centrifugal cleaners;
- filtrates from washers, thickeners and sludge handling;
- excess white water depending on the rate of water recycling.

Most mills discharge directly to the surface water after primary and biological treatment at the site. Others discharge the effluents to a municipal sewage treatment plant after primary clarification for suspended solids removal. In Table 6.9 average water emission data after only primary treatment for RCF-based paper mills discharging to municipal waste water treatment plants are given. The data have been measured by competent water authorities and self-control measurements of the companies in 1994/95.

Table 6.9: Average water emissions for RCF mills after primary treatment and before discharge to a sewage treatment plant

Parameter	Without deinking		With deinking	
	mg/l (min.-max.)	kg/t (min.-max.)	mg/l (min.-max.)	kg/t (min.-max.)
BOD_5 (1)	1 900	4.7	550	10
COD	3 800 (570 – 9 000)	9.4 (1.2 – 24)	1 100 (440 – 1 900)	20 (7 – 40)
Kjeldahl-N (2)	16 (10 – 40)	0.05 (0.02 – 0.1)	20 (13 – 25)	0.35 (0.19 – 0.62)
Discharge volume		5.5 (0.4 – 15.5) m^3/t		15 (9 – 39) m^3/t(3)

(1) The BOD_5 value is estimated assuming that COD = 2 × BOD_5.

(2) Kjeldahl nitrogen is the sum of organic and ammoniac nitrogen. Part of the organic N may be hydrolysed during the effluent treatment; the generated ammonium-N is a nutrient for the biomass of the treatment plant.

(3) In 2011, the lowest discharge volume was reported to be 6 m^3/t (*Source:* Stora Enso).

Source: [23, Dutch Notes on BAT 1996]

Table 6.10 shows emission data before and after on-site biological treatment. The data have been measured by competent water authorities and self-control measurements of the companies in 1994/95.

Table 6.10: Average water emissions for RCF mills discharging to water bodies after primary and biological treatment at the site

Parameter	Without deinking		With deinking	
	mg/l (min.-max.)	kg/t (min.-max.)	mg/l (min.-max.)	kg/t (min.-max.)
BOD_5 before treatment (1)	1 800 (2)	12.3	770 (2)	8.3
BOD_5 after treatment	10 (3 – 28)	0.06 (0.01 – 0.13)	9	0.09
COD before treatment (1)	3 200 (2)	22	1 900 (2)	21
COD after treatment	150 (60 – 270)	0.77 (0.29 – 1.12)	290	3.1
Kjeldahl-N (3)	5.6 (3 – 13)	0.03 (0.01 – 0.04)	7.8	0.08
Tot-P	1.5 (0.5 – 1.8)	0.01	NA	NA
TSS	25 (17 – 40)	0.13 (0.06 – 0.21)	NA	NA
Discharge volume		5.7 (3.1 – 11) m^3/t		11 m^3/t

(1) Influent data on BOD_5 were not available. Therefore, the influent data are calculated based on waste water loading data of one mill without deinking and one mill with deinking.

(2) Experience from Myllykoski, 2011, is that for RCF mills with deinking higher BOD_5 and COD values are also measured before treatment now and then. BOD_5 before treatment: 770 – 1 150 mg/l, COD before treatment: 1 900 – 2 800 mg/l. A similar experience was reported by Mondi Austria, 2011, for RCF mills without deinking: BOD before treatment: 3 750 mg/l, corresponding COD: 6 250 mg/l.

(3) Kjeldahl-N after effluent treatment gives only an indication of the amount of organic N in the effluent and does not cover the Total N load which also includes the oxidised N compounds, nitrates and nitrites.

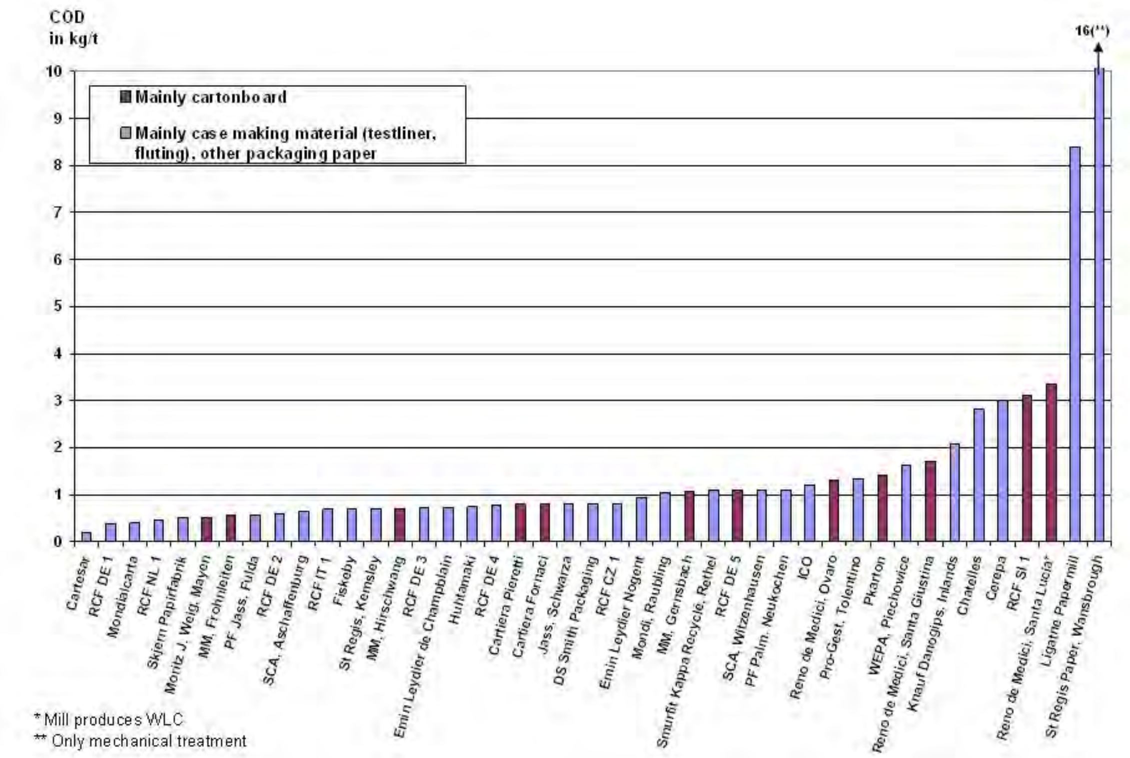
Source: [23, Dutch Notes on BAT 1996]

Chemical oxygen demand (COD)

COD emissions originate from the processing of the raw materials and the input of chemical additives not retained in the paper. The deinking (and bleaching) of paper for recycling often results in higher COD emissions than those from mills processing paper for recycling without deinking.

In Figure 6.12 and Figure 6.13, the specific COD load as yearly average values after waste water treatment is given for mills processing paper for recycling with and without deinking.

More than half of the RCF-based paper mills without deinking that responded to the EIPPCB questionnaires discharge less than 1 kg COD/t and only nine mills discharge organic loads of >1.5 kg COD/t as a yearly average. In this group of mills, some mills operate with a totally closed water system and zero effluent. These mills have however not filled in the questionnaire and are therefore not shown in Figure 6.12. Including these mills would have reduced the average specific COD load discharged from these mills.



* Mill produces WLC
** Only mechanical treatment

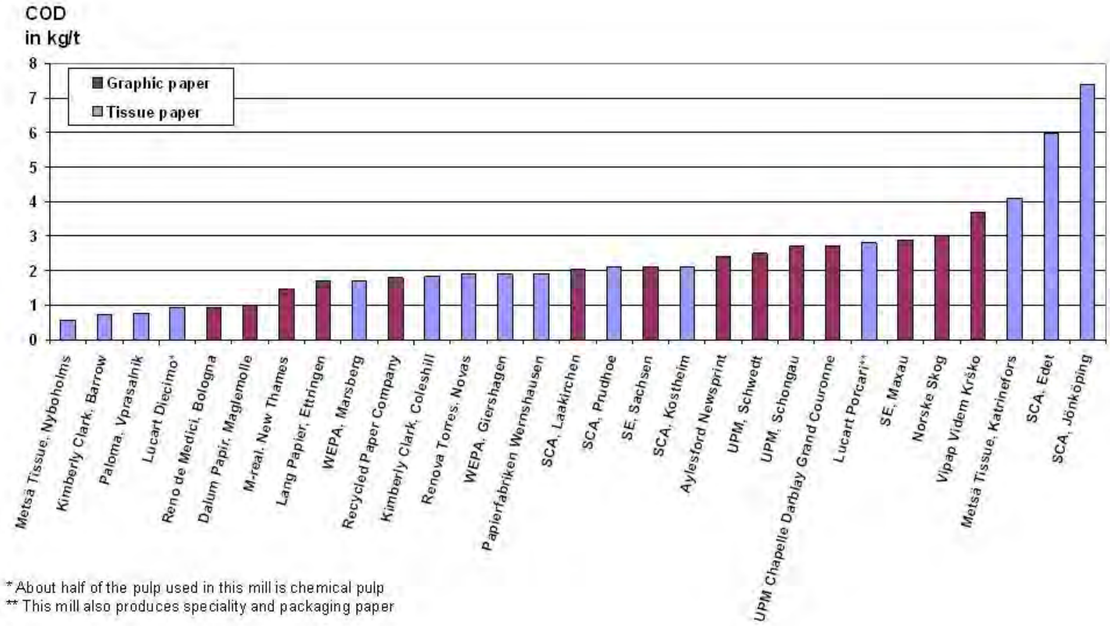
Source: EIPPCB questionnaires filled in by operators of pulp and paper mills, reference year: 2006 and 2008

Figure 6.12: Specific COD load as a yearly average after waste water treatment from mills processing paper for recycling without deinking

Within the non-deinked RCF-based paper mills, the largest group comprises mills manufacturing case-making materials (Testliner, Wellenstoff, and fluting). The manufacturing of cartonboard or folding boxboard is the second largest group. For cartonboard manufacturing, different qualities of paper for recycling and stock preparation lines are operated to produce the different layers of the final multi-layer board. A certain layer (e.g. topliner) might consist of deinked recovered fibres. However, the emission levels to water associated with the use of BAT in these mills are in the same range as the emissions of other RCF paper mills without deinking listed in Figure 6.12.

There are examples of RCF-based mills producing folding boxboard that apply deinking processes to reach, on the basis of lower quality paper for recycling furnish, higher product qualities. Those mills, and any other board grade produced mainly by deinking (>50 % deinked pulp) should benchmark themselves with the mills shown in Figure 6.13.

As shown in Figure 6.13, more than half of the RCF-based paper mills **with** deinking that responded to the questionnaires discharge less than 2.5 kg COD/t and only four mills discharge organic loads of >3 COD/t, as a yearly average. Mills manufacturing RCF-based graphic paper and tissue mills achieve a comparable performance.



* About half of the pulp used in this mill is chemical pulp
** This mill also produces speciality and packaging paper

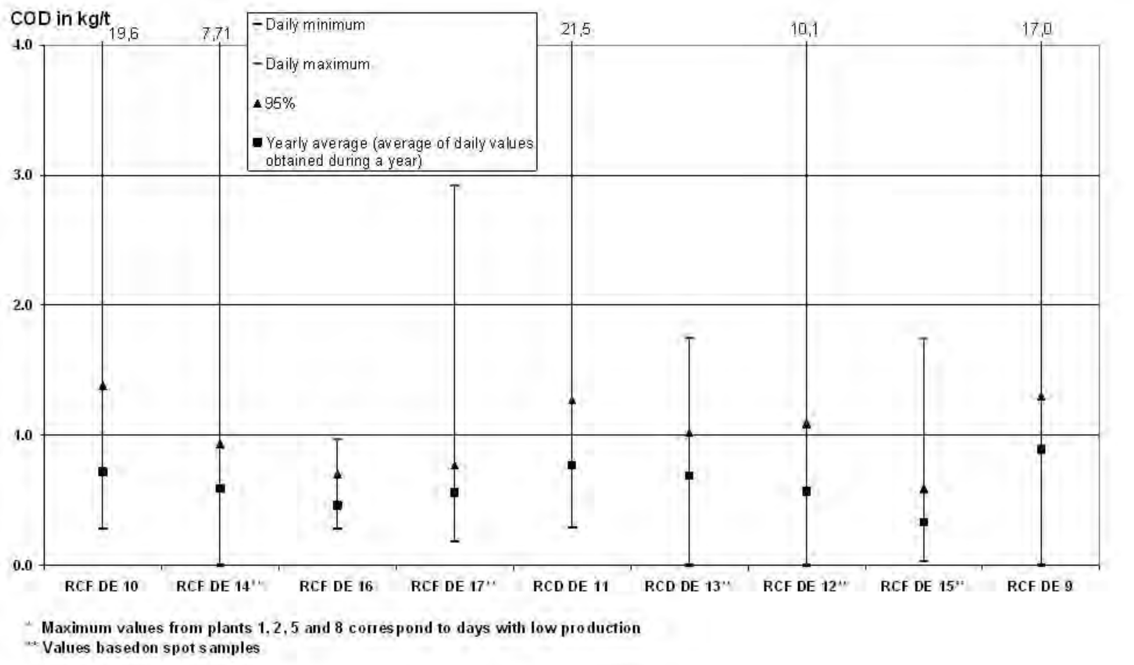
Source: EIPPCB questionnaires filled in by operators of pulp and paper mills, reference year: 2006 and 2008

Figure 6.13: **Specific COD load as a yearly average after waste water treatment from mills processing paper for recycling with deinking**

While in graphic paper mills, furnish mainly consists of recovered fibres and in some cases of integrated produced mechanical pulp (e.g. TMP, GW), the furnish in RCF tissue mills consists mainly of recovered fibres and often some purchased chemical pulp. The emissions to water associated with the use of BAT do not vary significantly between RCF-based graphic paper and tissue mills with the exception of the waste water amount (see Figure 6.10).

RCF-based tissue mills may use different shares of paper for recycling as furnish. There are tissue mills using 100 % virgin fibres and others using 100 % recovered fibres and all types of fibre mixtures ranging from 10 – 100 % recovered fibres. Higher shares of purchased chemical pulp may result in lower COD emissions after biological treatment compared to those mills that manufacture 100 % RCF-based tissue.

Regarding short-term averages of COD, the short-term values reported from mills processing paper for recycling without deinking are shown in Figure 6.14.



Source: Germany, 2012

Figure 6.14: **Short-term averages of COD emissions from mills processing paper for recycling without deinking**

Since data gathering of short-term averages for mills processing paper for recycling with deinking does not allow enough representative data to be shown, variations of daily COD loads for a single mill (RCF DE 18) over the course of a year are shown in Figure 6.15.

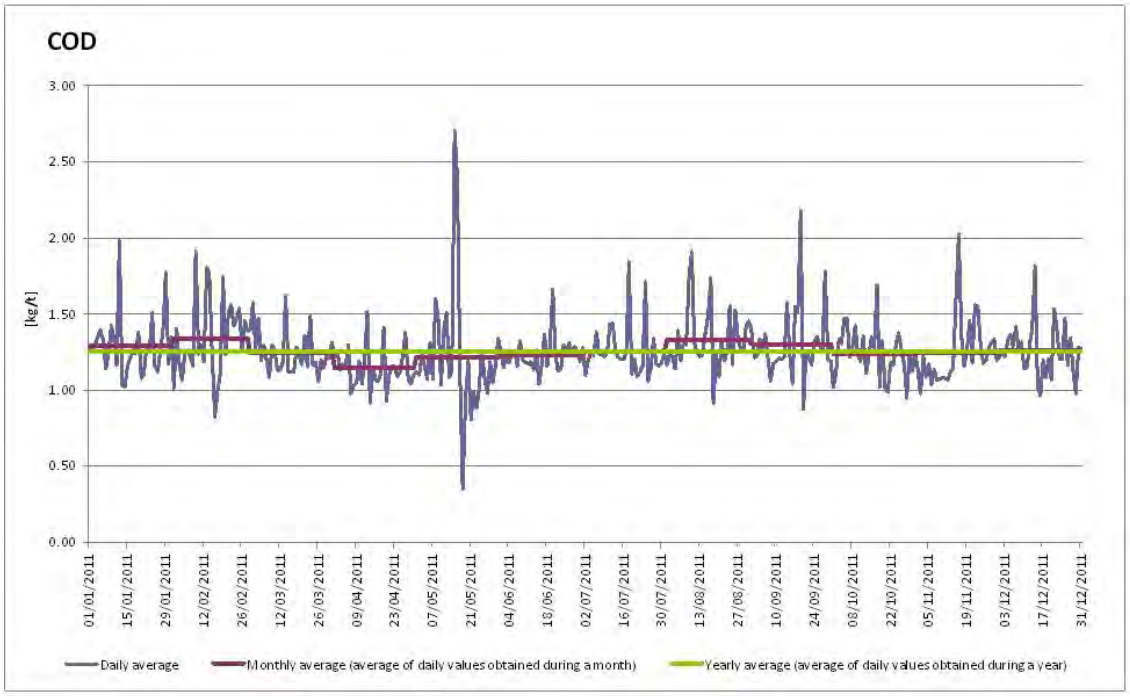
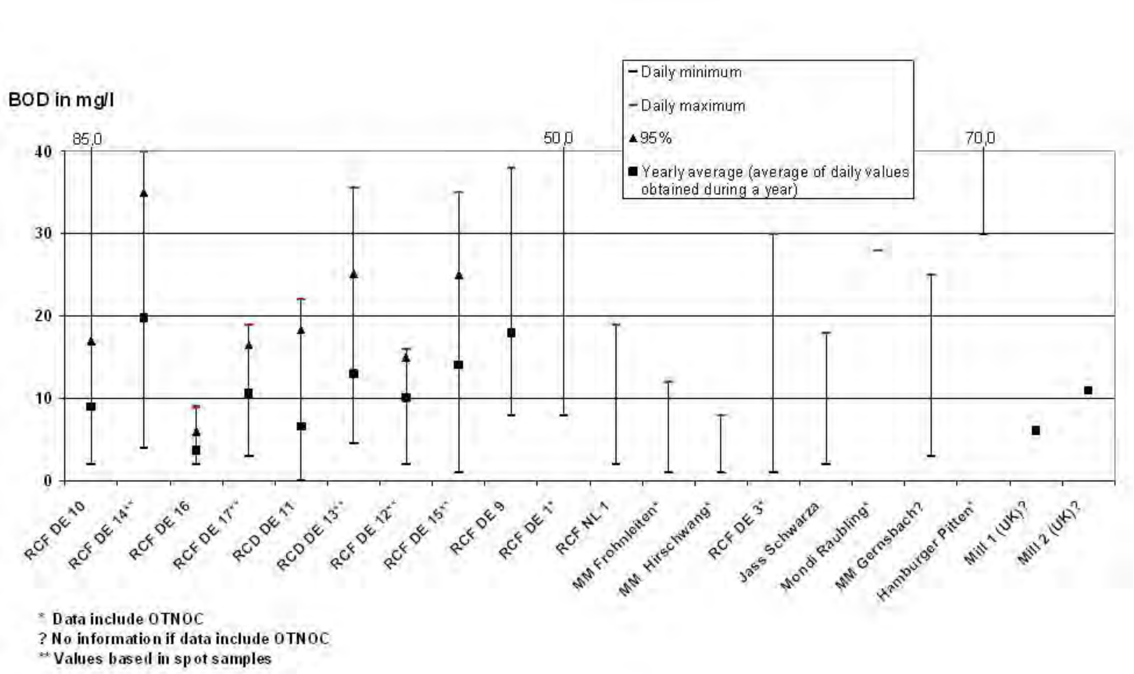


Figure 6.15: **Daily COD loads over one year from a mill processing paper for recycling with deinking (RCF DE 18)**

Biological oxygen demand (BOD_5 or BOD_7)

BOD_5 emissions data after biological treatment show no significant difference between processing paper for recycling with and without deinking. In properly working treatment plants, the concentration of BOD_5 or BOD_7 after treatment is below 20 mg/l independent of the concentration of the inflow. BOD levels of around 5 mg/l are difficult to measure accurately and reproducibly. They should be interpreted as values close to the detection limit. After biological treatment, BOD_5 emissions of 0.01 – 0.13 kg/t paper and board have been reported [23, Dutch Notes on BAT 1996]. The differences in the specific BOD load are mainly caused by differences in the water flow.

Short-term averages of BOD emissions reported from mills processing paper for recycling without deinking are shown in Figure 6.16.



* Data include OTNOC
? No information if data include OTNOC
** Values based in spot samples

Source: EIPPCB questionnaires from 2007/2009 and Germany and UK, 2012

Figure 6.16: Short-term averages of BOD emissions from mills processing paper for recycling without deinking

Since data gathering of short-term averages for mills processing paper for recycling with deinking does not allow enough representative data to be shown, variations of BOD daily concentrations for a single mill (RCF DE 18) over the course of a year are shown in Figure 6.17.

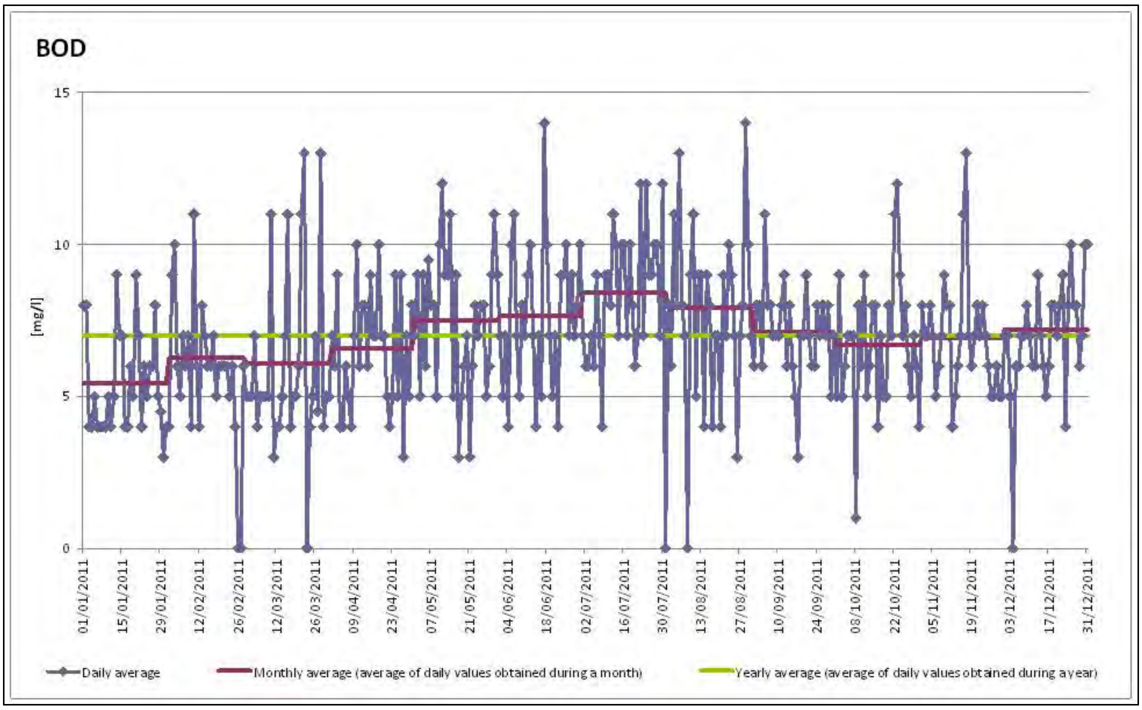


Figure 6.17: **Daily BOD concentrations over one year from a mill processing paper for recycling with deinking (RCF DE 18)**

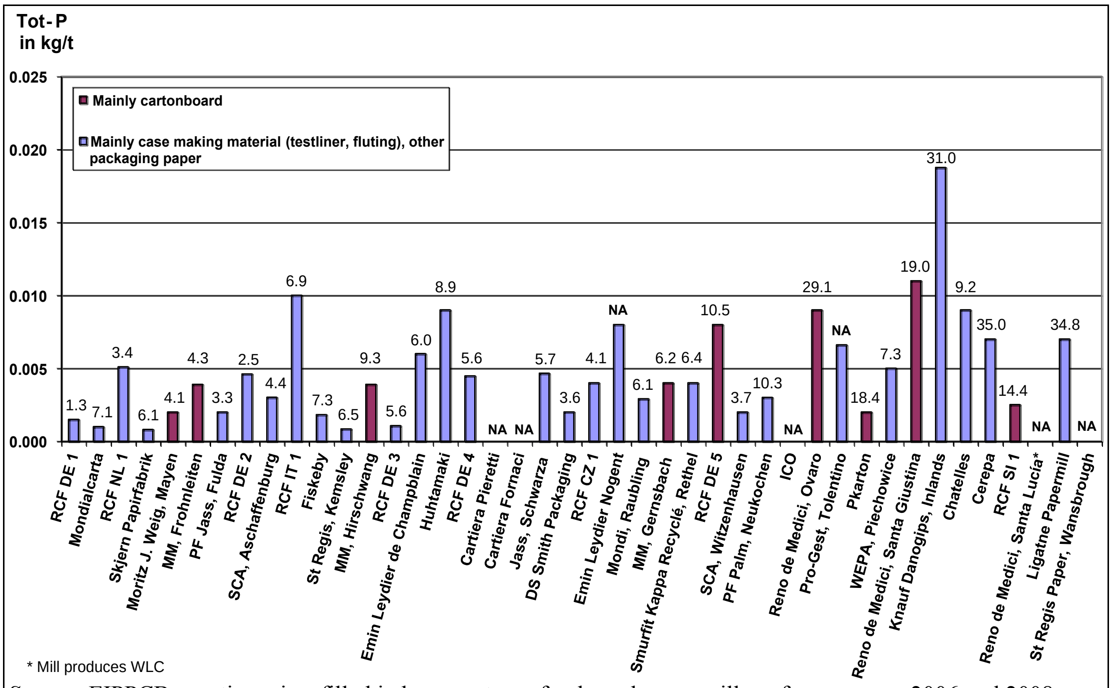
Nutrients

Effluents from RCF-based paper mills normally contain low concentrations of nutrients (nitrogen and phosphate). A controlled dosage of phosphates and ammonium to the biological waste water treatment is therefore necessary to provide nutrients necessary for the growth of the microorganisms that are responsible for biological degradation of the organic pollutants. The active biomass theoretically needs a nutrient supply in the ratio of BOD_5:N:P = 100:5:1. In practice, lower nutrient dosing is often achieved (see Section 2.9.11.2.3). However, some mills reported that higher dosages are needed to ensure good efficiency of the water treatment plant in terms of BOD/COD removal.

Organically bound nitrogen compounds (Kjeldahl-N) may also originate from some chemical additives. During biological treatment part of the organic nitrogen may be hydrolysed into ammonium and transformed to nitrate compounds in the aerated basins. Assuming a controlled dosage to ensure optimal performance of the waste water treatment system, tot-N concentrations of 5 – 15 mg/l and tot-P concentrations of 1 – 2 mg/l are achievable (as daily average).

In Figure 6.18 and Figure 6.19, the specific tot-P load as a yearly average value after waste water treatment is given for mills processing paper for recycling with and without deinking respectively.

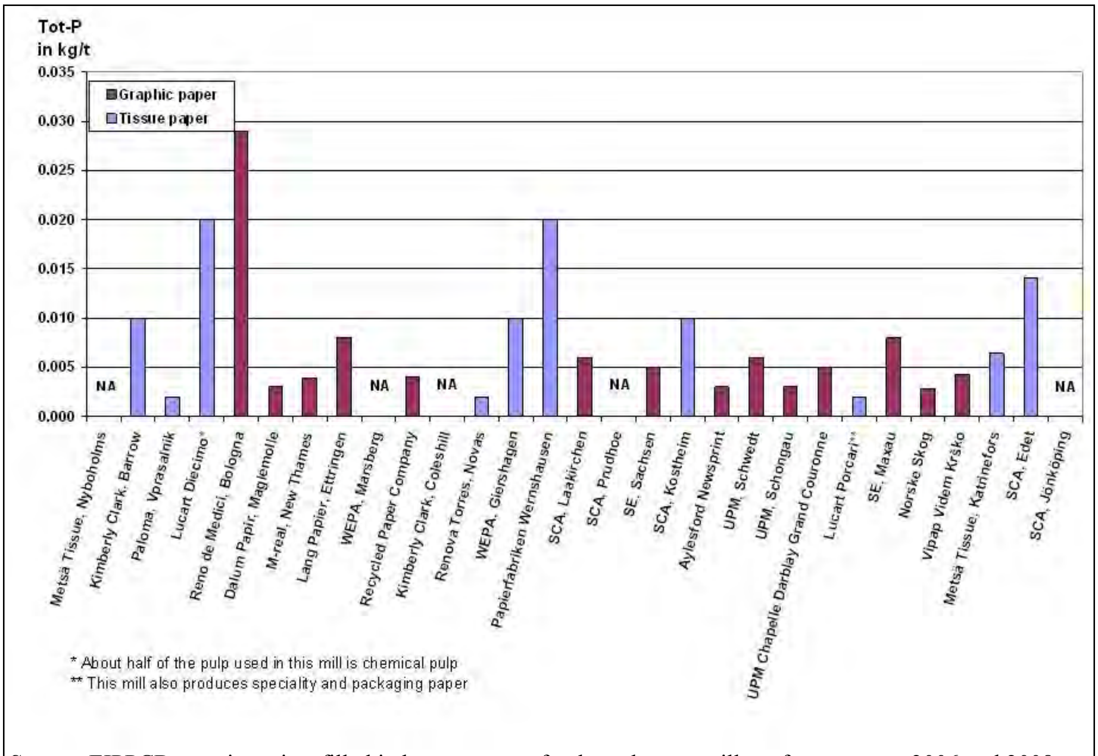
As shown in Figure 6.18, most RCF-based paper mills **without** deinking that responded to the EIPPCB questionnaires discharge less – or significantly less – than 0.01 kg tot-P/t, e.g. four mills reported yearly average values of 0.001 kg tot-P/t. Of the 24 mills that also reported concentration values, only three exceeded 1 mg/l tot-P as a yearly average value (1.12 mg/l; 1.5 mg/l; 1.92 mg/l). Nine mills reported tot-P values of ≤ 0.5 mg/l as a yearly average.



Source: EIPPCB questionnaires filled in by operators of pulp and paper mills, reference year: 2006 and 2008

Figure 6.18: **Specific tot-P load as a yearly average after waste water treatment from mills processing paper for recycling without deinking, with indication of waste water flow**

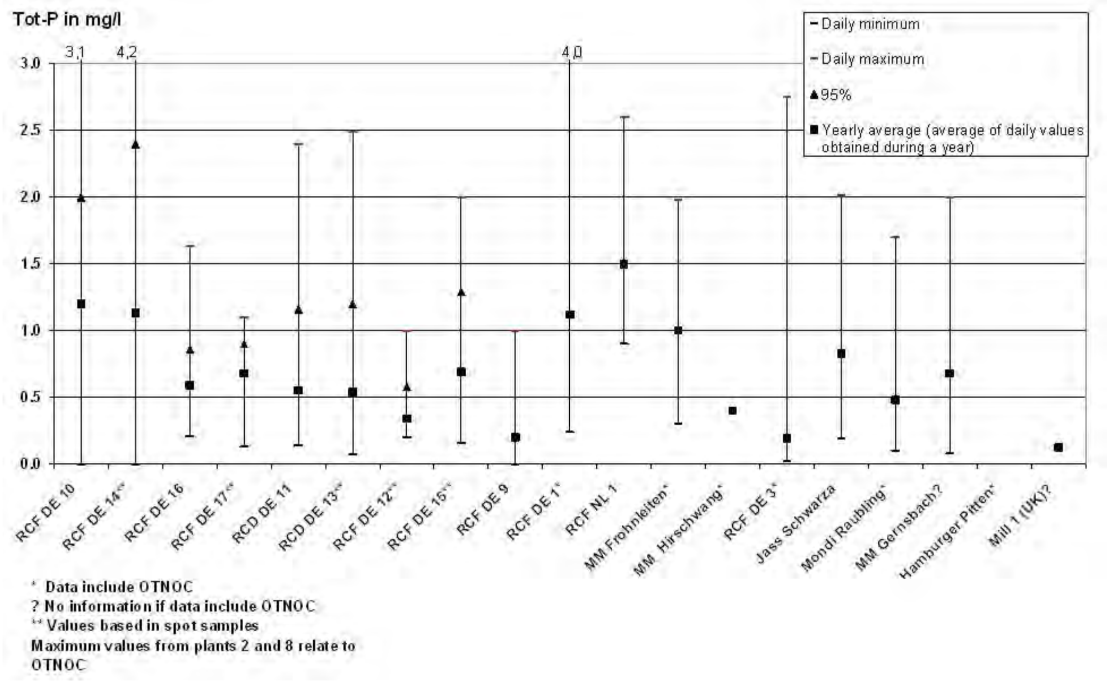
As shown in Figure 6.19, all but four RCF-based paper mills **with** deinking that responded to the EIPPCB questionnaires discharge less – or significantly less – than 0.01 kg tot-P/t. And 12 mills reported yearly average values equal to or below 0.005 kg tot-P/t. Of the 15 mills that also reported concentration values, only three exceeded 1 mg/l tot-P as a yearly average value (1.1 mg/l; 1.2 mg/l; 1.3 mg/l). Six mills reported tot-P values of ≤0.5 mg/l as a yearly average.



Source: EIPPCB questionnaires filled in by operators of pulp and paper mills, reference year: 2006 and 2008

Figure 6.19: **Specific tot-P load as a yearly average after waste water treatment from mills processing paper for recycling with deinking**

Regarding short-term averages of tot-P, the short-term values reported from mills processing paper for recycling without deinking are shown in Figure 6.20.



* Data include OTNOC
? No information if data include OTNOC
** Values based in spot samples
Maximum values from plants 2 and 8 relate to OTNOC

Source: EIPPCB questionnaires from 2007/2009 and Germany and UK, 2012

Figure 6.20: Short-term averages of tot-P emissions from mills processing paper for recycling without deinking

Since data gathering of short-term averages for mills processing paper for recycling with deinking does not allow enough representative data to be shown, variations of tot-P daily concentrations for a single mill (RCF DE 18) over the course of a year are shown in Figure 6.21.

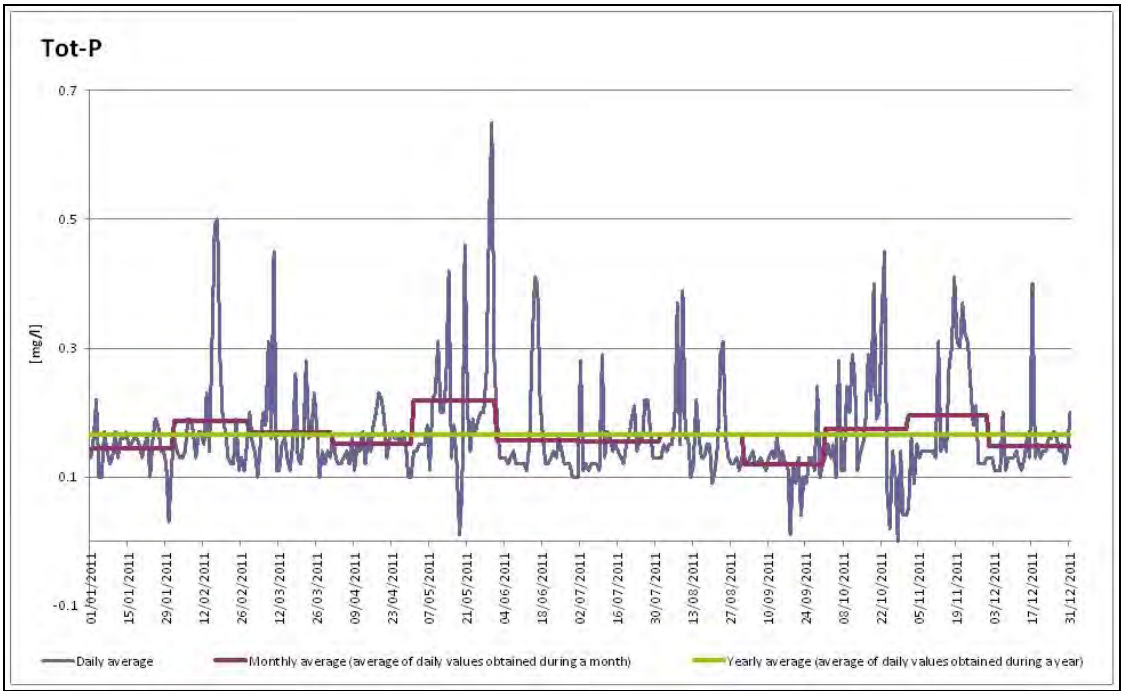


Figure 6.21: Daily tot-P concentrations over one year from a mill processing paper for recycling with deinking (RCF DE 18)

As shown in Figure 6.22, 12 RCF-based paper mills **without** deinking that responded to the EIPPCB questionnaires discharge less than 0.02 kg tot-N/t and four mills reported very low N emission loads of 0.004 kg tot-N/t as yearly average values. Another 17 mills reported N emission loads between 0.02 and 0.08 kg tot-N/t. Of the 25 mills that also reported concentration values, only one exceeded 10 mg tot-N/l as a yearly average value (23.7 mg/l).

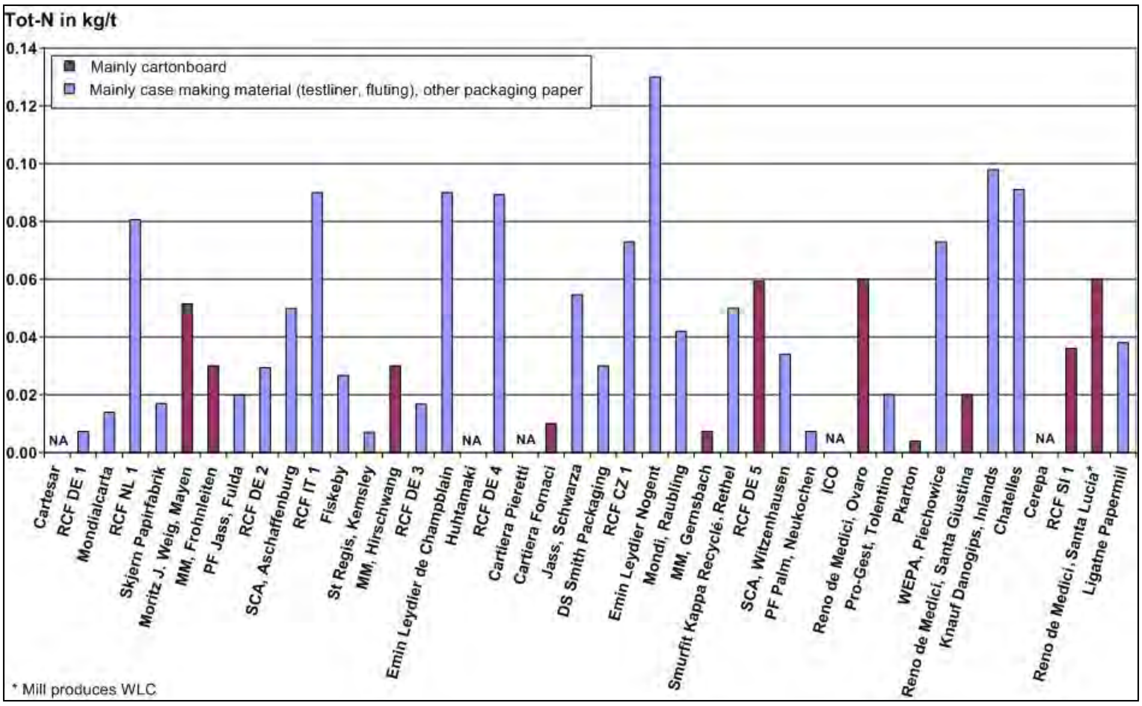
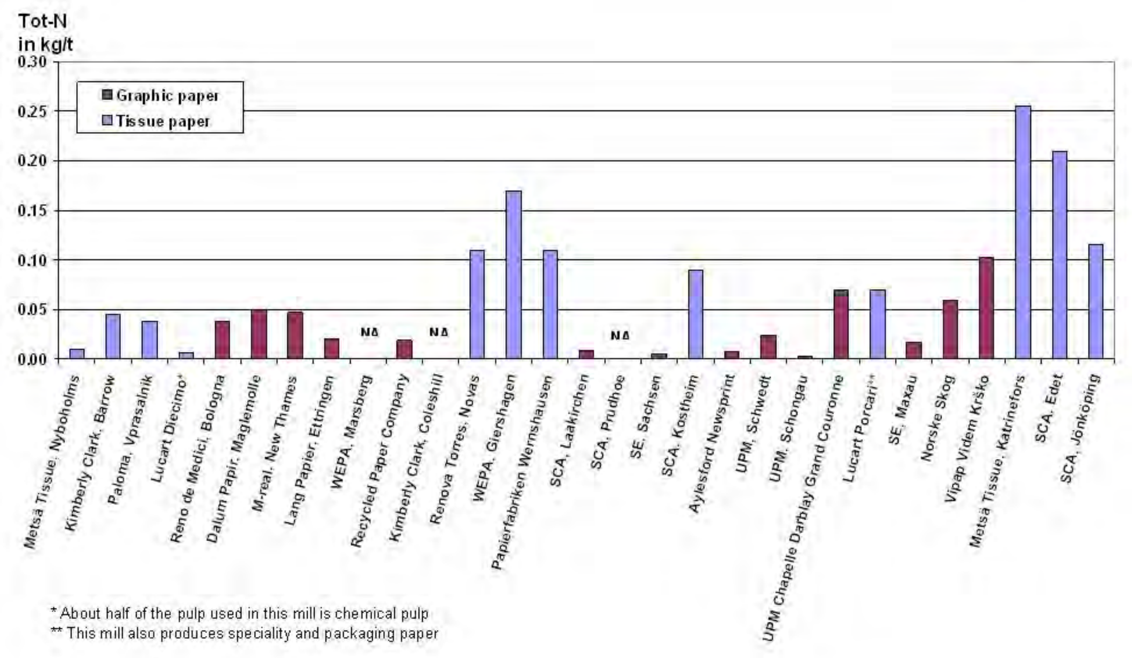


Figure 6.22: **Specific tot-N or TN$_b$ load as a yearly average after waste water treatment from mills processing paper for recycling without deinking**

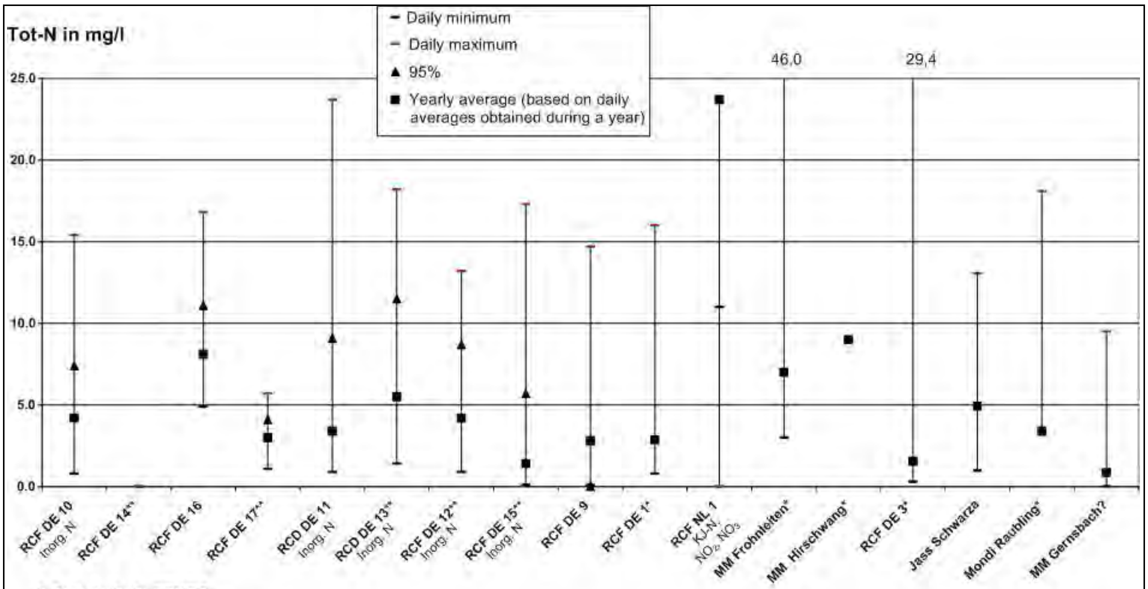
As shown in Figure 6.23, 15 RCF-based paper mills **with** deinking that responded to the EIPPCB questionnaires discharge less than 0.05 kg tot-N/t, of which nine mills reported N emission loads of ≤0.02 kg tot-N/t as yearly average values. Eleven mills reported N emission loads of ≥0.05 kg tot-N/t. Of the 13 mills that also reported concentration values, only one exceeded 10 mg tot-N /l as a yearly average value (17 mg/l).



* About half of the pulp used in this mill is chemical pulp
** This mill also produces speciality and packaging paper

Figure 6.23: Specific tot-N or TN_b load as a yearly average after waste water treatment of mills processing paper for recycling with deinking

Regarding short-term averages of tot-N, the short-term values reported from mills processing paper for recycling without deinking are shown in Figure 6.24.



* Data include OTNOC
? No information if data include OTNOC
** Values based in spot samples

Source: EIPPCB questionnaires from 2007/2009 and Germany, 2012

Figure 6.24: Short-term averages of tot-N emissions from mills processing paper for recycling without deinking

Since data gathering of short-term averages for mills processing paper for recycling with deinking does not allow enough representative data to be shown, variations of tot-N daily concentrations for a single mill (RCF DE 18) over the course of a year are shown in Figure 6.25.

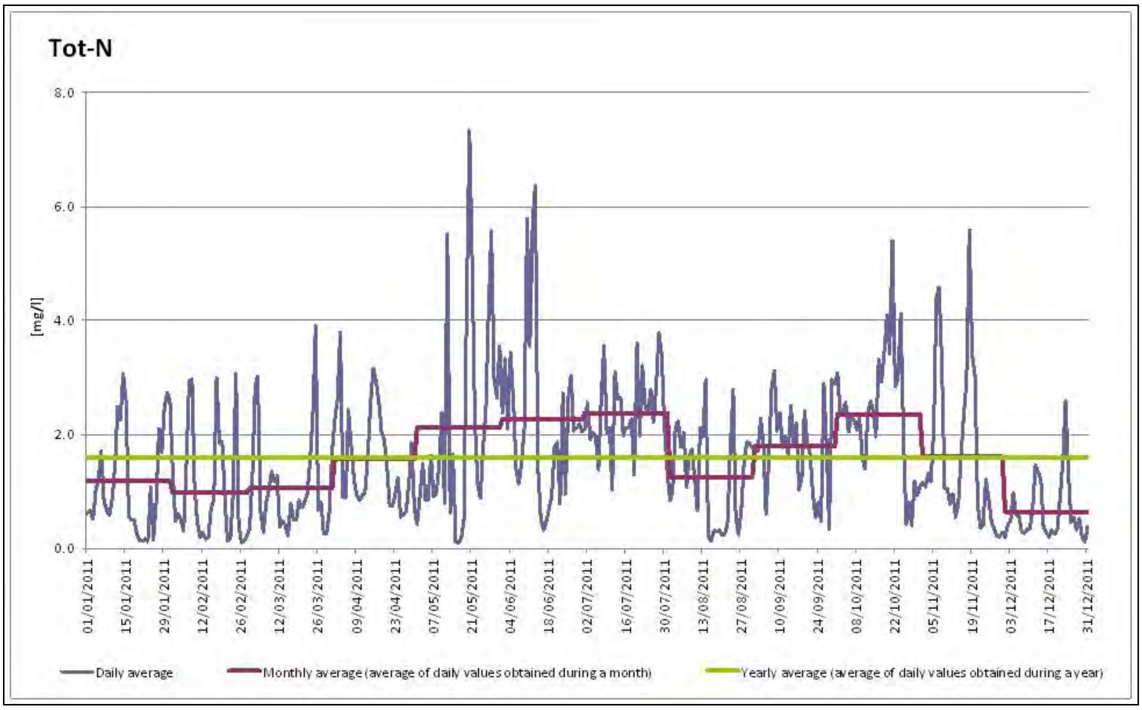
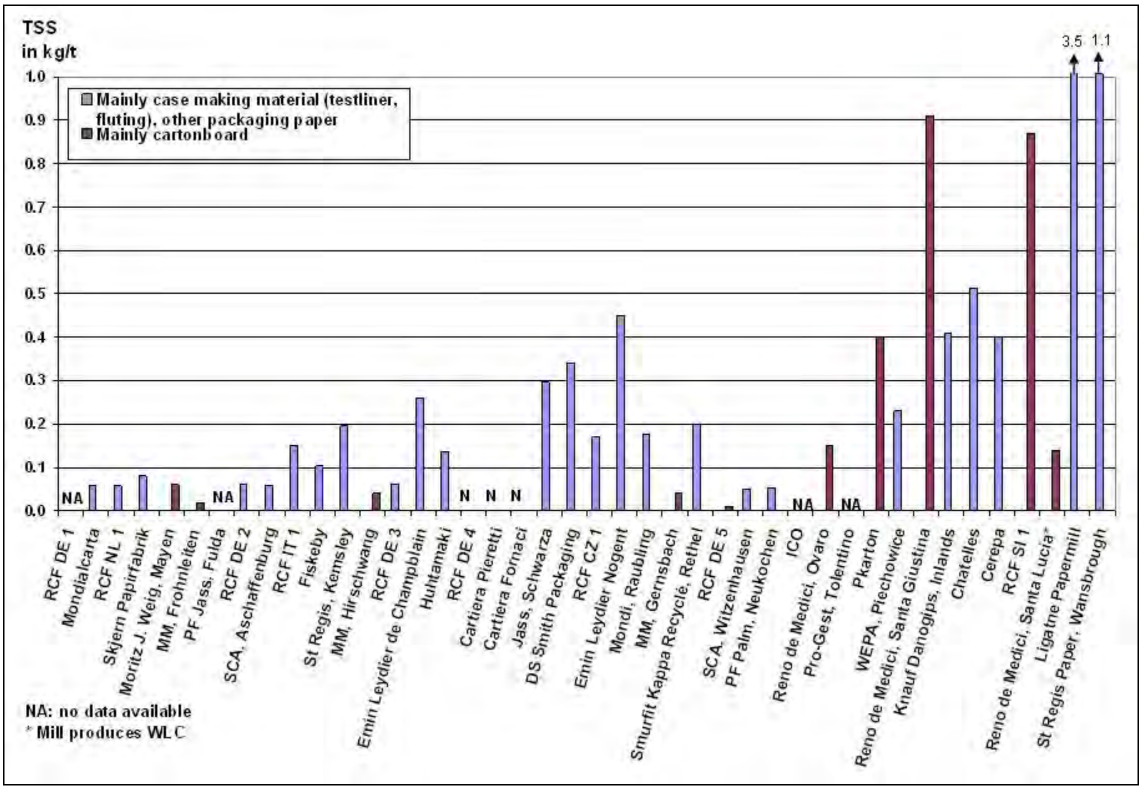


Figure 6.25: Daily tot-N concentrations over one year from a mill processing paper for recycling with deinking (RCF DE 18)

Total suspended solids

Because of paper mill waste water characteristics, there is a tendency for bulking sludge to build up in activated sludge treatment systems. However, experience of control measures to avoid this undesirable phenomenon are well documented (see Section 2.9.11.2.3) and are applied by many mills.

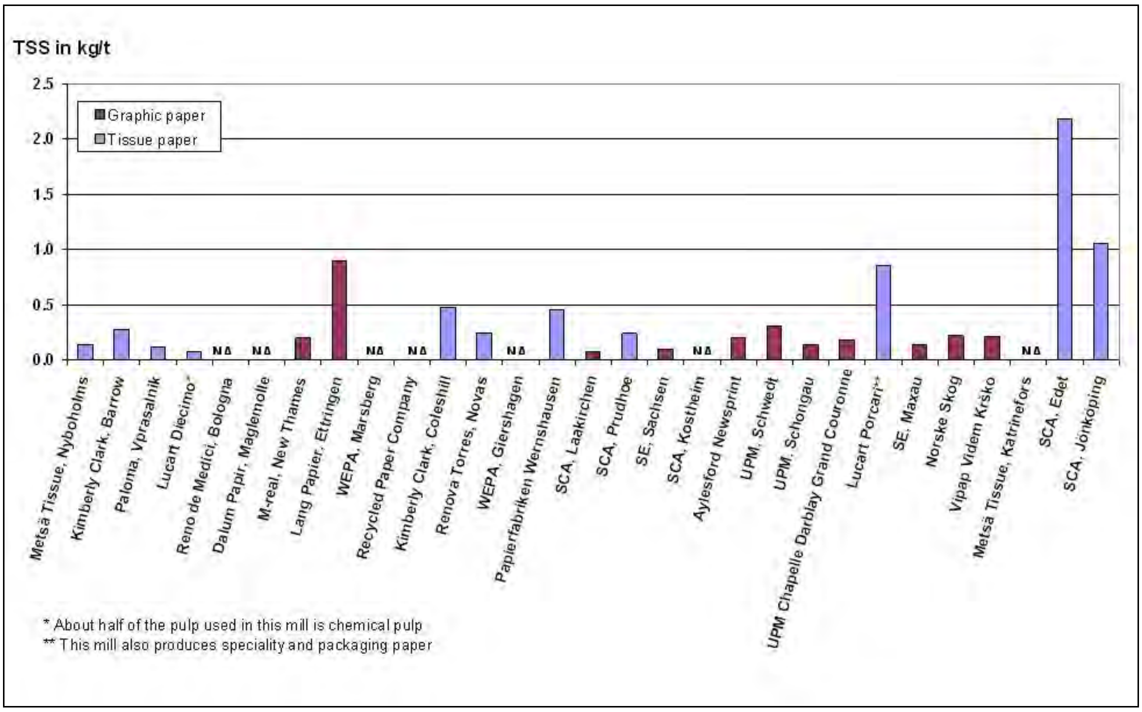
As shown in Figure 6.26, 22 RCF-based paper mills **without** deinking that responded to the EIPPCB questionnaires discharge less than ≤0.20 kg TSS/t, of which thirteen mills reported TSS emission loads of ≤0.1 kg as yearly average values. Five mills reported TSS emissions of ≥0.5 kg TSS/t. Of the 21 direct dischargers that also reported concentration values, six mills exceeded 20 mg TSS/l and only three exceeded 30 mg TSS/l (31; 32 and 53 mg TSS/l) as yearly average values.



NA: no data available
* Mill produces WLC

Figure 6.26: **Specific load of suspended solids as a yearly average after waste water treatment of mills processing paper for recycling without deinking**

As shown in Figure 6.27, 13 RCF-based paper mills with deinking that responded to the EIPPCB questionnaires discharge less than ≤0.25 kg TSS/t; of which seven mills reported a TSS emission load of ≤0.15 kg TSS/t as yearly average values. Four mills reported TSS emissions of ≥0.5 kg TSS/t. Of the fifteen mills that also reported concentration values, only two exceeded 20 mg TSS/l as yearly average values (31 and 33 mg/l).



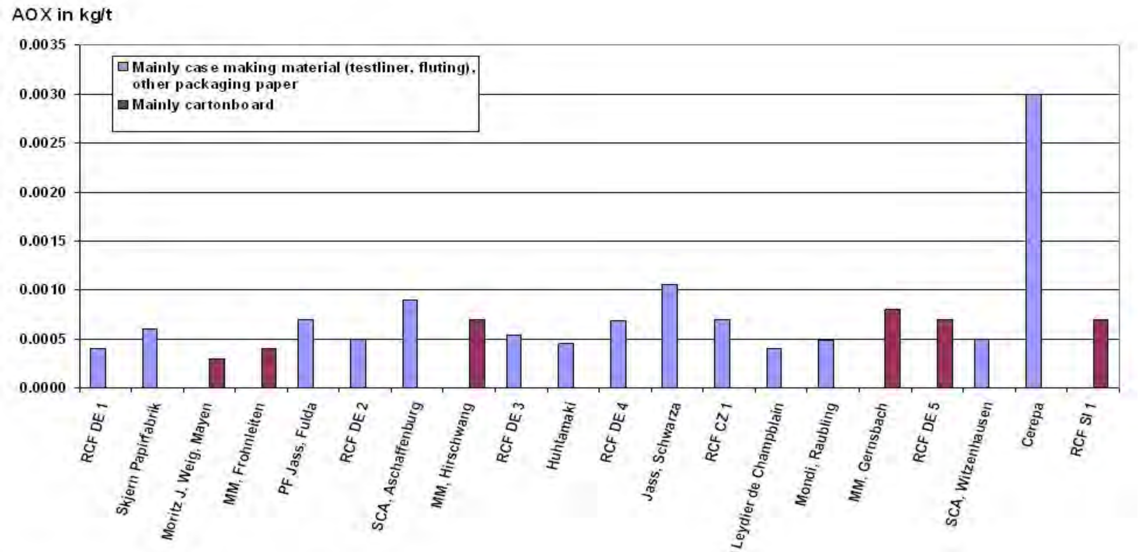
* About half of the pulp used in this mill is chemical pulp
** This mill also produces speciality and packaging paper

Figure 6.27: **Specific load of suspended solids as a yearly average after waste water treatment of mills processing paper for recycling with deinking**

Heavy metals
Heavy metals concentrations in paper mill effluents are generally low. There is no significant increase in concentrations if secondary fibres are used. Nevertheless, occasional measurements of Dutch deinking processing mills have shown that some deinking process mill effluents may contain elevated concentrations of copper and zinc. In that case, printing ink in paper for recycling is considered to be the main source of heavy metals. The heavy metals observed occasionally in the effluents are mainly in the form of stable organic complexes (*Source*: Luttmer, 1996, quoted in [23, Dutch Notes on BAT 1996]).

AOX and other organic micro-pollutants
Sources of absorbable organic halogen compounds are some chemical additives (especially wet strength agents), traces of organic halogens originating from ECF pulp in the paper for recycling and printing inks. As chlorine bleaching of virgin pulp is practically abandoned today, AOX-containing compounds stemming from paper for recycling have considerably decreased. AOX-reduced neutral wet strength agents are also available on the market and are an option for further reduction of AOX emissions. Activated sludge treatment results in further AOX reductions of between 30 % and 50 %. However, this reduction is partly achieved by stripping these compounds during waste water treatment. Occasional measurements in Dutch RCF paper mills (with and without deinking) have shown that average AOX concentrations are in the range of 0.2 mg/l.

An overview of specific AOX loads for individual plants is given in Figure 6.28. Reported loads vary from 0.3 g/t to 3.0 g/t.



[1] Companies with no values means data were either NA or ND

Source: Data collection/questionnaires, data from 2006 and 2008

Figure 6.28: Annual averages of AOX loads for individual mills processing paper for recycling without deinking

Organic micro-pollutants such as chlorophenols or polychlorinated biphenyls may be detectable in some RCF paper mill effluents in very low concentrations depending on the origin of the raw materials used (paper for recycling, printing inks, and additives). In occasional measurements in Dutch RCF mills, chlorophenols up to 1 µg/l (0.1 – 0.7 µg/l) and polychlorinated biphenyls only in traces (values below the detection limit to 0.11 µg/l) have been observed [23, Dutch Notes on BAT 1996].

Salts

Salts, mainly sulphate and chloride, are introduced mainly through paper for recycling and some additives as alum. In certain areas, for instance if surface water is a main resource for the production of drinking water or for water quality reasons, attention is given to the discharge of salts. Depending on the types of paper for recycling used as raw material and the degree of closure of the water circuits, sulphate concentrations of up to 1 000 mg/l have been observed even if during processing no aluminium sulphate has been used.

Boron can also be detected in the waste water of some paper for recycling mills even though it is not added during processing of paper for recycling and papermaking (*Source:* Assocarta, 2011). It may enter the recycled fibre cycle via converting processes such as the production of corrugated board and boxes. No specific treatment is applied for the abatement of boron.

6.2.2.6 Solid waste generation

Most of the impurities from the processed paper for recycling end up as waste. The major waste materials are ragger ropes, rejects, different types of sludge and, in cases of on-site incineration of residues, ashes and filter dust. The major sources of solid waste in RCF-based paper mills are stock preparation, process water clarification and waste water treatment. Depending on the raw materials used, process design and type of process and waste water treatment, different amounts and qualities of residues (rejects, sludge) are generated.

The residues have to be handled and treated (thickened and dewatered) to generate a residue with a high DS content. Achievable dry contents for rejects and sludge are compiled in Table 6.11 and Table 6.12.

Table 6.11: Achievable dry contents for rejects and corresponding energy consumption for different fibre contents

Applied reject handling machines	Hydraulic reject press	Pneumatic reject press
Achievable dry contents at	50 – 65 %	
<70 % fibre content	60 –70 %	55 – 58 %
<30 % fibre content		60 – 63 %
Energy consumption [kWh/t]	15 – 20	8 – 12
Source: Machinery supplier, 1998 and TWG comments, 2011		

Table 6.12: Achievable dry contents for sludge and corresponding energy consumption for different ash contents

Applied sludge handling machines	Wire press including pre-thickening	Screw press including pre-thickening
Achievable dry contents at		
<50 % ash content	50 %	55 %
>50 % ash content	55 %	60 %
Energy consumption [kWh/t] (including pre-thickening)	10 – 15	18 – 20
Source: Machinery supplier, 1998 and TWG comments, 2011 Data found in industrial applications reported by CTP, France, 2011. If deinking and paper sludge is mixed with biological sludge, achievable dryness is lower.		

The residues can be subdivided roughly into heavy and coarse rejects, light and fine rejects and sludge. Depending on its origin and nature, the sludge may be subdivided again into deinking sludge, sludge from micro-flotation units from process water clarification and sludge from waste water treatment (primary sludge, excess sludge from biological treatment). The achievable DS contents after dewatering and thickening are 60 – 70 % for coarse rejects, 50 – 60 % for fine rejects and about 50 – 60 % for sludge.

The amount of residues generated in RCF-based paper mills depends on the quality of the paper used as raw material for recycling, on the stock preparation concept for processing secondary fibres and on the product properties and paper grade. For the main paper grades and paper for recycling qualities, the average amounts of residues related to the input of raw material are given in Table 6.13.

Table 6.13: Amount of residues related to the input of raw material (%) depending on qualities of paper used for recycling and paper grade produced

			Rejects		**Sludge**		
Product	**Recovered paper quality**	**Total losses**	**Coarse/ heavy**	**Fine/ light**	**Deinking**	**Process water clarification**	**Waste water**
Graphic papers	Newspaper, magazines Higher qualities	15 – 20 20 – 35	1 – 2 <2	3 – 5 <3	8 – 13 10 – 20	2 – 5 1 – 5	~ 1
Tissue	Office paper for recycling, files, ordinary and medium qualities	28 – 40	1 – 2	3 – 5	8 – 13	15 – 25	~ 1
Market DIP	Office paper for recycling	32 – 40	<1	4 – 5	12 – 15	15 – 25	~ 1
Testliner /fluting	Shopping centre waste, paper for recycling from households, kraft qualities	4 – 9 3 – 6	1 – 2 <1	3 – 6 2 – 4	–	0 – (1) 0 – (1)	~ 1
Paper board	Shopping centre waste, paper for recycling from households	4 – 9	1 – 2	3 – 6	–	0 – (1)	~ 1

According to [8, Borschke et al. 1997], the amount of waste water treatment sludge is assessed assuming an amount of excess sludge of 0.6 kg/kg BOD_5 eliminated (as DS) generated during treatment, which is a common figure for activated sludge plants. Thus, depending on the quality of paper for recycling and on the process design, about 10 kg excess sludge from biological treatment per tonne of paper (on a dry basis) may be expected.

Generally, the production of non-deinked grades produces less solid waste than the production of deinked grades. Within deinked grades, the manufacturing of printing and writing papers from paper for recycling normally generates higher amounts of solid waste than newsprint. For RCF-based tissue production there is a need to wash out the fillers and fines by wash deinking. This process generates significantly more waste to be handled and further treated than other deinked paper grades.

Rejects

Rejects are impurities in paper for recycling and consist mainly of lumps of fibres (shives), staples, and metals from ring binders, sand, glass, plastics and adhesives. In all RCF mills ragger ropes also have to be handled as waste fractions. Rejects are removed in the largest possible form and at the earliest possible stage in the stock preparation. Rejects constitute approximately 6.5 % of the purchased paper for recycling and have no recycling potential and so are dumped or incinerated. If the thickened residues are incinerated in an environmentally compatible incineration plant, e.g. fluidised bed generating steam for mill consumer points, the residue is reduced to ash which may be used in the building industry or disposed of. However, whether reuse of ashes produced by incineration is feasible depends on the market demand for this material. On-site incineration of rejects is only applicable to large mills, which generate higher amounts of solid waste (see also Section 6.3.14). A typical composition of rejects from the processing of paper for recycling (differences in raw materials and products) is given in Table 6.14.

Table 6.14: Composition of rejects from the processing of paper for recycling to corrugated medium (4 – 6 % rejects)

Parameter	Share of single fractions (1)	Average values from a single mill
Water content	45 %	33.3 %
Plastics	25.9 %	
Fibre	27 %	
Glass and stones	0.11 %	
Metals	0.88 %	
Organic substances	1.05 %	
Cl content of the plastics	5.45 % (2)	
Cl content related to fuel	1.43 %	1.21
Calorific value H_U (100 % DS)	23 800 kJ/kg	25 335
Calorific value H_U (55 % DS)	11 991 kJ/kg	12 828 kJ/kg

NB: The qualities of the processed paper for recycling are mainly 'collected paper for recycling' from households and markets and corrugated board residues.

(1) Average from 18 single samplings in German RCF paper mills.

(2) Tests carried out by the Spanish research institute CIEMAT with rejects from different residues of paper for recycling showed that the Cl content is lower than 1 %, Cl referred to 100 % dry matter (*Source:* CIEMAT, report CG/VE-11/IF-05: Valorización energetica de residuos de papelera, 2005).

Sludge from process water clarification (paper residue)

These types of sludge are mainly generated at the fibre recovery in the white water circuits and the mechanical treatment unit of the waste water treatment plant. The paper residue consists of mostly short fibres and fillers (both around 50 %) depending on the paper for recycling being processed. In the board industry and for the production of corrugated medium it is often recycled to the process. For higher grade products, paper residue does not meet the quality requirements for recycling and is normally incinerated or delivered to a waste management company. Depending on whether there is a previous deinking process, the sludge may contain a certain amount of ink and pigment particles. Fibre recovery contributes to minimising the quantity of residues. The typical composition of paper residue from fibre recovery and mechanical treatment of waste water is given in Table 6.15.

Table 6.15: Composition of sludge from fibre recovery and chemimechanical treatment of waste water

Parameter	Unit	Range of values
DS content	%	29.4 – 52.7
Organic solids	% DS	25.5 – 76.1
Lead	mg/kg DS	10 – 210
Cadmium	mg/kg DS	0.01 – 0.98
$\text{Chromium}_{\text{total}}$	mg/kg DS	8.8 – 903
Copper	mg/kg DS	19.9 – 195
Nickel	mg/kg DS	<10 – 31.3
Mercury	mg/kg DS	0.1 – 0.89
Zinc	mg/kg DS	34.2 – 1 320

NB: A synopsis of the complete results of chemical analysis of solid wastes from paper manufacturing conducted at German Paper Research Institute PTS Munich.

Source: [132, Solid waste handbook 1996]

Deinking sludge

This residue contains mainly short fibres, coatings, fillers, ink particles, extractive substances and deinking additives. Ink particles are a potential source of heavy metals but, as shown in Table 6.16, typical deinking residue has pollutant loads comparable to those of sludge from biological waste water treatment plants with slightly higher values for some substances such as copper and zinc. There are relatively significant variations in the pollutant content of the paper for recycling and consequently in the deinking sludge.

Table 6.16: Typical pollutant contents of deinking sludge from RCF paper mills compared to sludge from municipal waste water treatment plants

Component	Unit	Contents per kg dry solids			
		Deinking sludge (¹)	Deinking sludge (²)	Deinking sludge (³)	Municipal waste water treatment sludge (¹)
Cadmium (Cd)	mg	<0.1	<0.67	0.02 – 1.54	<0.1
Mercury (Hg)	mg	<0.1	0.08	0.1 – 0.89	<0.1
Copper (Cu)	mg	350	238	64.2 – 345	40
Zinc (Zn)	mg	350	141	34.2 – 1 320	250
Lead (Pb)	mg	35	41	9.5 – 79.4	30
Nickel (Ni)	mg	5	5.7	<10 – 31.3	10
Chromium (Cr)	mg	20	24(Cr_{total})	4.8 – 96.6	10
PCBs	µg	95	ND	<300	5
Chlorophenols	µg	75	ND	ND	120
Volatile solids	% DS	ND	33.2	32.7 – 63.6	48

NB: ND = not determined.

(1) [23, Dutch Notes on BAT 1996].

(2) Representative sampling from a German paper mill.

(3) A synopsis of the complete results of chemical analysis of solid wastes from paper manufacturing conducted at German PTS, published in [132, Solid waste handbook 1996].

Deinking sludge is normally incinerated or delivered to a waste management company. The ash from deinking sludge incinerators can serve as a resource for building materials. One mill reported that the paper and deinking sludge is supplied to a board- or fluting-producing mill to be used as raw material.

Waste water treatment sludge

These sludges are generated at the biological units of the biological waste water treatment plant and are either recycled to the product (corrugated medium and board) or thickened, dewatered and then incinerated (on-site or off-site) or delivered to a waste management company. Council Directive 99/31/EC on the landfill of waste [265, Directive 1999/31/EC 1999] discourages the dumping of waste with high organic content by setting targets to cut the amount of biodegradable waste sent to landfills. The typical composition and pollution potential of sludge from biological waste water treatment are given in the right-hand column of Table 6.16 and in Table 5.8.

6.2.2.7 Emissions to air

Emissions to air from energy generation

Emissions to air from paper and board mills originate mainly from energy generation (steam and electricity) and less from the manufacturing process itself (see Section 2.6.2). Major pollutants in the case of gas firing are CO_2 and NO_X, and in the case of oil or coal firing CO_2, NO_X, SO_2, dust and low concentrations of heavy metals.

Steam is normally generated on site in steam boilers In many cases, electricity is purchased from the grid, i.e. the emissions occur at the external power plant. The electricity/steam consumption ratio at paper mills favours the cogeneration of heat and power (CHP). Many paper mills apply CHP and then all emissions to air associated with the energy consumption occur on site. The typical emissions from on-site installations for heat and power cogeneration are presented in Section 2.9.6.3 and for steam generation by combustion of different types of fuels (gas, coal, oil) in Section 2.6.2.

Minor emissions of volatile organic substances may be released from the dryer section of the paper machine (measured as organic carbon). These emissions are caused by the evaporation of chemical additives in the drying section of the paper machine (mainly coating chemicals) or by direct dryers after coating (methane emissions), but in most cases are of minor concern (low concentrations).

Air emissions from on-site incineration of sludge or rejects (optional)
The processing of paper for recycling and papermaking generates a number of wastes with a high organic content (e.g. paper, rejects, deinking sludge, and biosludge). As landfilling of these waste fractions is discouraged or prohibited in many Member States, an increasing number of companies incinerate rejects and sludge in on-site incineration plants, generating steam that can be used in production processes. The incineration is associated with emissions to air. Examples of measured emissions from incineration of different types of RCF paper mill residues are compiled in Table 6.17.

The left-hand column refers to measured average values of a RCF packaging paper mill (without deinking). The right-hand column shows measured values from incineration of different types of sludge from a deinking plant (sludge from raw and waste water treatment, sludge from process water clarification, rejects and deinking sludge) before and after measures for NO_X reduction. The values are compared with German legal standards.

Table 6.17: Measured emission data from incineration of rejects and sludge from two German RCF mills

Parameter	Unit	Measured values (average figures for 1997) Rejects from a RCF packaging paper mill (without deinking) (¹)	Measured values (yearly average 2008) Rejects and deinking sludge from a RCF newsprint mill (²)	Limit values according to German regulations (daily mean values) (³)
Dust	mg/Nm^3	3.2	5	10
SO_2	mg/Nm^3	26.0	1	50
NO_X	mg/Nm^3	195	190	200
CO	mg/Nm^3	14.1	2	50
HCl	mg/Nm^3	1.7	3	10
HF	mg/Nm^3	0.06	ND	1
Total-C	mg/Nm^3	1.4	1	10
Cd, TI	µg/Nm^3	<17.0	ND	50
Hg	µg/Nm^3	5	<10	30
Sb, As, Cr, Co, Cu, Mn, Ni, V, Sn	µg/Nm^3	71.0	<20	500
Dioxins/Furans	ng I-TEQ/Nm^3	0.097	0.004	0.1

(¹) Emission data of reject incineration in a multiple-hearth combustion plant; the flue-gas purification is equipped with a two-stage wet scrubber for the removal of acid pollutants (mainly SO_2 and HCl). For minimising dioxin emissions, a mixture of activated carbon and zeolite is injected into the recycled flue-gas stream. Reduction of NO_X emissions is achieved by SNCR using ammonia, which is injected into the combustion chamber. Dust emission is reduced by an electrostatic precipitator.

(²) Incineration in a fluidised bed boiler. The reduction of NO_X has been achieved by use of SNCR, i.e. injection of ammonia; dust emission is reduced by use of bag filters.

(³) According to the Seventeenth Ordinance on the Implementation of the Federal Immission Control Act (Ordinance on Incinerators for Waste and similar Combustible Material), of 23 November 1990. [corrected on 14 August 2003]

NB: ND = Not detectable.
All values refer to standard conditions and an oxygen content of 11 % per volume.
Source: [Landesdirektion Leipzig, Abt. Umwelt, Continuous emission monitoring. Yearly report 2008]

Odour from vapours and from waste water treatment plant

Especially in the case of closing up the water circuits below a water consumption of around 4 m^3/t, odours caused by lower organic acids and H_2S may be perceived in the vicinity of paper mills. But annoying odours may also be found in paper mills with less water circuit closure. They may be caused by excessive retention times of process water in the water system (pipes, chests, etc.) or deposits of sludge causing the build-up of hydrogen sulphide. If so, they can be avoided by suitable process engineering measures (see Section 2.9.14 on the reduction of odour). The waste water treatment plant of RCF paper mills may also emit significant quantities of odour. If the waste water and sludge treatment is well designed and controlled, annoying odours can be prevented.

Coarse dust from raw material handling (local)

The paper for recycling is stored in designated yards that are integrated in the paper mill. During the transport of the recycled paper to the pulper, dust might be generated especially when paper for recycling is delivered as loose material in large containers or by bulk dumping. The control of this dust is more a matter of industrial safety than of environmental protection. It is not further described here.

Dust emissions are also generated during charging and unloading of dusty raw materials (e.g. talc powder, bentonite) from silos and may be retained by the use of cloth filters when handling these goods.

6.2.2.8 Noise and vibration from paper machines

Paper machines may give rise to noise nuisances in the surrounding area. Many mills have taken measures to reduce noise generation. For more details on noise levels from paper machines, please refer to Section 2.9.13 on the reduction of noise. Besides noise, (low-frequency) vibrations may sometimes give rise to nuisances at the local level.

6.3 Techniques to consider in the determination of BAT

This section describes techniques (or combinations thereof), and associated monitoring, considered to have the potential for achieving a high level of environmental protection in the activities within the scope of this document. The techniques described will include both the technology used and the way in which the installations are designed, built, maintained, operated and decommissioned.

It covers environmental management systems, process-integrated techniques and end-of-pipe measures. Waste prevention and management, including waste minimisation and recycling procedures are also considered, as well as techniques that reduce the consumption of raw materials, water and energy by optimising use and reuse. The techniques described also cover measures used to prevent or to limit the environmental consequences of accidents and incidents, as well as site remediation measures. They also cover measures taken to prevent or reduce emissions under other than normal operating conditions (such as start-up and shutdown operations, leaks, malfunctions, momentary stoppages and the definitive cessation of operations).

Annex III to the Directive lists a number of criteria for determining BAT, and the information within this chapter will address these considerations. As far as possible, the standard structure in Table 6.18 is used to outline the information on each technique, to enable a comparison of techniques and the assessment against the definition of BAT in the Industrial Emissions Directive.

This section does not necessarily provide an exhaustive list of techniques which could be applied in the sector. Other techniques may exist, or may be developed, which could be considered in the determination of BAT for an individual installation.

Table 6.18: Information for each technique described in this chapter

Headings within the sections
Description
Technical description
Achieved environmental benefits
Environmental performance and operational data
Cross-media effects
Technical considerations relevant to applicability
Economics
Driving force for implementation
Example plants
Reference literature

In most cases, plants processing paper for recycling are integrated with paper production (there are only two non-integrated DIP plants in Europe). Therefore, there is a certain overlap between processing paper for recycling (pulping and stock preparation) and papermaking and associated processes. For integrated RCF mills also refer to Chapter 7.

6.3.1 Good housekeeping in handling and storage of paper for recycling

Description

After sorting, the paper for recycling is delivered to the paper mills either as loose material on trucks or in the form of bales. Loose paper for recycling is sometimes stored in special bunkers or enclosed facilities with roofs (see Figure 6.29), but can also be stored in the open without roofs.

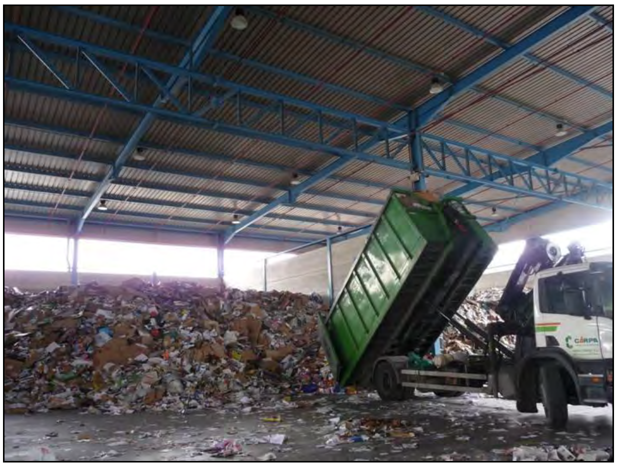


Figure 6.29: Unloading and storage of loose paper for recycling in an enclosed facility with a roof

Both deinking and non-deinking mills for paper for recycling receive loose paper for recycling and sort it on site. It may be an advantage to operate the sorting or final sorting on site as it better allows for the control of the quality of the sorted paper for recycling.

Most RCF mills receive sorted bales of defined grades. In the paper for recycling yard, bales are stored mostly outdoors in the open air on a concrete-paved area with rainwater drainage (see Figure 6.30), in some cases also under a roof. Paper for recycling stored outdoors is exposed to weather influences such as wind, rain, snow, frost, or sunshine. Risks that need to be covered are water run-off both from rainfall and also fire water in the event of a fire. Some form of containment with the ability to treat contaminated run-off is necessary.

Figure 6.30: Outdoor storage of paper for recycling with concrete paving

Inside storage is used more for higher quality and therefore more expensive paper grades or when the storage time is longer. It also prevents raw material loss and minimises spreading during windy conditions.

In some mills, the bales are stored outdoors under a roof to protect the material from weather influences (moisture, microbiological degradation processes, etc.) as shown in Figure 6.31.

Figure 6.31: **Storage of paper for recycling in bales under a roof**

Achieved environmental benefits

If good housekeeping measures are applied, handling and storage of paper for recycling do not have significant negative impacts on the environment, safety or public health.

Environmental performance and operational data

Sorted bales of RCF paper of defined grades are mostly stored in the open air, in some cases also under a roof. Paper for recycling stored outdoors in the open air should be placed on a concrete-paved area with rainwater drainage and/or containment for contaminated flows. In cases of rainfall, some contaminated water is generated in these outdoor paper for recycling yards. The contaminated rainwater is preferably collected and treated in a waste water treatment plant; uncontaminated rainwater, e.g. from roofs, can be discharged separately.

In other mills, during occasional heavy rainfall, the contaminated run-off from rainfall from the paper for recycling yard bypasses the waste water treatment plant, especially when the plant is not designed for sudden flow increases. However, this is associated with an uncontrolled discharge of contaminated rainwater to the receiving water body and storing these flows in the meantime in some form of containment reduces the pollution load to water bodies.

In order not to clog the sewer system in the event of rainfall, the surface drain and the sewer system should be protected against solids from the paper for recycling yard (e.g. paper sheets or paper debris) by installing and maintaining sieves.

In some mills, the bales are stored outdoors under a roof to protect the material from weather influences (moisture, microbiological degradation processes, etc.) as shown in Figure 6.31. An example is the UPM Steyrermühl paper mill, AT.

The terrain of the paper for recycling yard is normally surrounded with fences against wind drift. To reduce diffuse dust emissions, the storage area is cleaned regularly. This also avoids wind-blown paper debris and crushing of paper by on-site traffic that may cause additional dust emissions, especially in the dry season.

Cross-media effects
The good housekeeping measures have no negative effects. The sorting on site will create additional residues the mill has to take care of, and which otherwise accumulate at the off-site collection yards.

Technical considerations relevant to applicability
Measures/techniques can be applied in new and existing mills.

Economics
No information provided.

Driving force for implementation
Requirements of competent authorities and permits.

Example plants
At the UPM Steyrermühl paper mill, AT, mixed paper for recycling is stored under a roof. Most mills in Germany place paper for recycling stored in the open air on a concrete-paved area with rainwater drainage. Collected contaminated rainwater run-off is treated in the biological waste water treatment plant.

6.3.2 Separation of sealing and cooling water from contaminated process water and water reuse

Description and achieved environmental benefits
This measure reduces the fresh water requirement and is part of the overall water management in paper mills. Water management in paper mills is a complex task that has many aspects. To give an overview, the main principles for internal measures to reduce fresh water consumption and discharges from paper for recycling mills are briefly summarised below. In each case the reader is referred to the sections of the document where more detailed information can be found.

- Use of suitable techniques to separate less contaminated water from contaminated process water. Measures to be considered are the separation and reuse of cooling water and the reuse of less contaminated sealing and process waters used in vacuum systems.
- Reduction of fresh water consumption by the recycling of white water in different positions depending on the water qualities required. Positions in the process of special interest when reducing fresh water consumption are the dilution of fibre raw materials and fillers, dilution of process and product aids, the shower water system, the vacuum system and the sealing water for pumps and agitators (see Section 6.3.3 and Section 7.3.1) for example.
- Reduction of fresh water consumption by strict separation of water loops together with counter-current flows (see Section 6.3.3).
- Generation of clarified water from white water as a substitute for fresh water, usually made in the fibre recovery unit by use of bow screens, polydisc filters (see Section 7.1.3) or dissolved air flotation (see Section 6.3.11).
- Measures to handle the possible negative effects of the increased recycling of process water (see Section 7.3.2).
- In some cases the further purification of clarified white water is applied (see Section 7.3.3). This purified water meets relatively high quality requirements.

The separation of clean used cooling waters from process effluents and their reuse for other purposes are ways of reducing fresh water consumption. Cooling water should in any case be held separately from contaminated paper machine effluents and should not be mixed with process water before treatment. For protection, a micro-screen or other strainer is recommended to remove solids. Where cooling water fractions are sewered, mixing them with contaminated process water sewers should be avoided to ensure waste water treatment efficiency and reduce treatment costs.

The most common equipment for vacuum generation, the liquid ring pump, consumes large volumes of sealing water. For example, an efficient liquid ring pump vacuum system may need around 1 m^3/t of sealing water. The sealing water will be contaminated with fibres and the temperature rises when sealing water passes through the liquid ring pump. The need for fresh water as sealing and process water for the liquid ring pumps can be greatly reduced by recycling the water from the pumps through a heat exchanger or cooling tower. It is even possible to run liquid ring pump systems with a closed water circuit if there is a cooling tower to cool down the sealing water. In this case, fresh water is not needed, but possible scaling problems caused by calcium carbonate precipitation must be controlled. Sometimes the water for the ring pump must be clarified by use of a bow screen for example before it enters the heat exchanger. It may also be necessary to control the pH value in the recirculation loop. Increase of the capacity of the process water storage may be needed in order to prevent unnecessary overflows of recycled water when there is a break or other imbalance in the processing of pulp. The increase of capacity usually implies installation of additional tanks, pipes and pumps.

Instead of liquid ring pumps, water-free vacuum systems for dewatering in the wire and press section can be used. These systems use variable speed turbo blowers, need no sealing water and are also more energy-efficient (see Section 2.9.6.2.1).

Environmental performance and operational data
The separation and recycling of less contaminated water from contaminated water is common practice in many European mills but the degree of water recirculation varies.

By appropriate sealing water recirculation it is possible to reduce the fresh water consumption of liquid ring pumps to <1 m^3/t. At the same time it is possible to recover part of the energy if heat exchangers are used. Water-free vacuum systems need no sealing water (see Section 2.9.6.2.1).

Cross-media effects
No negative effects. Energy savings are possible especially when water-free vacuum systems are used instead of liquid ring pumps.

Technical considerations relevant to applicability
The separation and reuse of clean cooling waters and water from vacuum systems (sealing water) can be realised in new and existing mills. Separation and reuse of clean cooling waters from process effluents are relatively easy to carry out at new installations but more complicated to implement at existing plants. However, cooling water separation and recycling after cooling are common. The same is valid for the recirculation of sealing waters.

Economics
The recycling of cooling and sealing waters typically requires additional investments in piping, pumping and the filtration of the water. The increase of the water storage capacity usually implies the installation of additional tanks. Data on specific costs are not available.

Besides the costs for implementing the described measures, cost savings can be expected, e.g. lower costs for raw water (treatment) and energy consumption.

Driving force for implementation
Fresh water reduction by recirculation of less contaminated water is a reasonable measure from an economic point of view. Discharge of less contaminated cooling and sealing water fractions together with contaminated process water are discouraged in many countries.

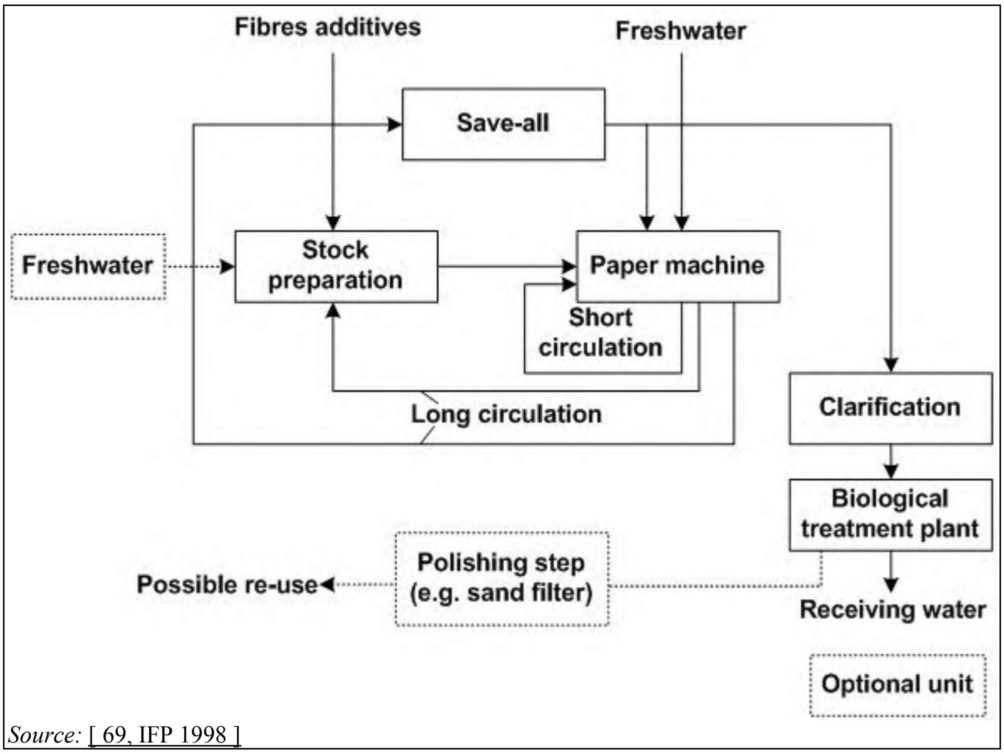
Example plants
Numerous plants in Europe.

Reference literature
[14, CEPI 1997], [74, Pöyry 1994], [163, J.Lahtinen et al. 2009].

6.3.3 Optimal water management, water loop separation and arrangement, counter-current flows and internal water clarification

Description

The water loops in the production of RCF-based paper can be laid out for minimised fresh water consumption (see also Section 2.9.3 and 2.9.4). In today's water loop systems, process water is reused several times, as shown in Figure 6.32. This requires the continuous monitoring of the process water quality.



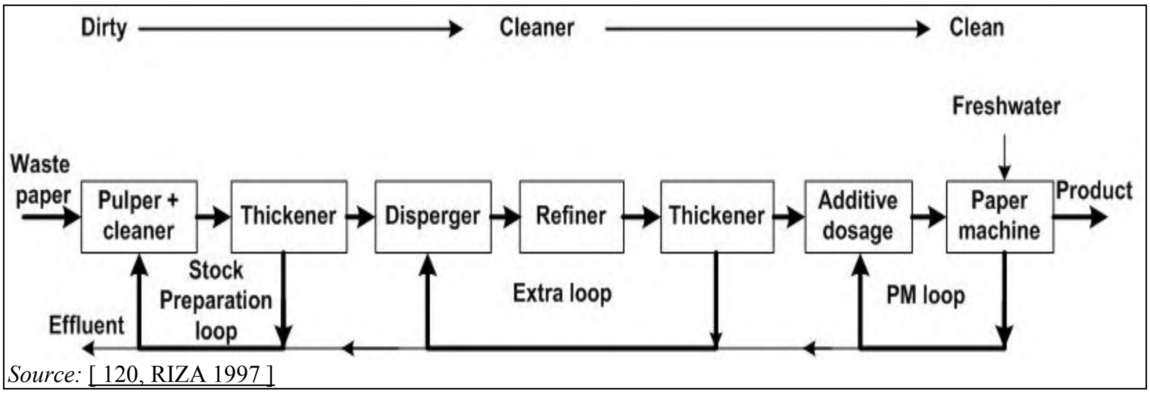
Source: [69, IFP 1998]

Figure 6.32: Scheme of water loops in paper mills

All paper mills use untreated, fibre-enriched white water from the paper machine for stock dilution in the mixing chest ahead of the paper machine (short circulation or primary circuit) or in the stock preparation (long circulation or secondary circuit). The main principle of the reuse of process water is the backward process water flow in the systems: the white water flow from paper mill to pulp mill should be organised counter-current to the fibre flow. In an integrated pulp and paper mill, the pulp department, the bleaching department (if existing) and the paper mill each have their own white water circulation, from which the excess water goes backwards to the previous department where water quality requirements are less demanding. The excess white water from the paper machine is used instead of fresh water in the bleaching department, and the excess water from the bleaching department is used instead of fresh water in the pulp mill.

It is of great importance to minimise the white water going in the same direction as the product flow, i.e. from the bleaching plant to the paper machine. This is accomplished by removing as much water as possible from the fibre flow before it enters the bleaching system and again before it enters the paper machine system. In this way, the carry-over of process-disturbing compounds to relatively clean process water systems is minimised.

The separation of the water loops is carried out with thickeners like dewatering screws and wire presses or a washing stage i.e. a thickening step. Figure 6.33 shows the proposed layout for a Dutch paper mill that has investigated the potential for water loop closure. In this example, it has been calculated that the amount of COD generated in the stock preparation that enters the PM loop can be reduced by a factor of about 2 – 4. The extra thickener leads to an improved separation of the 'dirty' stock preparation and the 'clean' paper machine and thus to a significant reduction in organic substances that enter the paper machine loop.



Source: [120, RIZA 1997]

Figure 6.33: **Layout of water loops in a paper mill with separation of water loops and counter-current flows**

Part of the white water (see Figure 6.32) is clarified in save-alls (see Section 7.1.3) by filtration (polydisc filters, drum filters and in some cases ultrafiltration, see Section 7.3.3) or flotation (dissolved air flotation, DAF, see Section 6.3.11). The clarified water is then reused replacing fresh water, for example, at the showers used for cleaning machine clothing (wires, felts). Excess clarified process water is discharged to the waste water treatment plant. In some cases, purified waste water is partly reused as process water, e.g. for RCF-based Wellenstoff and Testliner and to a lesser extent in RCF-based newsprint.

In many paper mills fresh water is only used for boiler feedwater, the dilution of chemical additives and at locations of the paper machine where a highly solid-free water quality is necessary, e.g. spray pipes and edge sprays.

However, closing up the process water system offers both advantages and disadvantages. Enhanced water system closure leads to a considerable loading of the process water with colloidal and dissolved organic and inorganic compounds which may cause serious problems in the production process if no control measures to avoid possible drawbacks are undertaken (see Section 7.3.2). Some of the advantages and disadvantages of water system closure are summarised inTable 6.19.

Table 6.19: **Some advantages and disadvantages of water system closure in paper mills**

Advantages	Disadvantages
• Less water consumption. • Less fresh water pretreatment. • Lower volumes to effluent treatment. The treatment plant can be built smaller (lower investment and operational costs). Contaminants are more concentrated which allows often higher removal efficiency and thus lower emissions. • Increase of production not hindered by exceeding permitted flow. • Decreased fibre in filler losses. • Elevated process temperature which leads to improved dewatering of the paper web. • Reduced energy demand.	• Build-up of (suspended) solids. • Build-up of organic and inorganic substances. • Increase of odour problems due the build-up of organic substances. • More complicated processes. • Corrosion problems. • Increased use of additives. • Clogging of equipment. • Product quality-related problems. • Scaling and slime forming. • Increased temperature of the process water (can also be an advantage, see left column).

Source: [23, Dutch Notes on BAT 1996]

In totally closed water systems (only applicable for Testliner and Wellenstoff production), additional operational problems may occur which need to be controlled including:

- significant decrease of the oxygen content of the process water, approaching anaerobic conditions associated with a microbiologically induced reduction of sulphate to hydrogen sulphide and the formation of odorous, low-molecular fatty acids;
- intensified growth of microorganisms and a higher demand for slimicides;
- aggressive corrosion caused by high temperature and high contents of chlorides, sulphates and organic acids;
- significant emission of odorous organic compounds from the dryer section of the paper machine to the surroundings of the paper mill;
- impaired quality of the paper produced, affected by odorous compounds.

Most of these problems may occur at fresh water consumption levels below 4 – 6 m^3/t of paper (this corresponds to a waste water flow of 2.5 – 4.5 m^3/t) if no counteraction is taken.

A few European paper mills installed in-line biological treatment plants to reduce the organic load of the process water in order to reduce and better control the possible drawbacks of their closed process water loops (see Section 6.3.4). In order to control these problems, some mills manufacturing 'brown papers' reopened their already completely closed water circuit and are now producing with a small volume of waste water in the range of 2.5 – 4.5 m^3/tonne paper produced.

Due to its suitable BOD_5/COD ratio, the waste water can be treated very efficiently in combined anaerobic-aerobic or aerobic treatment plants (refer to Section 6.3.7).

Achieved environmental benefits

Considerable amounts of fresh water can be saved with this technique. Fresh water is only needed as make-up for the paper machine system.

Water reduction measures together with optimised water loop separation and arrangement and process water clarification do not increase the concentration of undesired substances in the paper machine water loop, thus maintaining the runnability of the process. The achievable fresh water reduction rate depends mainly on the situation before the improvements and the waste water system applied afterwards. The achieved environmental improvements should be considered together with the effluent treatment applied. Strict separation of water loops generates good opportunities for in-line treatment, in order to remove disturbing substances (so-called 'kidney treatment'). For further information on kidney treatment the reader should refer to Sections 6.3.4, 6.3.9, 7.3.3 and 7.4.1.

Measures for the reduction of emissions to surface water are often closely related to the reduction of fresh water. Water circuit closure generates a lower waste water flow with increased concentration levels. As a result the efficiency of the waste water treatment is often higher. In general, concentrated waste water flows can be treated more effectively and sometimes a reduction in the discharge load of COD can be achieved.

Environmental performance and operational data

In RCF-based mills without deinking, no fresh water is needed in the stock preparation. As these mills are all producing pulp and paper at the same site (integrated production), fresh water is required in the paper machine part.

For the production of non-deinked Wellenstoff and Testliner and some types of cartonboard, a specific fresh water consumption of 4 – 8 m^3/tonne paper produced is achievable. Experiences show that this range of fresh water consumption does not result in negative effects on the runnability of paper machines and on paper quality. The experiences are good in new and existing mills and current paper machine design supports their application. A number of plants manufacturing corrugating medium with this water consumption achieve high product quality standards. Low water flows increase the COD of the process water to a concentration range which is especially suitable for an anaerobic waste water treatment that is associated with the benefit of biogas generation.

Many paper mills recycle a partial stream of the biologically treated process water back into the water circuit, especially mills that produce corrugated medium or Testliner. Some mills with extensively closed water circuits face difficulties with regard to the accumulation of calcium in the process water, causing calcium carbonate precipitation and scaling on pipes, wires and felts. Recently, a possible solution has been applied in some paper mills to cope with this challenge (see Section 6.3.5). For example, a paper mill manufacturing LWC and white-coated Testliner recirculates anaerobically treated process water as a fresh water substitute after controlled precipitation of calcium carbonate (Leipa, Schwedt, DE).

There are also a few applications of the anaerobic-aerobic treatment in 'bio-kidneys' that operate as an integral part of the process water treatment (e.g. RCF DE 6; UIPSA, Durango McKinley USA), see Section 6.3.4. A few RCF mills without deinking are even operating with a totally closed water system.

In stock preparation, the cleanliness of the process water is less critical than in the white water of the paper machine. Therefore, the stock preparation utilises to a very large extent excess clarified white water from the paper mill and internally clarified white water.

In RCF paper mills with deinking, the degree of water system closure is more limited due to the paper properties to be achieved (brightness, cleanliness). Waste water flows down to about 6 – 8 m^3/t are achievable in the most efficient plants. Their waste water was commonly treated by aerobic systems. Since approximately 2007, anaerobic treatment has been successfully applied for RCF tissue mill effluent and more recently also for newsprint effluent. In the latter cases, the major COD load is attributed to the deinking process. Concentrated flows and new high-load reactor designs made this energy-efficient option possible (see Section 6.3.8).

A RCF-based tissue mill may require more water for the efficient washing of machine felts.

For more data regarding water consumption in real mills, the reader is referred to Sections 6.2.2.2, 6.3.7 and 6.3.8.

The potential drawbacks of water system closure need to be controlled (see Section 7.3.2). Otherwise the build-up of suspended solids as well as dissolved organic and inorganic substances in the white water system may cause negative effects.

Cross-media effects
Intensified process water reuse increases the temperature of the process water. Therefore, steam consumption for heating up the process water can be reduced. Each mill has to find the optimal water balance together with measures to avoid, reduce or control possible drawbacks of water system closure. The higher concentration in the circuits might require additional anaerobic biological treatment. The application of anaerobic waste water treatment methods results in a reduction of fossil fuel demand for papermaking (see Section 6.3.7).

The installation of water loops by inserting thickeners that separate process water from the fibres leads to a considerable change in the composition of the paper machine water loop with respect to the levels of organic and inorganic substances (e.g. anionic trash). This will lead to a changed additive efficiency in the wet end. The increase of salinity (ionic content) due to the enrichment of mineral matter in the water circuits and its impact on retention aid, starch and other additives' efficiency has to be taken into account and controlled.

Technical considerations relevant to applicability
The described measures for water management can be realised in both new and existing mills. In some older mills that may have higher fresh water consumption, the reduction may cause

corrosion problems depending on the quality of materials used for machines and pipes. A gradual change of this equipment is then required. The existing waste water treatment plants have to be adapted to changes of flows and loads.

Arranging white water flowing backwards in the system counter-current to the fibre flow can be applied only in integrated pulp and paper/board mills. Paper recycling plants are, with very few exceptions, integrated with a paper mill.

Economics
Minimising fresh water consumption decreases the costs of fresh water purification and waste water treatment. The measures applied depend on the specific conditions in paper mills. The costs of this measure depend on the number and nature of water circuit rearrangements necessary and the type of additional installation needed. Therefore, it is not possible to indicate specific costs. Sufficient storage capacity for the storage of white water is necessary.

Driving force for implementation
The driving force for recycling process water is to decrease the waste water load from integrated RCF mills. Closing up the water system is a prerequisite for efficient waste water treatment (a lower investment and operating cost and higher removal efficiencies). Driving forces for implementing measures to reduce fresh water consumption are as follows:

- saving fresh water costs (in some countries),
- saving costs of waste water purification,
- saving costs for waste water duties,
- a local driving force could be the reduction of groundwater abstraction.

Example plants
Many RCF paper mills in Europe have implemented the described measures.

Reference literature
[14, CEPI 1997], [23, Dutch Notes on BAT 1996], [69, IFP 1998], [74, Pöyry 1994], [93, Mönnigmann et al. 1996], [120, RIZA 1997].

6.3.4 In-line biological process water treatment for closed water loops

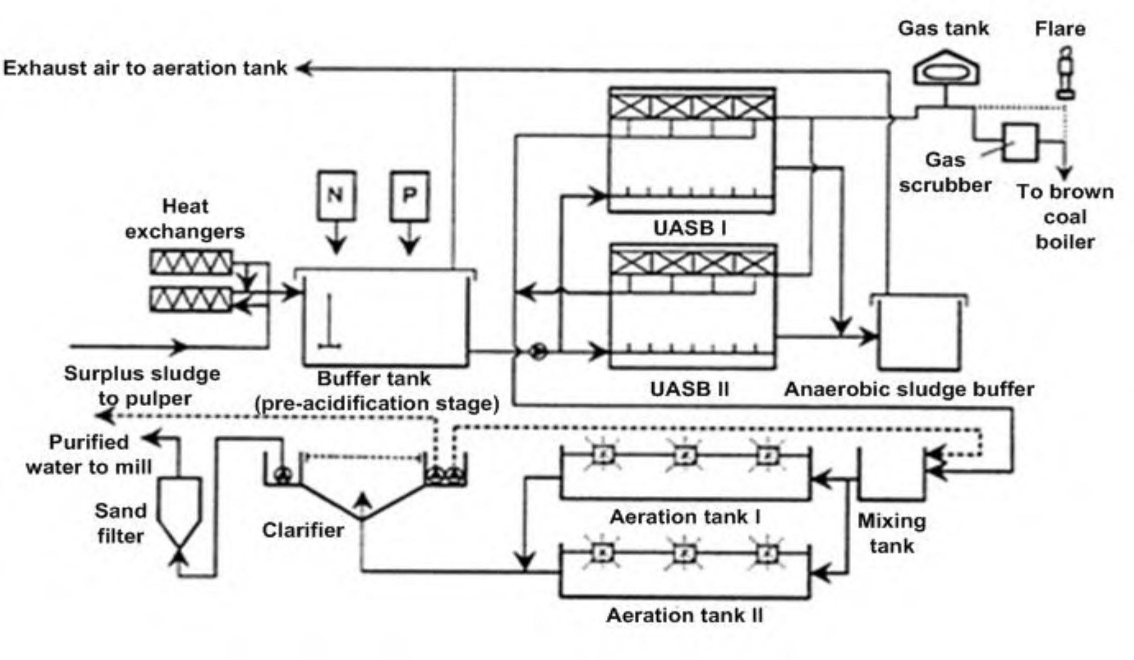
Description
A few paper mills producing Wellenstoff and Testliner in Europe and North America had been successful in bringing their waste water discharges to zero and operating a 'closed water system'. However, the inevitable accumulation of dissolved and colloidal organic matter in closed water circuits creates, in most cases, severe problems such as corrosion, unpleasant odours in the paper produced and also in the vapour exhaust of the paper machines. In order to reduce the organic pollution of the process water, treatment techniques ordinarily used for end-of-pipe waste water treatment are adapted to in-mill treatment. A partial stream of the process water (e.g. one third of the white water volume) is treated in biological treatment plants and the purified water is reused for paper production. The main advantage of in-line treatment is that only a part of the COD load from a purge of white water needs to be eliminated to keep a given level of contaminants in the circuits. This makes the in-line waste water treatment plant economically attractive. There are different technical options in operation. One technical solution is briefly described in this section.

Example: Anaerobic treatment combined with an activated sludge system and a sand filter at RCF DE 6

Since 1995, the in-line treatment plant at the RCF DE 6 mill has been in operation without any significant difficulties (Herberz 2006). The paper mill produces 400 000 tonnes/year of Testliner and Wellenstoff on two paper machines. A partial stream of the process water is cooled in order to bring the water temperature down from 55 °C to 35 °C.

A buffer tank/pre-acidification reactor is used for preconditioning the water with nutrients before feeding it into the UASB reactor. This reactor is followed by aerobic treatment in two parallel aeration tanks. After passing a sedimentation tank, the treated water is sent to sand filters in order to reduce the concentration of solid substance. The biogas produced in the anaerobic reactors is scrubbed to remove the H_2S and is then used for steam generation.

A simplified scheme of the process water treatment is shown in Figure 6.34.



Source: [21, Diedrich et al. 1997]

Figure 6.34: Example for the in-line treatment of closed water loops, process water treatment system of RCF DE 6

Through in-line treatment it is possible to achieve the desired level of COD in the circuits depending on the flow treated and the size of the plant. The zero discharge option does not imply reaching a high efficiency of pollution reduction corresponding to regulations but only acceptable concentration levels in circuits to give good characteristics to the paper products. When keeping the COD level near 7 000 – 8 000 mg/l in the closed water circuit, the process water quality is similar to mills with a current average effluent volume amounting to about 3 – 4 m^3/t.

The example mill mentioned above has produced Wellenstoff and Testliner since 1970 under completely effluent-free conditions (but without in-line biological treatment). The mill observed considerable improvements of process water quality, paper quality and emissions of organic substances via the vapour exhaust of the paper machines after the start-up of the in-line biological process water treatment plant in 1995 [145, UBA Report 1996] (see Figure 6.34).

A similar solution has been realised at the Tillmann paper mill in Zülpich-Sinzenich, DE. The major difference is that Tillmann has introduced a decarbonisation stage between the anaerobic reactors and the activated sludge plant in order to prevent an enrichment of calcium carbonate in the water system or uncontrolled precipitation of calcium in the waste water treatment system (see also Section 6.3.5). For the reduction of the calcium concentration, a basin of the old waste water treatment plant was converted into an aerated decarbonisation stage. The precipitated lime is withdrawn from the system after sedimentation.

Achieved environmental benefits

Closed water loops with in-line treatment result in zero emissions to water. The amount of fresh water for paper production is reduced to around 1 m^3/t paper produced. This is the amount of water evaporated in the drying section of the paper machine (without size press).

Where a paper mill is already operating an effluent-free process water system, the in-line treatment can be an efficient measure to reduce the pollution of the produced paper and the concentration of odorous compounds in the vapour exhaust of the paper machine.

Environmental performance and operational data

Internal biological treatment is reported as an efficient method to lower white water COD and consequently odour problems.

At the example paper mill (RCF DE 6), the in-line process water treatment was started up in September 1995. The expected efficiency of the biological treatment was achieved within a few weeks. Since that time, the plant has been operating without any significant difficulties. Nevertheless, problems caused by the precipitation of calcium carbonate in pipes and in the aeration basin have to be solved. Measures to reduce calcium carbonate precipitation have been applied (see Section 6.3.5).

The hydraulic reliability of the circuit closure involves introducing continuously only 50 % of the water flow that is evaporated in the drying section of the paper machine as fresh water (about 1 m^3/t). Internal modifications of the water circuits have to be applied to be compatible with decreased water consumption.

Cross-media effects

Anaerobic techniques for in-line treatment reduce the generation of excess biomass to a minimum. The excess biomass can either be reused for paper production or incinerated. The energy demand of the in-line treatment plant (pumps, aerators, agitators) is completely covered by the thermal use of the generated biogas. Compared to the totally closed water system without in-line treatment, the concentration of odorous compounds in the process water (e.g. formic acids, acetic acid, propionic acid and lactic acid) can be reduced by 95 %. This results in a significant decrease in emissions of these organic substances in the vapour exhaust of the paper machine. Thus, unpleasant odours can be reduced significantly [145, UBA Report 1996].

Technical considerations relevant to applicability

This technique is only applicable for 'brown papers' manufactured from paper for recycling (e.g. Wellenstoff, Testliner).

There are several reasons why this technique is not generally regarded as BAT. The main reason is the risk of calcium carbonate precipitation in the process water circuit, as well as in the anaerobic and aerobic treatment plants. The control of the calcium concentration in the white water is very complex and not completely understood. Technical solutions for this problem are still under development (see Section 6.3.5). Additionally, for the application of biological in-line treatment in an existing paper mill, the total water-fibre system has to be optimised, which could take a few years, especially in older mills.

However, reuse of partial streams of biologically treated waste water as process water is carried out by a large number of paper mills in Europe producing corrugating medium. In some mills, the share of treated waste water for reuse can reach 50 % to 60 %.

But even if the scaling problem can be solved, other questions arise, e.g. how to guarantee an efficient and undisturbed operation of high-speed paper machines producing packaging papers with lower grammages than in prior years.

Economics

Anaerobic installations require smaller, but more expensive installations than aerobic treatment with lower operating costs and energy savings through the production of methane. For the example mill described (RCF DE 6), an investment of EUR 6 million was reported (prices in 1995; EUR 1 million of which were subsidies). The annual total operating costs covering chemicals, disposal of separated sulphur, staff and maintenance amount to EUR 165 000. Net energy savings of EUR 13 000 per year are included in this figure. Assuming a paper production of 360 000 tonnes/yr and an amount of treated process water of 1 000 000 m^3/yr, specific operational costs of EUR 0.5/tonne paper and EUR 0.2/m^3 process water are calculated. The specific costs including capital costs and operational costs total EUR 1.8/tonne paper and EUR 0.7/m^3 process water respectively [145, UBA Report 1996].

Driving force for implementation

Paper mills producing Wellenstoff and Testliner are sometimes located at rivers used for drinking water supply or on small watercourses which are susceptible to unacceptable levels of pollution at times of low flow. To guarantee an acceptable quality of the river water, local authorities set stringent discharge standards based on water quality targets defined for the river. In some cases, paper mills cannot fulfil these discharge standards with the end-of-pipe treatment of waste water. Therefore, they have to close the water circuit completely. However, the closure of the water circuit has negative effects on paper quality and the vapour exhaust of paper machines. To avoid an increase in salt content, water hardness and the concentration of odorous volatile fatty acids, the biological in-line treatment of process water can be a suitable measure. Nevertheless, further research is necessary to solve the problem of calcium carbonate precipitation and some other side effects.

Example plants

RCF DE 6; VPK Oudegem, BE; Papelera de la Aqueria, ES.

Reference literature

[145, UBA Report 1996], [21, Diedrich et al. 1997].

6.3.5 Removal of calcium from process waters

Description and achieved environmental benefits

The significant increase in the use of calcium carbonate as filler and pigment in paper manufacturing has resulted in a high concentration of dissolved calcium ions in the process water of paper mills. This is especially true for mills processing paper for recycling, where this trend is further intensified by continuously increasing water circuit closure. Depending on the degree of system closure, the calcium concentration can exceed more than 1 500 mg/l. Consequent precipitation and scaling mostly as calcium carbonate occur in the water systems, e.g. in section rolls, wires, felts and shower nozzles, in heat exchanger systems as well as in biological waste water treatment plants. Precipitation and scaling of calcium carbonate can be the limitation for reusing biologically treated water as process water because the potential for precipitation in this water stream is especially high [152, I.Demel et al. 2004]. Removal of calcium from process water allows mills processing paper for recycling with advanced water circuit closure to keep using paper for recycling.

The avoidance of calcium carbonate precipitation and scaling can be achieved by various measures:

a) Use of chemical additives as precipitation inhibitors. A phosphonate inhibitor is used in a German paper mill with a totally closed water system. The inhibitor is added to the biologically anaerobic-aerobic treated process water in a concentration of 40 ppm. This treated process water is mainly used for the replacement of fresh water as shower water in the paper machine. Since the usage of the inhibitor, calcium carbonate scaling on section rolls, wires and felts and shower nozzles has been minimised to a very low level. The runnability of the paper machine has increased considerably.
b) Lowering of calcium concentration by controlled precipitation of calcium carbonate. According to the carbonate-bicarbonate equilibrium, the precipitation of calcium carbonate depends on the pH value of the process water and the corresponding concentration of carbonates. The appropriate water stream for a controlled precipitation is the effluent of an anaerobic reactor. The pH value in this effluent already lies in the range of 6.8 – 7.2 and can be increased by use of alkaline solutions or by stripping the CO_2 generated from biological degradation.

Environmental performance and operational data

In German mills processing paper for recycling, two systems for calcium carbonate precipitation are installed. The first system is an aeration reactor. Compressed air is pumped into a reactor filled with process water via two closed-circuit pipes [150, Bülow et al. 2003], [151, Bülow et al. 2003]. The stripping of CO_2 results in an increase of the pH up to 7.8 – 8.0. In this pH range calcium carbonate begins to form and is then sedimented. The reduction in calcium concentration, measured as water hardness, is only in a range of 10 – 20 %. A further increase in pH value can be obtained by the use of lime milk. At pH values of about 8.0 – 8.4, the hardness reduction rates are in the range of 50 – 90 % The hardness of the untreated effluent of the anaerobic reactor is about 60° dH, corresponding to a calcium concentration of about 400 mg/l. The sedimented calcium carbonate, removed continuously at the conic bottom of the reactor, is reused in the paper manufacturing process. In 2001, two of these aeration reactors with a volume of 320 m^3 each were installed as a second treatment stage after an anaerobic IC reactor in the Julius Schulte Söhne paper mill, in Düsseldorf, DE. The treated effluent volume is about 850 m^3/d. This system has not yet been installed in other German paper mills.

A further development of the described aeration reactor is the lime trap. This system is based on the dissolved air flotation principle. The shift in pH value is achieved by the stripping of CO_2 and the addition of a sodium hydroxide solution. The precipitated calcium carbonate is floated and removed by a sludge collection scrubber in the upper part of the flotation cell. This kind of dissolved air flotation, already well known in papermaking, is used for the separation of solids from white water.

In the German paper industry, four lime traps have so far been installed. The largest plant is installed in a mill processing paper for recycling with an annual production of LWC and white-coated Testliner of about 600 000 tonnes. A volume of 700 – 800 m^3/h of anaerobically purified effluent is treated in the lime trap in order to prevent calcium carbonate scaling in the membrane aeration system of the activated sludge plant.

The pH value in the effluent is shifted by CO_2 stripping and the addition of sodium hydroxide from 7.2 – 7.5 to 7.9 – 8.1. The necessary amount of sodium hydroxide solution (50 % by weight) is between 0.25 l/m^3 and 0.45 l/m^3. The water hardness in the influent of the lime trap is about 40° dH. In the effluent, the hardness is reduced to 20° dH. Reduction rates of over 50 % can be achieved with the application of a higher amount of sodium hydroxide. In the case described, the obtained hardness of 20° dH is sufficient to guarantee only an insignificant calcium carbonate scaling in pipes and in the following treatment stages. Cleaning of the aggregates is not necessary.

Cross-media effects
Controlled precipitation of calcium carbonate in most applications requires some sodium hydroxide to increase the pH value of the process water. However, there are developments to reduce the need for NaOH dosing. The decarbonisation stage at the Tillmann paper mill (see Section 6.3.4) achieves the targeted calcium reduction with air injection only.

The sedimented calcium carbonate, removed continuously from the reactor, can either be reused in the paper manufacturing process or delivered to other users.

Technical considerations relevant to applicability
The technique can be applied to both new and existing mills. Reactor design, air injection devices and the possible dosing of sodium hydroxide require some adaption to optimise the process.

Economics
Option a) The costs of inhibitor application are between EUR 0.20/m^3 and EUR 0.30/m^3 depending on the inhibitor quality. This corresponds to EUR 0.60/tonne of paper and EUR 0.90/tonne of paper produced, respectively. In the case of foodstuff packaging paper production, the inhibitor should have a certificate for its use in paper which is intended to come into contact with foodstuffs.

Option b) The investment required for the lime trap related to the first year after installation amounts to about EUR 0.13/m^3 treated effluent. For the described RCF paper mill that manufactures about 600 000 tonnes of LWC and white-coated Testliner per year, the costs are about EUR 850 000.

Driving force for implementation
High concentrations of dissolved calcium ions in the process water of the mills. Prevention of precipitation and scaling of calcium carbonates in the water systems, e.g. section rolls, wires, felts and shower nozzles, in heat exchanger systems and biological waste water treatment plants. The removal of calcium from process water allows mills processing paper for recycling with advanced water circuit closure to keep on using paper for recycling without reopening the water loops.

Reference literature
[248, Hamm 2007], [150, Bülow et al. 2003], [151, Bülow et al. 2003], [152, I.Demel et al. 2004].

6.3.6 Installation of an equalisation basin and primary treatment of waste water

Refer to Section 7.3.10.

6.3.7 Anaerobic biological waste water pretreatment

Description
See Section 2.9.11.2.2.

Achieved environmental benefits
Anaerobic pretreatment reduces the organic pollution load of waste water, reduces the excess sludge generated in comparison to stand-alone aerobic treatment and utilises the energetic content inherent in the organic pollution load (biogas production).

Environmental performance and operational data

I. *RCF paper mills without deinking*

Treatment efficiencies in anaerobic reactors depend on plant design and operating conditions. Typical efficiencies are within the range of 60 – 85 % for COD removal and 85 – 95 % for BOD removal. The total efficiency of combinations of anaerobic and aerobic techniques is in the range of 95 – 97 % for COD removal and 99.0 – 99.8 % for BOD removal. The organic load in the effluent is reduced to 0.5 – 1.0 kg COD/tonne paper produced and to 0.02 – 0.1 kg BOD_5/tonne paper produced.

A German 100 % RCF-based paper mill (without deinking) reported an improvement in treatment efficiency by use of combined anaerobic-aerobic treatment compared to a two-stage aerobic treatment (see also emissions from RCF folding boxboard mills in Table 6.21, Table 6.22 and Table 6.24 below). The yearly average values given in Table 6.20 were reported.

Table 6.20: Yearly average values of treated effluent of a German 100 % RCF-based paper and board mill without deinking

Parameter	Unit	Two-stage aerobic treatment	Anaerobic-aerobic treatment
COD concentration	mg/l	290	190
BOD_5 concentration	mg/l	21	12
COD load	kg/t	0.93	0.68

Emissions to water of RCF paper mills without deinking after anaerobic-aerobic treatment are shown in Table 6.21 and Figure 6.35. The list comprises a selection of mills for which qualified data were provided and is not intended to be complete. The selected mills have installed processes and techniques for achieving a high level of environmental protection. All the mills use anaerobic treatment with high load reactors (e.g. EGSB reactors) as a first stage of combined anaerobic and aerobic biological treatment.

Table 6.21: Annual average emissions to water from RCF paper mills without deinking after anaerobic-aerobic treatment

Examples of RCF-processing paper mills without deinking	Reported achieved emission levels after anaerobic-aerobic treatment							Production (t) 2006 and type of treatment
	COD	BOD_5	Tot-P	Tot-N	AOX	TSS	Flow [m^3/t]	
RCF paper mills producing folding boxboard (fibre supply: 100 % RCF or RCF and 0 – 10 % mechanical pulp)								
Moritz J.Weig Mayen, DE	127 mg/l	3.0 mg/l	0.49 mg/l	6.4 mg/l	0.077 mg/l	15 mg/l	4.1	535 600 folding boxboard
	0.52 kg/t	0.012 kg/t	2 g/t	26 g/t	0.3 g/t	0.061 kg/t		UASB/IC + single-stage AS, sand flotation
RCF paper mills producing base paper for corrugated boxboards (Testliner, corrugated medium): 100 % RCF								
RCF NL 1	110 mg/l	4 mg/l	1.2 mg/l	18.6 mg/l	ND	13.5 mg/l	4.3	507 300 Testliner, fluting
	0.47 kg/t	0.015 kg/t	5 g/t	80 g/t	ND	0.058 kg/t		Anaerobic IC + one-stage AS
German Mill 1, DE	230 mg/l	16.0 mg/l	1.8 mg/l	8.7 mg/l	0.17 mg/l	17 mg/l	2.6	583 700 corrugated medium, folding boxboard, Testliner
	0.62 kg/t	0.04 kg/t	5 g/t	24 g/t	0.5 g/t	0.040 kg/t		UASB/IC + single-stage AS

Examples of RCF-processing paper mills without deinking	Reported achieved emission levels after anaerobic-aerobic treatment							Production (t) 2006 and type of treatment
	COD	BOD_5	Tot-P	Tot-N	AOX	TSS	Flow [m^3/t]	
RCF DE 4	188 mg/l	13.6 mg/l	1.1 mg/l	12.1 mg/l	0.12 mg/l	ND	5.1	364 000 corrugated medium, folding boxboard, Testliner
	1.0 kg/t	0.07 kg/t	6 g/t	64 g/t	0.6 g/t	ND		UASB/IC + single-stage AS/MBBR
RCF DE 1	310 mg/l	17 mg/l	1.2 mg/l	3 mg/l	0.4 mg/l	ND	1.3	285 000 Testliner, corrugating medium laminating paper, bookbinding board
	0.4 kg/t	0.022 kg/t	1.5 g/t	4 g/t	0.5 g/t	ND		Anaerobic IC + aerobic
SCA Packaging Witzenhausen, DE	214 mg/l	21 mg/l	0.5 mg/l	4.5 mg/l	0.138 mg/l	13 mg/l	3.7	320 000 Testliner
	1.1 kg/t	0.1 kg/t	2 g/t	17 g/t	0.5 g/t	0.05 kg/t		UASB + two-stage AS
SCA Packaging Aschaffenburg, DE	147 mg/l	7.9 mg/l	0.73 mg/l	5.6 mg/l	0.2 mg/l	12.7 mg/l	4.4	314 000 corrugated medium
	0.65 kg/t	0.035 kg/t	3 g/t	25 g/t	0.9 g/t	0.06 kg/t		IC + single-stage AS
Papierfabrik Jass Fulda, DE	174 mg/l	11.7 mg/l	0.59 mg/l	3.1 mg/l	0.20 mg/l	0.19 mg/l	3.3	476 000 Testliner, corrugated medium
	0.57 kg/t	0.10 kg/t	2 g/t	10 g/t	0.7 g/t	0.000 6 kg/t		IC + two-stage AS
Papierfabrik Jass Schwarza, DE	155 mg/l	10.2 mg/l	1.0 mg/l	7.9 mg/l	0.13 mg/l	ND	5.7	380 000 Testliner, corrugated medium
	0.88 kg/t	0.06 kg/t	6 g/t	45 g/t	0.7 g/t	ND		IC + single-stage AS
RCF DE 6	0	0	0	0	0	0	0	400 000 Testliner, corrugated medium
	0	0	0	0	0	0		UASB + single-stage AS, sand filtration

NB: ND = no declaration; UASB = upflow anaerobic sludge blanket, IC = high load anaerobic reactor with internal circulation; AS = activated sludge; MBBR = moving bed biofilm reactor.

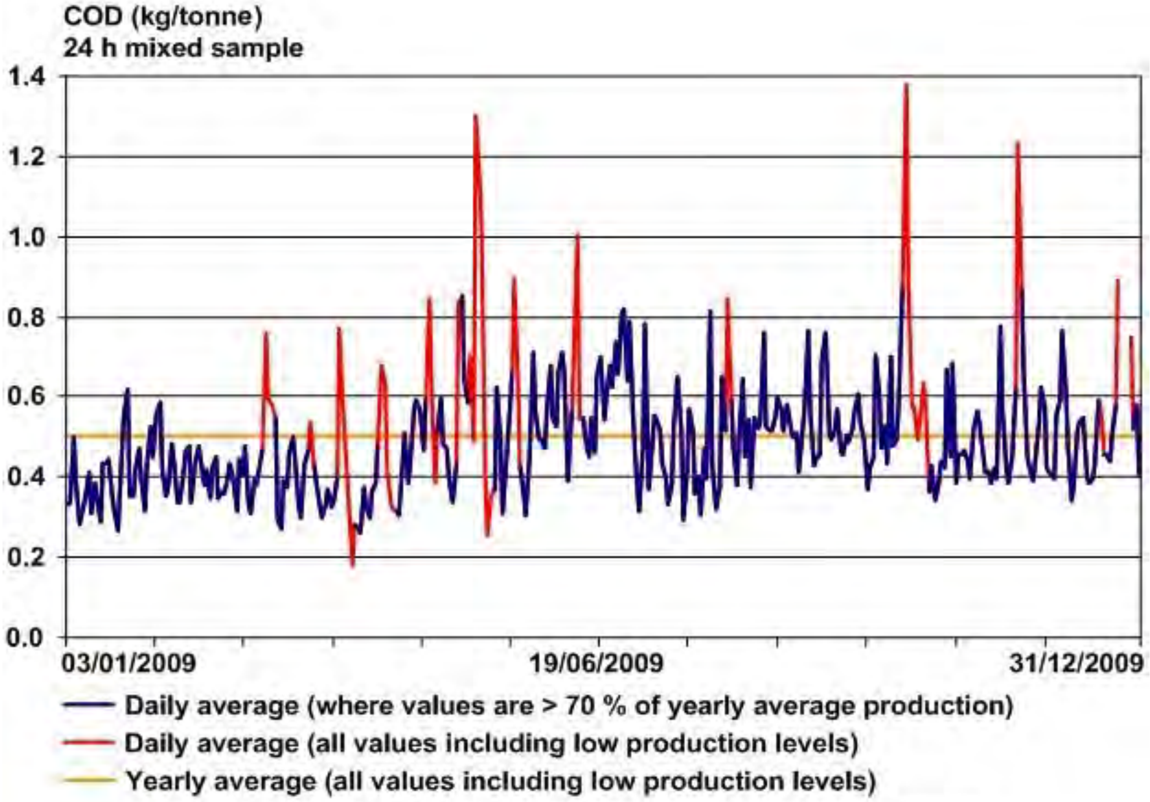
With regard to tot-N, data for German example mills only include inorganic nitrogen compounds (organic N excluded).
Source: [248, Hamm 2007]

Further data on achieved emissions are given in Section 6.2.2.5.

In some of the mills, treated water is partially recycled after biological treatment. A share of biologically treated waste water of about 15 – 30 % is fed back into production. The RCF paper mills without deinking do not differ very much in terms of emissions to water achieved after biological treatment. The organic load in the effluent is reduced to 0.5 – 1.1 kg COD/tonne paper produced and to 0.01 – 0.1 kg BOD_5/tonne paper produced, respectively.

The mills producing folding boxboard achieve the same values as far as the organic load is concerned. The specific waste water amount in this RCF-based paper group is slightly higher than in the RCF paper group of corrugated based paper (see Table 6.24). A further differentiation between the two paper grades is not necessary.

Figure 6.35 shows the organic load after anaerobic-aerobic waste water treatment (anaerobic IC reactors + activated sludge) of a RCF paper mill that manufactures Testliner, schrenz and fluting based on 100 % paper for recycling on three paper machines. The daily average values of the discharge COD load over a complete year is compiled in the figure and a statistical evaluation is presented. The data for the daily average values are assessed for two different cases: a) considering all data (red line) and b) dismissing the days where the production is considerably below the annual average (purple line). The advantage of approach b) is that dismissing the days of clearly below average production reduces the misleading mathematical effect of dividing similar daily COD emission loads by relatively lower denominators (in case of decreased net production). A few atypical peaks are removed by this means. This results in more adequate conclusions with regard to the stability of the real performance of the mill. For yearly and monthly averages, this effect is not relevant.



Statistics	Values > 70 % of yearly average production	All values
Yearly average	0.48	0.50
1st decile	0.33	0.33
Daily maximum	0.87	1.38
Standard deviation	0.12	0.16
95th percentile	0.79	0.79

Source: [158, RFC NL 1 2010]

Figure 6.35: Daily average COD load over a complete year (RCF NL 1)

The example represents a mill that has implemented all effluent-related process-integrated BAT and that possesses a well designed and operated biological treatment plant. The discharge flow during the reported year was on average 3 m^3/ADt, the yearly average COD concentration 145 mg COD/l (95th percentile of the daily average value: 180 mg COD/l).

II. *RCF paper mills with deinking*

Emissions to water of RCF paper mills with deinking after anaerobic-aerobic treatment are shown in Table 6.22. RCF paper mills producing graphic RCF paper (newsprint, SC paper) as well as tissue belong to this group. The kinds of fibre furnish used vary. While in graphic paper mills, furnish mainly consists of recovered fibres and in some cases of integrated produced mechanical pulp, the furnish in RCF tissue mills consists of recovered fibres and some chemical pulp. All the mills use anaerobic treatment with high load reactors (e.g. IC reactor) as a first stage of combined anaerobic and aerobic biological treatment. An increased water closure is required, resulting in more concentrated effluents (COD: 1 000 – 2 000 mg/l) which can be treated effectively by the new anaerobic systems.

The RCF paper mills with deinking do not differ very much in terms of emissions to water achieved after biological treatment. The organic load in the effluent is reduced to 1.9 – 2.7 kg COD/tonne paper produced and to 0.01 – 0.2 kg BOD_5/tonne paper produced.

Regarding the specific waste water volume, graphic RCF-processing mills and RCF-processing mills producing tissue must be distinguished. With one exception in tissue production, the specific waste water amount is slightly higher than in manufacturing RCF-based graphic paper.

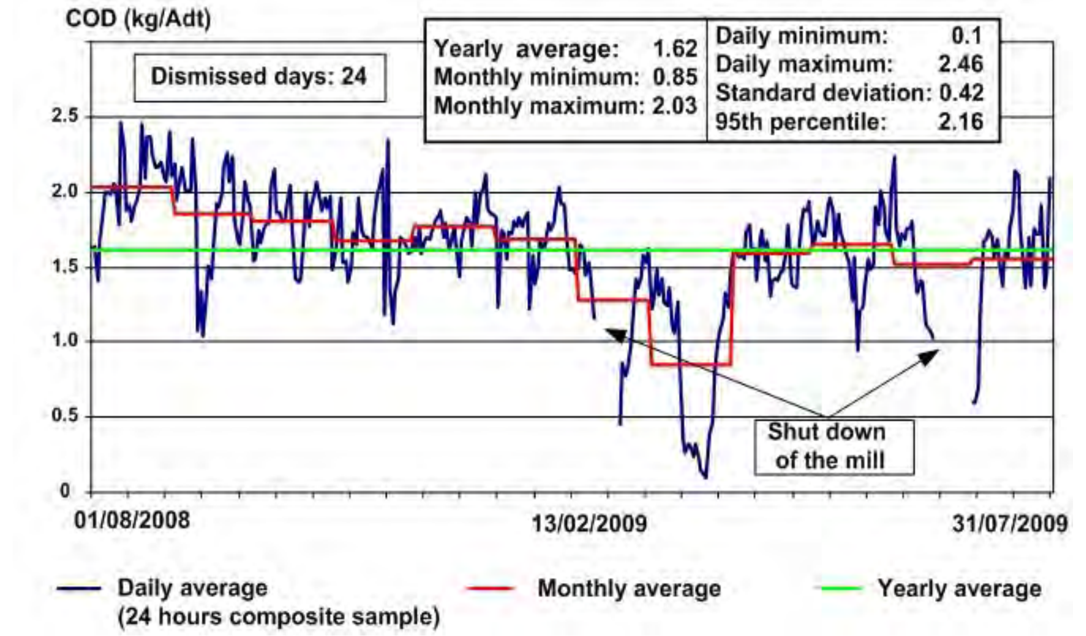
Table 6.22: Annual average emissions to water from RCF paper mills with deinking (after anaerobic-aerobic treatment

Examples of RCF processing paper mills with deinking	Reported achieved emission levels after anaerobic-aerobic treatment							Production (t) 2006 and type of treatment
	COD	BOD_5	Tot-P	Tot-N	AOX	TSS	Flow [m^3/t]	
RCF paper mills producing graphic RCF paper (newsprint, SC paper)								
UPM-Kymmene Schwedt, DE (100 % RCF)	271 mg/l	6.6 mg/l	0.66 mg/l	2.6 mg/l	0.09 mg/l	33 mg/l	9.4	295 000 newsprint, SC paper
	2.5 kg/t	0.06 kg/t	6 g/t	24 g/t	0.8 g/t	0.31 kg/t		Anaerobic IC + two-stage AS
Paper mill 2, DE (100 % RCF)	198 mg/l	2 mg/l	0.46 mg/l	0.6 mg/l	0.17 mg/l	10 mg/l	10.4	328 600 newsprint; 34 200 market DIP
	2.1 kg/t	0.02 kg/t	5 g/t	5 g/t	2 g/t	0.10 kg/t		IC + single-stage AS/micro-flotation
UPM-Kymmene Schongau, DE (85 % RCF, 15 % GW)	349 mg/l	6 mg/l	0.4 mg/l	0.4 mg/l	0.18 mg/l	18 mg/l	7.6	716 600 newsprint
	2.7 kg/t	0.005 kg/t	3 g/t	3 g/t	1 g/t	0.14 kg/t		IC + two-stage AS/MBR
RCF paper mills producing tissue (fibre supply: 100 % RCF or 75 % RCF and approx. 25 % purchased CP)								
WEPA Giershagen, DE (75 % RCF))	187 mg/l	10 mg/l	1.17 mg/l	17.4 mg/l	0.25 mg/l	ND	10.0	83 000 tissue
	1.9 kg/t	0.1 kg/t	10 g/t	170 g/t	3 g/t	ND		IC + single-stage AS/ micro-flotation
Papierfabriken Wernhausen, DE (75 % RCF)	125 mg/l	16 mg/l	1.05 mg/l	7.2 mg/l	0.12 mg/l	31 mg/l	14.6	96 300 tissue
	1.9 kg/t	0.2 kg/t	20 g/t	110 g/t	1.8 g/t	0.45 kg/t		IC + single-stage AS

NB:
ND = no declaration; IC = high load anaerobic reactor with internal circulation; AS = activated sludge; MBBR = moving bed biofilm reactor; GW = groundwood; CP = chemical pulp.
With regard to tot-N, data for German example mills only include inorganic nitrogen compounds (organic N excluded).

Further data on achieved emissions are given in Section 6.2.2.5.

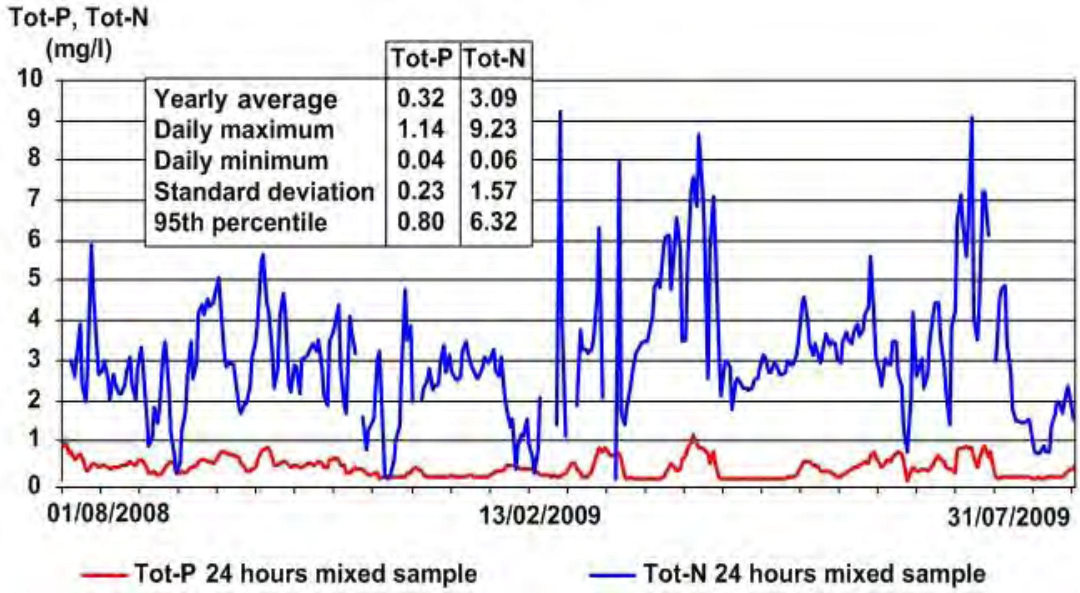
The emission of a RCF paper mill with deinking that manufactures mainly newsprint is given in Figure 6.36. The daily COD emission load refers to the installed machine capacity because no daily production data for the whole year were available. In 2009, the real net production of the mill was slightly below the installed machine capacity. If the daily COD load values had been referred to, the real production (instead of the capacity) specific COD load values would have been slightly higher than the ones shown in Figure 6.36 (around 2 kg COD/t as a yearly average). The waste water treatment plant of the mill consists of an anaerobic stage followed by a low-loaded activated sludge process. After the secondary clarifier, part of the water is sent to a tertiary treatment (micro-flotation unit) where polyelectrolytes and polyaluminium chloride are added as flocculating agents and the flocs generated are separated by flotation. A partial current is always treated in the micro-flotation unit in order to keep it available when it is required because of temporarily higher emissions of COD, suspended solids or phosphorus.



Source: [156, LD Leipzig 2010]

Figure 6.36: COD load of a RCF newsprint mill with deinking after anaerobic-aerobic biological treatment for different reference periods

As can be seen in Figure 6.37, the achieved emissions of nitrogen and phosphorus and TSS are relatively low which can be partially explained by the micro-flotation of a partial waste water stream. TSS values normally vary between 10 and 20 mg TSS/l (two-hour mixed sample). Total phosphorus is below 1 mg/l during the whole year; the inorganic nitrogen concentration (around 50 % of the total nitrogen in this case) is normally below 6 mg $N_{inorganic}$/l in a 24-hour mixed sample. The flow is between 9 and 10 m^3/ADt of paper.



Source: [156, LD Leipzig 2010]

Figure 6.37: Concentration of tot-P and tot-N after anaerobic/aerobic biological treatment and partial tertiary treatment of the waste water of a RCF newsprint mill

Cross-media effects

For some 'brown' paper grades, external depositing of the sludge can be prevented by returning the excess sludge to the paper production process. The proportion of sludge on the raw materials input is less than 1 %. However, returning excess sludge into the paper is only applicable in specific cases (e.g. it is not possible for tissue or graphic paper mills).

Technical considerations relevant to applicability

While anaerobic pretreatment is common for paper for recycling-based paper mills producing corrugated medium, Testliner and board, fewer applications of this technique are still observed for deinked grade effluents such as from tissue and newsprint mills, where the major COD load is attributed to the deinking process.

The extensive closure of water circuits in RCF-based paper mills processing recycled paper causes high concentrations of dissolved organic substances in the process water circuits. For an economic application of anaerobic techniques as a first stage of biological waste water treatment, the COD concentration of the process water should not be less than 1 000 – 2 000 mg/l. Paper mills producing 'brown grades' at a low level of fresh water consumption are easily reaching this level. Paper mills manufacturing deinked grades can also reach this level before any treatment. The application of anaerobic-aerobic waste water treatment for deinked grades is becoming more popular (e.g. Stora Enso Eilenburg, UPM-Kymmene Schongau [149, H.Hilbert 2008]). The anaerobic degradation process could be disturbed by dissolved sulphate, when the concentration exceeds 1 000 mg/l, because during the anaerobic process sulphate is transformed into hydrogen sulphide (H_2S) which at high concentrations is toxic to anaerobic microorganisms. Normally, a toxic level will not be reached.

Economics

The investment required for combined anaerobic-aerobic waste water treatment plants varies widely depending on the specific COD load and the volume of waste water. Assuming COD loads of 20 – 35 tonnes per day, which correspond to an annual production of Wellenstoff and Testliner of 200 000 – 350 000 tonnes, the investment required is in the range of EUR 7 – 12 million.

Taking into account the net energy savings by use of the produced biogas as fuel, the annual operating costs including chemicals and operating materials, waste disposal, staff and maintenance are in the range of EUR 0.6 – 1.0 per tonne of paper produced.

Driving force for implementation

The most important reason for installing combined anaerobic-aerobic systems for the biological treatment of process water is the improved stability with regard to fluctuations of COD loading compared to a stand-alone aerobic treatment plant. Another incentive is the production of biogas and its use as fuel in power plants. Finally, the considerably smaller volume of excess sludge produced has to be considered. By using combined anaerobic-aerobic techniques instead of a single-stage or two-stage aerobic technique, sludge production is reduced by 70 – 80 %. This is of special interest for paper mills that do not have their own facilities for energetic utilisation of excess sludge and do not recycle sludge into the production process, and therefore have to provide for expensive external disposal.

Example plants

Numerous anaerobic plants are operated as the first stage of waste water treatment in many European paper mills producing Testliner, Wellenstoff or cartonboard. For deinked grades, anaerobic-aerobic treatment is used, e.g. at Stora Enso Eilenburg (newsprint), UPM Schongau (newsprint, SC-B paper), UPM Schwedt (newsprint), WEPA Giershagen (tissue), SCA Kostheim (tissue), Wernhausen Papierfabriken (tissue).

Reference literature

[22, Driessen et al. 2007], [59, Hamm et al. 1991], [69, IFP 1998], [80, Koepp-Bank 1991], [248, Hamm 2007], [149, H.Hilbert 2008], [156, LD Leipzig 2010].

6.3.8 Aerobic biological waste water treatment

Description

See Section 2.9.11.2.1.

Achieved environmental benefits

Reduction of emissions of organic matter (COD, BOD), AOX, phosphorus, nitrogen and chelating agents to water.

Environmental performance and operational data

The aerobic biological treatment of effluents from paper for recycling mills has been used since 1980 to remove oxygen-consuming organic substances and specific organic compounds. These substances are converted by different variants of biological treatment systems into biomass, carbon dioxide and water. Low-loaded aerobic activated sludge systems are widely used in the sector. The nutrient content in waste water of paper for recycling mills is generally low.

Example MBR at Köhler Pappen, Gengenbach (DE)

The mill manufactures 35 000 tonnes/year of paper for recycling-based cartonboard (grey board) on three paper machines. Many different grades are produced, some of which are coloured. Before implementing the MBR, the waste water was purified by sedimentation only and was then sent to a common municipal biological treatment plant. The average product-specific amount of waste water is approximately 8 m^3/t or 38 m^3/day.

The municipality decided to drastically increase the waste water fees from EUR 0.35/m^3 up to EUR 2.05/m^3. The mill also has to pay for the fresh water ('water cent'). Fresh water reduction and waste water volume reduction were therefore a necessity. Furthermore, the Köhler Pappen cardboard mill wanted to recover heat from the warm process water for economic reasons. The implementation of the measure was considered an opportunity to safeguard the production site.

Despite the high product variety, the objective of the waste water treatment concept is to recirculate the highest possible ratio of purified water back to production in order to achieve a closed water circuit. Figure 6.38 shows the flowsheet of the process water treatment at the Köhler Pappen mill including MBR.

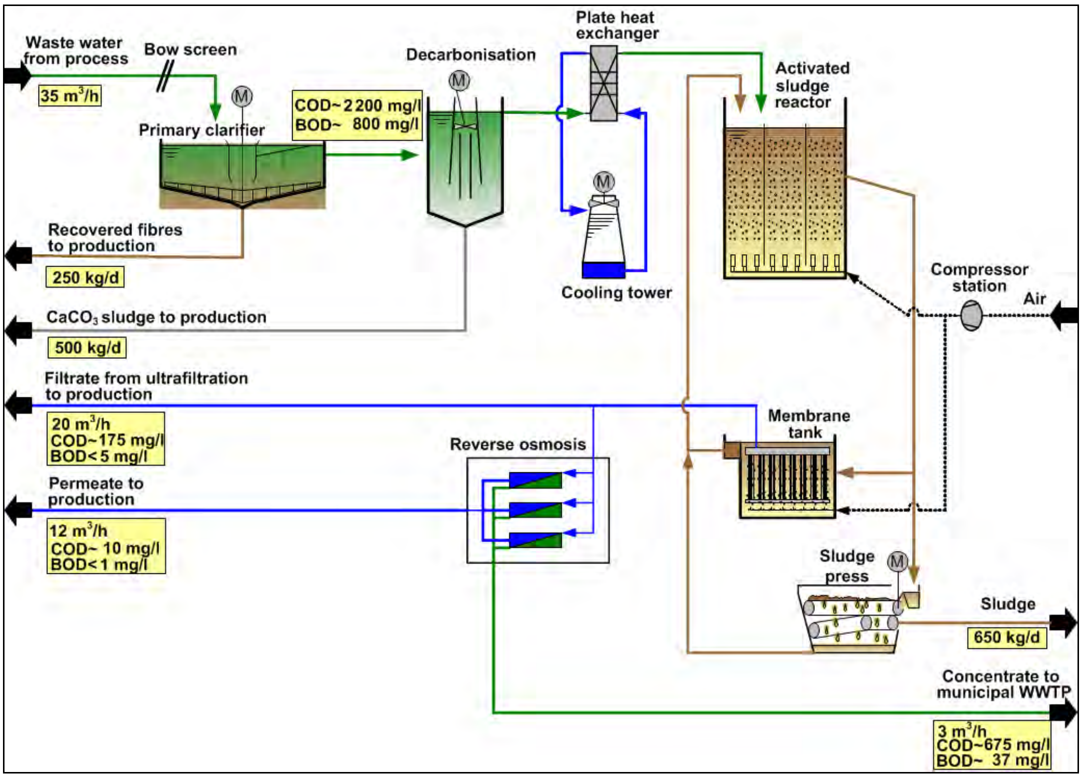


Figure 6.38: **Flow chart of the process water treatment at the Köhler Pappen mill including MBR**

The main components of the process water treatment concept at Köhler Pappen are given below:

- A bow screen to remove plastic rejects, foamed polystyrene and other trash material.
- A primary settling tank for fibre recovery.
- A decarbonisation reactor including a clarifier. The controlled removal of calcium is necessary because the use of mixed paper for recycling as raw material and the well-closed water circuits increase the risk of calcium carbonate scaling on the membranes. Soda, lime milk and iron(II) chloride and some acid are added to the calcium-rich waste water, are mixed, and microparticles of calcium carbonate are formed. The added flocculant agents and the proper mixing help build agglomerated particles of calcium carbonate that can be separated by sedimentation and removed with a sludge rake and a pump. The pumpable suspension of calcium carbonate has a concentration of 50 g/l to 300 g/l and is used as a filler for cartonboard grades. The target value is to keep a calcium concentration of 50 mg/l.
- An activated sludge cascade (600 m^3, biomass concentration 10 – 12 g/l, food to mass ratio <0.2 kg BOD/kg SS×d).
- Three parallel operating submerged hollow fibre membrane units (average pore size: 0.04 microns which corresponds to ultrafiltration). Each tank holds 10 m^3, and contains three racks of membranes which hold 16 modules of membranes each. This gives 5 000 m^2 of total membrane surface with a calculated flux of 8 $l/m^2 \times h$.
- To reduce the remaining dissolved salts of the filtrate from the MBR plant, a partial flow (up to 50 % of the MBR filtrate) can be further cleaned by a two-stage reverse osmosis (maximum 15 bar). At the time of writing (2013), the RO is operated only with low capacity as a kind of police filter for different types of salts because no precipitation of $CaCO_3$ occurs.

By recirculating the filtrate from the MBR and the partial flow of the reverse osmosis permeate, the original flow of the waste water could be reduced by more than 90 %. The remaining flow (approximately 0.6 m^3/t) of the waste water (the concentrate of the reverse osmosis) is fed into the municipal sewage treatment plant in Gengenbach.
The average power consumption of the treatment plant (decarbonisation, activated sludge, MBR, reverse osmosis) is 2.3 kWh/kg $COD_{eliminated}$ or 2.0 kWh/kg $COD_{eliminated}$ without reverse osmosis. Around 650 kg dewatered biosludge per day is generated which has to be further treated or disposed of. For the decarbonisation unit, flocculation chemicals are used.

The achieved average waste water quality, after the primary clarifier, of the MBR filtrate, the RO permeate and the RO concentrate are compiled in Table 6.23 (2010 data).

Table 6.23: Achieved average waste water quality along the different treatment steps of the Gengenbach cartonboard mill

Parameter	Value	Sedimentation outflow	Filtrate MBR	Permeate reverse osmosis	Concentrate reverse osmosis
Feed	**m^3/h**	28	28	10	3
COD concentration	**mg/l**	2 600	165	10	675
BOD_5 concentration	**mg/l**	1 300	<5	<1	37
COD load	**kg/t**	17.5	1.1	0.07	0.49
BOD_5 load	**kg/t**	8.75	0.03	0.007	0.03
Conductivity	**µS/cm**	2 500	2 400	110	6 700
Calcium concentration	**mg/l**	300	43	10	75
Total suspended solids	**mg/l**	150	<2	<1	<1
NO_3-N	**mg/l**	4.1	0.9		
PO_4-P	**mg/l**	1.3	0.2		
Temperature	**°C**	41	35	32	31
pH value	**[-]**	6.6	8.1	6.5	6.2

The costs for the process water treatment of the Köhler cartonboard mill are partially compensated for by energy recovery (less heating of fresh water as the heat content of the recirculated filtrate can be used), the recovered $CaCO_3$ that is reused as filler and the fact that this treatment is considerably cheaper than the alternative treatment in the municipal waste water treatment. Considering the investment, the total specific costs are in the range of EUR 0.50/m^3 which is slightly more than the specific costs to be paid to the municipality in 2007 before the construction of the on-site treatment. The specific total costs of EUR 0.50/m^3 can still be reduced by 30 % because the water quality of the MBR filtrate is already suited to supplying all parts of the cartonboard production without using the reverse osmosis unit. The water hardness has been reduced sufficiently by the decarbonisation unit, so that the installed reverse osmosis is not required as a 'kidney' for the removal of salts or calcium. On the other hand, if decarbonisation of the process water is required, around EUR 0.22/m^3 has to be added.

Economics
The costs of the MBR system (investment and operational costs) are higher than for the standard aerobic two-stage system suspended carrier reactor plus low-loaded activated sludge treatment.

A recent case study determined operational and total costs of different MBR systems by use of a realistic model for the treatment of a partial flow of the paper mill effluent after primary treatment. The cost assessment included the activated sludge bioreactor. The data were derived in coordination with engineering companies and manufacturers [118, A.Helble et al. 2009]. The total operational costs for MBR with submerged membranes and with aerated tubular cross-flow membranes amounted to EUR 0.22/m^3. This cost includes the specific energy consumption of the activated sludge bioreactor (EUR 0.05/m^3), the specific energy consumption of the membrane stage (EUR 0.06/m^3), membrane replacement and spares costs, costs for nutrients, defoamers and cleaning chemicals and personnel costs. The operational costs of different MBR systems for the treatment of paper mill effluents vary between EUR 0.18/m^3 and EUR 0.28/m^3. All MBR systems examined were UF systems, i.e. pore size <0.1 µm (energy cost assumed is EUR 0.06/kWh). The specific total annual costs (capital + operational costs) are in the range of EUR 0.56 – 0.59/m^3.

Although membrane prices have dropped significantly and the life expectancy of the membranes has increased, the MBR is still more expensive than traditional biological systems. However, to evaluate the total costs, benefits such as water recirculation, energy recovery, reliability of the process, effluent quality achieved and reduced costs for sludge treatment also have to be taken into account.

Achieved emissions to water of RCF paper mills with and without deinking after aerobic treatment are shown in Table 6.24. In Table 6.24, the major paper groups considered, the products manufactured, the kinds of fibre furnish used and the type of treatment applied are indicated. The reference year is 2006 and for some mills 2008.

Table 6.24: Annual average emissions to water from RCF paper mills with and without deinking after aerobic treatment

Examples of RCF paper mills and fibre supply	**Reported achieved emission levels after aerobic treatment**							**Production (t) 2006 and type of treatment**
	COD	**BOD$_5$**	**Tot-P**	**Tot-N**	**AOX**	**TSS**	**Flow [m^3/t]**	
RCF paper mills with deinking producing graphic RCF paper (newsprint, LWC, copy paper, SC paper)								
SE Maxau, DE (52 % RCF, 42 % RMP, 6 % CP)	359 mg/l	7 mg/l	0.72 mg/l	1.6 mg/l	0.12 mg/l	13 mg/l	10.5	670 000 newsprint, SC paper
	2.9 kg/t	0.05 kg/t	0.008 kg/t	0.017 kg/t	0.001 kg/t	0.14 kg/t		Two-stage AS/MBR
Gebr. Lang Ettringen, DE (90 % RCF, 8 % GW, 2 % CP)	226 mg/l	12 mg/l	0.6 mg/l	2.1 mg/l	0.13 mg/l	0.5 mg/l	8.9	555 200 newsprint, SC paper
	2.0 kg/t	0.09 kg/t	0.005 kg/t	0.02 kg/t	0.001 kg/t	0.005 kg/t		Single-stage AS/ trickling filter, ozonation/ biofilter
Paper mill, DE (100 % RCF)	157 mg/l	9 mg/l	0.4 mg/l	2 mg/l	0.1 mg/l	ND	11.5	240 000 LWC and copy paper
	1.8 kg/t	0.1 kg/t	0.004 kg/t	0.019 kg/t	0.001 kg/t	ND		MBBR + single-stage AS
Paper mill, NL (100 % RCF)	214	8.9	1.1	7.4	0.3	7.4 mg/l	13.1	230 000 SC paper (ref. year: 2010)
	2.8	0.12	0.014	0.1	0.003	0.1 kg/t		Pre-aeration/ single-stage AS
RCF paper mills with deinking producing tissue								
SCA Kostheim, DE (100 % RCF)	135 mg/l	12 mg/l	0.8 mg/l	5.6 mg/l	0.29 mg/l	ND	15.8	104 000 tissue
	2.1 kg/t	0.2 kg/t	10 g/t	90 g/t	4 g/t	ND		MBBR + AS
RCF paper mills without deinking producing folding boxboard								
MM Gernsbach, DE (100 % RCF)	183 mg/l	15.0 mg/l	0.60 mg/l	1.6 mg/l	0.18 mg/l	6 mg/l	6.0	200 000 folding boxboard
	1.1 kg/t	0.09 kg/t	0.004 kg/t	0.010 kg/t	0.001 kg/t	0.004 kg/t		Single-stage AS/ MBR
RCF DE 5 (85 % RCF, 10 % MP, 5 % CP)	103 mg/l	7.3 mg/l	0.80 mg/l	2.6 mg/l	0.07 mg/l	8.3 mg/l	10.5	200 000 folding boxboard
	1.1 kg/t	0.08 kg/t	0.008 kg/t	0.03 kg/t	0.0007 kg/t	0.009 kg/t		Single-stage AS/ MBR, biofilter

NB: ND = no declaration; AS = activated sludge; MBBR = moving bed biofilm reactor; RCF = recovered fibre; MP = mechanical pulp; RMP = refiner mechanical pulp; CP = chemical pulp.

With regard to tot-N, data for German example mills only include inorganic nitrogen compounds (organic N excluded).

Source: [248, Hamm 2007], [Questionnaires 2007 and 2009]

Further data on achieved emissions are given in Section 6.2.2.5. The achievable removal efficiency is in the range of 95 – 99 % for BOD_5 and 75 – 90 % for COD. Removal efficiencies by use of combined anaerobic-aerobic biological treatment are usually slightly higher than aerobic treatment only (see Table 6.20 in Section 6.3.7).

BOD levels exceeding 25 mg O_2/l over a longer time period are an indicator of disturbances in the biological processes. Adjustment of the operating parameters and/or analysis of the biomass are required to recover the treatment plant performance.

Recycling part of the water after biological treatment seems to be possible for both RCF paper with and without deinking. However, RCF paper mills manufacturing deinked grades recycle no more than 10 % of the treated waste water to the paper mill whereas some RCF mills manufacturing corrugated medium recycle up to 30 % of the treated water. A few mills even run completely closed water circuits (see Section 6.3.4).

During aerobic waste water treatment, excess sludge is produced which has to be thickened, dewatered and further treated. A typical value for activated sludge plants is in the range of 0.6 kg excess sludge/kg BOD_5 eliminated (as DS) generated during treatment. Thus, depending on the quality of paper for recycling and on the process design, about 10 kg excess sludge from biological treatment per tonne of paper (on a dry basis) may be expected.

Usually control parameters are measured daily or at least a few times a week. Continuous measurement is also used in some plants (see Section 2.2.2.1.2). Additional measurements to control the activated sludge system are necessary, e.g. O_2 content, SVI (sludge volume index), water flow, and at times analysis of the biomass.

For aeration of the active biomass (activated sludge) and for pumps, electrical energy is needed. The specific consumption of energy for degradation/elimination of 1 kg BOD_5 amounts to 0.6 – 3 kWh/kg BOD_5 eliminated. If the system is well designed, a value of <1 kWh/kg BOD_5 eliminated can be achieved [91, Möbius 1997].

[118, A.Helble et al. 2009] reported for the MBR treatment of a typical paper mill's waste water a power consumption of 0.90 kWh/m^3 for the first biological stage and 0.5 kWh/m^3 for the submerged membranes, i.e. a total specific power consumption of 1.4 kWh/m^3.

A RCF-based paper mill reported for its WWTP, which consists of primary clarification, a biological stage, secondary clarification and a sand filter, 1 – 1.2 kWh/kg COD eliminated. The values include the turbo aerator, sludge dewatering, all pumps and other aggregates (like screens, scrapers, etc.).

Cross-media effects
Aerobic biological waste water treatment consumes energy (e.g. for aerators and pumps) and generates sludge that normally requires treatment before utilisation or disposal.

Especially during the summer period, the waste water treatment plant of RCF paper mills may emit annoying odours. If the waste water treatment is well designed and controlled, annoying odours can be avoided (see Section 2.9.14).

Technical considerations relevant to applicability
Applicable to both new and existing mills. MBR normally show fewer emissions of P, N and COD originating from lost biomass and produce less sludge than a conventional biological treatment. Very low TSS contents allow for reuse also in more sensitive areas of the production. However, only very few MBR plants are in operation in the pulp and paper industry. Mills manufacturing lower quality grades with well closed water circuits (e.g. a water intake below 8 m^3/t) may face an increased risk of lime precipitation (scaling) after the bioreactor and a lime removal stage might be required. In some cases, additional fine screening (e.g. by a drum

screen) is required in addition to normal primary treatment to protect the membranes from blocking. Another issue associated with MBR might be the biofouling of the membranes.

Economics

Data on costs are only available for an integrated paper mill manufacturing paper based on mechanical pulp. The waste water treatment system is comparable to the one applied for the treatment of effluent from processing paper for recycling. Therefore, the figures on costs can give a rough picture of the range of expected costs. The investment required for a completely new activated sludge treatment plant is approximately EUR 13.0 – 15.5 million for a new 1 000 ADt/day integrated mechanical pulp and paper mill. These costs also include the necessary primary treatment and sludge handling. The corresponding operating costs are EUR 1.2 – 1.5 million per year.

Driving force for implementation

Legal requirements.

Example plants

Numerous aerobic waste water treatment plants are operated in European RCF paper mills.

MBR plants: Papeteries du Rhin (cartonboard, MBR with submerged membranes), FR; Papeterie Lacaux (MBR with external submerged membranes), FR; VHP Veiligheidspapierfabriek Ugchelen BV (MBR, thermophilic, with external cross-flow tubular membranes), NL; Köhler Pappen Gengenbach (MBR with external submerged membranes), DE; Papierfabrik Louisenthal in Gmund and Königstein (MBR with external submerged membranes), DE.

Reference literature

[14, CEPI 1997], [91, Möbius 1997], [248, Hamm 2007] [Questionnaires 2007 and 2009].
MBR plants: [102, I.S.Kim et al. 2006], [107, H.Schwarz 2010], [118, A.Helble et al. 2009].

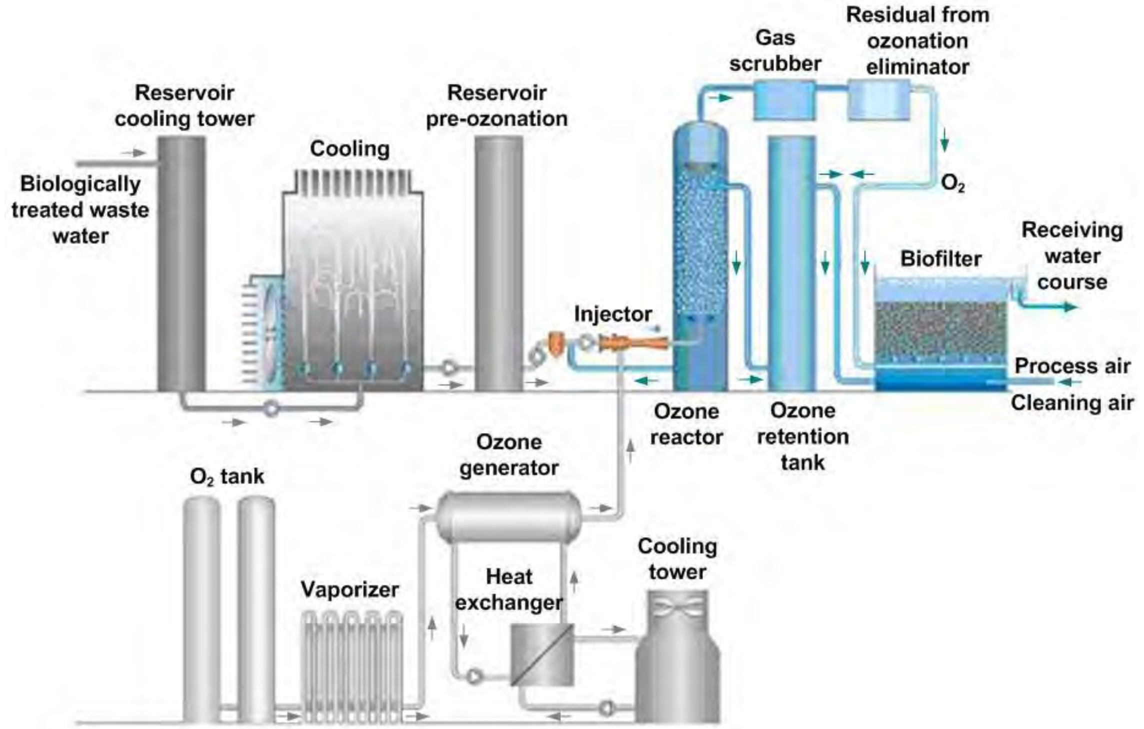
6.3.9 Combined ozonation and biofiltration

This technique can also be considered for the treatment of waste water from other paper grades that contain poorly biodegradable residual COD, e.g. wood-containing grades (see Chapter 5). Another advanced waste water treatment process (tertiary treatment) is described in Section 7.3.12 (chemical precipitation).

Description and achieved environmental benefits

Biological treatment of waste water from paper mills is the standard treatment method in most European paper mills thus reducing emissions to water significantly (see Section 6.3.7 and 6.3.8). In some cases, the best possible biological elimination of organic substances is not good enough to protect the receiving water body. Then, an advanced treatment of remaining pollutants after biological treatment is necessary that aims at a further reduction of COD, AOX, colour and TSS.

Ozone treatment – unless partial flows can be successfully pretreated – is normally applied most effectively and economically downstream of the biological stage. A combination of ozonation with fixed bed biofilm reactors reduces COD, colour and AOX, not readiliy degradable optical brighteners and chelating agents and bacteria depending on the amount of ozone applied. The layout of the ozone installation at SCA Laakirchen, AT, is shown in Figure 6.39.

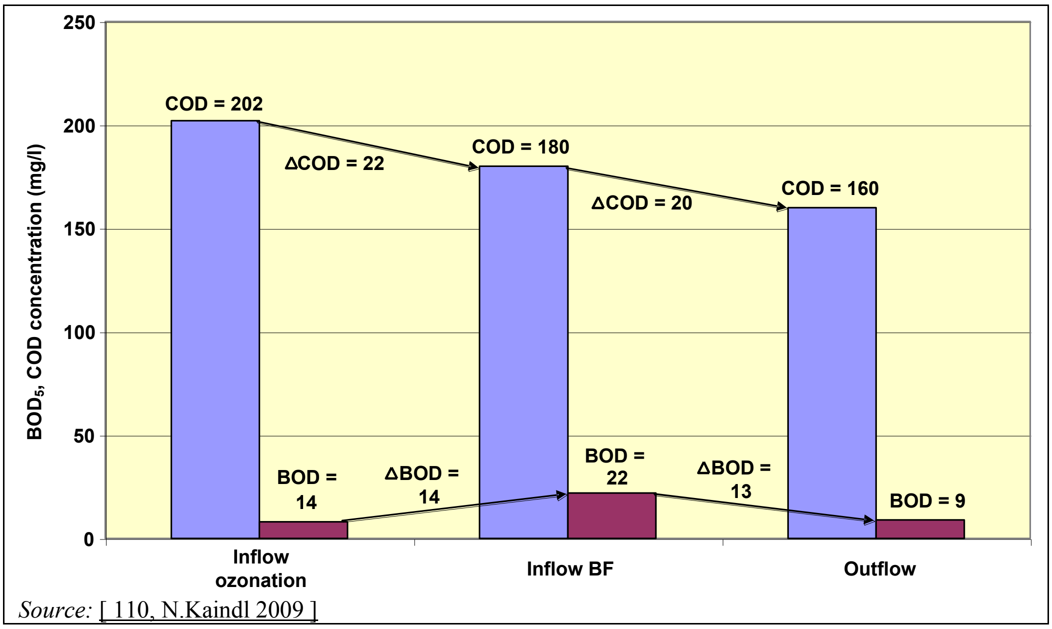


Source: [110, N.Kaindl 2009]

Figure 6.39: Layout of the ozonation stage with a subsequent biofilter

This process layout prevents full oxidation of organic matter by ozonation thus reducing the amount of required ozone and optimising the operational costs. The target of this layout is not to consume ozone for readily biodegradable matter but to only oxidise the persistent organic matter.

Ozonation is applied in two full-scale applications in Europe (AT, DE) to a completely biodegraded effluent, i.e. with low BOD concentrations. However, the persistent organic compounds are still at a level that is considered to be too high for the receiving water body. The process system chosen allows for parts of the persistent organic compounds (residual COD, AOX, and colour) to be transformed into biodegradable fractions. The combination of ozonation and subsequent biofiltration makes use of this effect of partial oxidation by limiting the use of expensive chemical oxidants (O_3) to the amount necessary to meet the targets. The partially oxidised compounds, now biodegradable, are then eliminated in the subsequent bioreactor. Figure 6.40 shows this effect. The three pairs of columns show the COD and BOD_5 gradient during ozonation, biofiltration and at the discharge point for a daily sampling with a specific ozone input of 0.15 kg O_3/kg COD_{inflow}.



Source: [110, N.Kaindl 2009]

Figure 6.40: Development of COD and BOD_5 concentration during ozonation and biofiltration

Due to the relatively low concentrations of biodegradable compounds following the partial oxidation (BOD_5 <50 mg/l), for the subsequent biotreatment only biofilm reactors are used, which give good results.

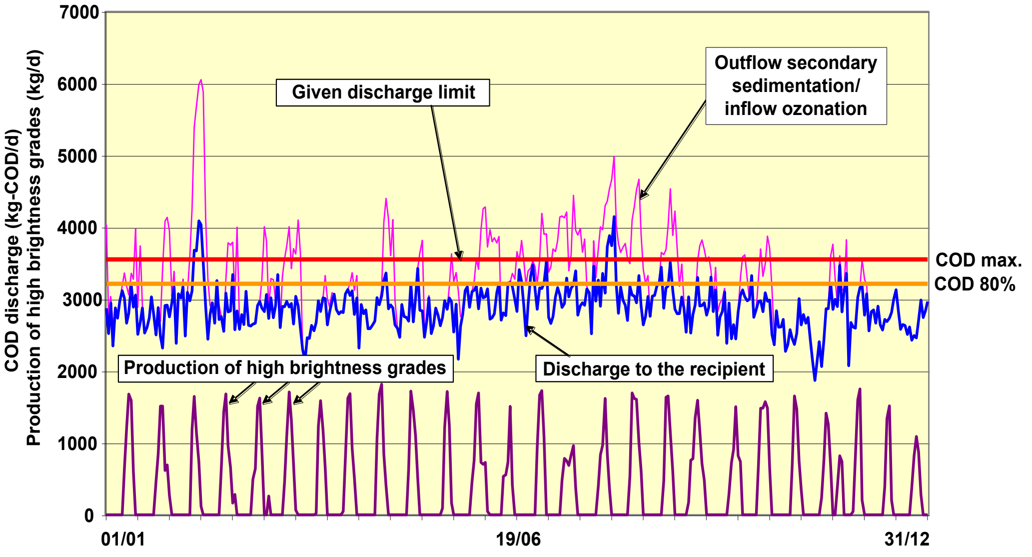
This type of advanced treatment is able to eliminate COD by 60 % (single stage) to up to 85 % (two stages), related to the waste water after biological treatment, with a specific ozone consumption of 0.4 – 1.0 kg/kg$COD_{eliminated}$. Operational costs of a plant like this will be EUR 0.3 – 0.4/m^3 of treated effluent (2009 data from Lang Ettringen paper mill, DE), depending on the type of waste water and the size and technical standard of the plant.

Apart from the enhanced COD removal, depending on the pretreatment and the O_3 dosing, ozonation may also reduce the colour of the effluent, the adsorbable organic compounds (AOX), the poorly biodegradable chelating agents such as DTPA and EDTA and the toxicity of the effluent (if it is still relevant). Ozonation can also be used for the disinfection of the treated waste water [117, Kaindl 2009].

Environmental performance and operational data
At the SCA Laakirchen paper mill, AT, the combination of ozonation and subsequent biofiltration is applied to meet the following objectives:

- enhanced COD reduction, which cannot be obtained by using conventional mechanical and biological treatment alone;
- controllability of the additional COD reduction and elimination of COD peaks which accompany special production situations (high brightness grades);
- reduction of operational costs by tailored dosing of ozone to COD peak loads in the biologically treated water and the combination of ozonation and subsequent biofiltration;
- decolourisation of waste water.

The higher residual COD peaks (up to 40 % higher) normally occur when the high brightness grades are manufactured (more intensive bleaching of groundwood pulp associated with more poorly biodegradable chemical additives, more NaOH, peroxide, chelating agents and more poorly degradable COD). The ozonation-biofiltration allows the treatment to be applied in such a way that the predictable peaks are eliminated (compensated) and the COD target values are met. By this means, the additional costs are reduced. Figure 6.41 shows the typical production and emission data over a complete year (2008) before and after ozonation-biofiltration. It shows that without ozonation the permitted limit values would not be met on many days of the year. The purple line at the bottom of the figure shows the production time intervals when the share of higher brightness grades is increased (more intensively bleached groundwood pulp). The manufacturing of higher brightness grades (73 – 80 ISO % instead of 67 – 68 ISO % for standard grades) is associated with higher initial COD loads (approximately 50 kg COD/t intensively bleached GWP instead of approximately 35 kg COD/t bleached standard GWP). The pink line at the top shows the daily COD load before entering the ozonation stage. The shape of this line basically follows the purple line. The blue line shows the daily COD load after ozonation-biofiltration. It shows that the adjustment of the treatment system allows for effectively meeting the COD emission targets (indicated as maximum allowed COD value and 80th percentile, see red and orange horizontal lines).



Source: [110, N.Kaindl 2009]

Figure 6.41: Typical production and emission data before and after ozonation and biofiltration

At the paper mill in Gmund, DE, ozonation is used as internal treatment. White water from the manufacturing of a large variety of coloured grades is recovered and the suspended solids are removed in a pressure disc filter. The coloured white water then enters an ozonation step where it is decoloured and subsequently sent to a storage tank. From there it is recirculated to the process and used for different purposes. Thus, water consumption has been reduced by 50 %.

Cross-media effects

With the exception of the small amount of biological excess sludge produced in the biofilters, polluting substances are really eliminated and not only separated. Therefore, this treatment does not generate a concentrate that requires further treatment, as is the case when membranes or evaporation are used.

Negative cross-media effects are the energy consumption for the ozone generator, which is in the range of 10 – 13 kWh/kg ozone, and a smaller amount of energy consumption for the production of pure oxygen. Furthermore, power is needed for the aeration pumps of the biofilter and its backwashing.

Based on the 2005 production (30 % high brightness grades) and cost data (for energy and oxygen), an example of the annual average energy consumption of this advanced treatment is given [117, Kaindl 2009].

Energy consumption related to COD$_{eliminated}$:
Biological treatment: 1.5 kWh/kg COD$_{\text{eliminated}}$
Ozone treatment: 20.8 kWh/kg COD$_{\text{eliminated}}$
Oxygen consumption for ozonation: 7.9 kg O_2/kg COD$_{\text{eliminated}}$.

Energy consumption related to gross paper production:
Biological treatment: 18.9 kWh/tonne of paper (gross)
Ozone treatment: 7.5 kWh /tonne of paper (gross)
Oxygen consumption for ozonation: 2.8 kg O_2/ tonne of paper (gross).

Technical considerations relevant to applicability
Principally, this treatment is applicable to all effluents where the residual COD levels are still too high to be discharged (see Figure 6.41). The ozone-treated water can then be either discharged or reused in the production process. At the Lang paper mill, DE, a similar concept to that used at Laakirchen is applied.

Decrease of the colour of the ozonated waste water results in better possibilities for reuse of the treated effluent in the paper mill. For the application of an ozone step for decolourisation and partial recirculation of the decoloured process water, an almost complete and stable fibre recovery before the ozonation is crucial. A partial rearrangement of the water system of the mill is associated with this application.

Economics
In comparison with other advanced treatment techniques such as flocculation/precipitation, ozone treatment provides an economically viable alternative under certain conditions. Ozone treatment can also achieve a more or less complete colour stripping at reasonable costs.

The investment costs in 2004 for the advanced treatment shown in Figure 6.41 were EUR 7.6 million (*Source*: Informationsfolder zur Kläranlage SCA-Laakirchen, 'High tech für eine saubere Traun').

The operational costs depend to a large extent on the targeted COD reduction. It is less informative to express the specific treatment costs per m^3 of treated effluent, as the ozone demand depends exclusively on the organic substance to be oxidised (e.g. COD load). It is therefore more meaningful to report operational costs related to the COD load eliminated. Based on the 2005 production (30 % high brightness grades) and cost data (for energy and oxygen) and the COD reduction described under 'Environmental performance and operational data', the following data on operational costs [110, N.Kaindl 2009] give an impression of the order of magnitude of the costs:

- biological COD reduction: EUR 0.27/kg COD$_{\text{eliminated}}$,
- COD elimination O_3 + biofilter: EUR 1.33/kg COD$_{\text{eliminated}}$,
- biological waste water treatment: approximately EUR 3.7/tonne of paper,
- ozonation + biofiltration: EUR 0.53/tonne of paper.

Although the costs for the elimination of COD by use of advanced treatment (ozonation and subsequent biofiltration) are considerably higher than those for conventional biological treatment only, it should be noted that the additional costs per tonne of paper are less significant as the readily biodegradable organic matter is already completely eliminated before the ozonation step. This allows the ozone dosage and the operational costs to be kept at a lower level. Thus, the ozone is effectively directed towards the poorly biodegradable organic substances.

Driving force for implementation
When the elimination of organic substances after two-stage biological treatment is not sufficient, ozonation with subsequent biofiltration is a stable and reliable option. Advanced effluent treatment is normally applied at mills that are located at sensitive or very small

receiving water bodies. It is also applied by mills which significantly increase their capacity and have no permit for increasing the load of effluent to the river accordingly. Advanced effluent treatment allows for compensating for higher organic loads caused by the manufacturing of higher brightness grades.

Example plants

SCA Laakirchen (ozonation for reduction of COD peak emissions), AT; Myllykoski Lang Papier Ettringen (ozonation for COD load reduction), DE; Papierfabrik Gmund (decolourisation of process water before discharge and partial recirculation), DE.

Reference literature

[110, N.Kaindl 2009], [111, Möbius 2009], [112, Kaindl 2006], [115, C.H.Möbius et al. 2004], [117, Kaindl 2009].

6.3.10 Examples of energy-saving techniques

There are multiple measures for energy savings in RCF paper mills. Three examples of energy-saving measures are described in this section. General measures for the reduction of thermal and electrical energy that are applicable not only to RCF paper mills but to (almost) all paper grades are given in Sections 2.9.5 and 2.9.6. For techniques that are mainly related to papermaking, the reader is referred to Section 7.3.15. The indicative energy consumption levels for RCF paper mills can be found in Table 6.25.

Table 6.25: Indicative energy consumption levels for heat and power for different types of paper for recycling mills

Type of RCF paper mill	Indicative energy consumption level for process heat (kWh/t)	Indicative energy consumption level for electricity (kWh/t)
RCF without deinking (packaging paper, e.g. Testliner and/or corrugated medium)	1 100 – 1 500	350 – 450
RCF without deinking (cardboard or folding boxboard (1), coated and uncoated)	1 200 – 1 600	400 – 500
RCF with deinking (graphic paper, e.g. newsprint (1)	1 000 – 1 800	900 – 1 300
RCF with deinking (folding boxboard) (1)	1 000 – 1 100	450 – 550
(1) The given figures refer to mills that do not produce mechanical pulp on site. Mechanical pulping requires significantly higher electrical energy than recycled fibre processing. For RCF paper mills that use relevant shares of on-site manufactured mechanical pulp as fibre furnish, the indicative energy consumption levels may be estimated case by case considering the pulping processes involved and their share.		

The following system boundaries were considered for the indicative energy consumption levels given in Table 6.25 above:

(1) The energy consumption levels refer to entire mills' net production and include pumps, agitators and compressed air. Peripheral subsystems for raw and waste water, sludge and rejects such as dissolved air flotation, reject screw presses or sludge presses, and waste water treatment are also covered.
(2) The ranges include all process units related to RCF processing and papermaking, starting with the feed conveyor and ending after the last slitter winder, i.e. before converting.
(3) The figures given for power consumption do not consider the primary energy input of fuels for the generation of power but represent process heat and power used. Electric infrared (IR) dryers are part of the power consumption.

(4) For heat, the consumption values refer to the thermal capacity of the steam used and the lower calorific value for gas in the case of IR or air dryers. Gas infrared dryers are included in the heat consumption.

6.3.10.1 High consistency pulping for disintegrating paper for recycling into separated fibre

Description

High consistency pulpers (HC pulpers) have specially designed agitators (e.g. slushing snail). For larger plants, pulping drums are often used. The slushing consistency for RCF grades usually ranges between 5 % and 7 %. An increase in the consistency of up to 20 % leads to a power reduction for pulping [Münster H., PTS Symposium Energy Management, Munich 2007]. The technique is explained here by the use of an example that also gives specific energy consumption data for the manufacturing of a RCF paper mill without deinking. The example mill shown in Figure 6.42 is located in southern Europe producing fluting papers on one paper machine.

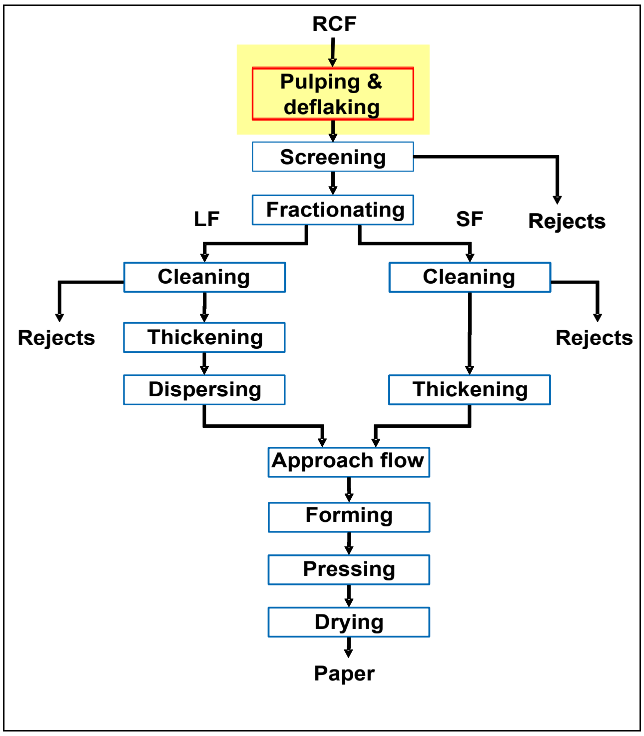


Figure 6.42: Process steps (subsystems) of the example RCF-processing mill without deinking

Achieved environmental benefits

Power savings due to a lower water content in the pulper and decreased agitation speed. The actual savings depend on the quality of the raw material used and the requirements of the pulp. Achieved savings range from 2 to 10 kWh/t slushed pulp.

Environmental performance and operational data

The total process energy consumption (heat and power) for the example mill is 1 600 kWh/t shippable paper. A breakdown at the level of the subsystems for this production is shown in Table 6.26 to give an indication of the energy consumption of the relevant subsystems. The values consist of summarised data derived from process examinations and estimations [249, Blum et al. 2007].

Table 6.26: Energy consumption for the RCF example mill without deinking

Energy-consuming processes	Net shippable production		Subsystem-related		Base of specific subsystem value
	Heat (kWh/t)	Power (kWh/t)	Heat (kWh/t)	Power (kWh/t)	
Pulping, deflaking		20		20	Pulp furnish
Screening		30		30	Pulp furnish
Cleaning		10		10	Pulp furnish
Thickening		10		10	Gross production
Dispersing	200	40	150	40	Gross production
Paper machine					
Approach flow		50		50	Gross production
Forming and web dewatering (including low vacuum)		50		45	Gross production
Pressing (including high vacuum)		70		70	Gross production
Paper drying (including hall ventilation)	1 000	50	900	50	Gross production
General mill services (WWTP, compressed air)		20		20	Net production
Total	**1 200**	**400**			
	1 600				

Cross-media effects

No significant effects.

Technical considerations relevant to applicability

Applicable for RCF grades with or without deinking. This technique requires a comprehensive conversion of the system and it is often implemented in the context of capacity enlargement of mills.

Economics

No data.

Driving force for implementation

Cost reduction due to power savings. An increase in production capacity is possible.

Example plants

There are numerous plants in Europe (including at least two in Germany).

Reference literature

[249, Blum et al. 2007], [Münster H., PTS Symposium Energy Management, Munich 2007].

6.3.10.2 Energy-saving screening techniques

Description

With screens, impurities and contaminants from paper for recycling are removed. Various screening concepts are applied in the RCF paper mills. With energy-saving screens, electrical power can be saved because the screens can be fed with higher consistency and more efficient screen baskets are used. The techniques are explained by the use of an example that also gives specific energy consumption data for the manufacturing of this paper grade. The example mill uses a hole screening with a subsequent multistage fine screening. The consistency could be increased from approximately 1.5 % to 2.5 %. The screens used have higher separation efficiencies. Therefore, the rotation speed could be decreased at the same production rate. The mill is located in Central Europe and produces newsprint papers on one paper machine. The process steps (subsystems) of the example RCF-processing mill with deinking are shown in Figure 6.43.

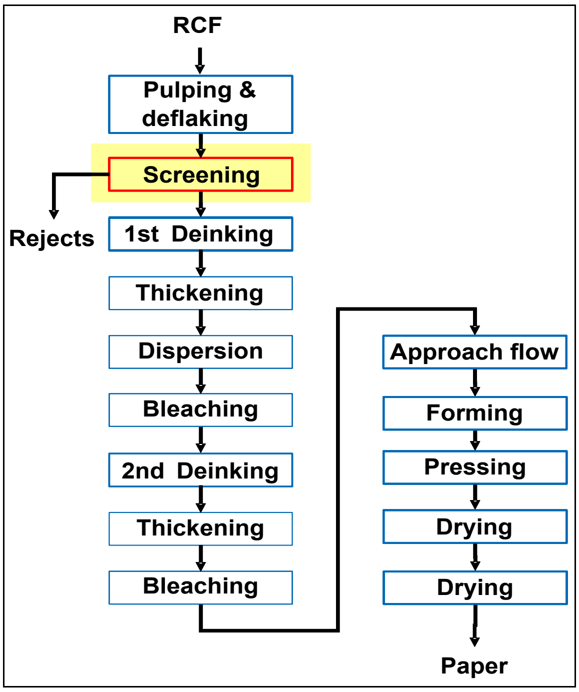


Figure 6.43: **Process steps (subsystems) of the example RCF-processing mill with deinking**

Achieved environmental benefits

Power savings due to a lower water content pulp system and reduced number of process steps. The actual savings depend on the quality of the raw material used and the requirements of the pulp. The achieved savings in the example mill were savings of electrical power of 18 kWh/t pulp.

Environmental performance and operational data

The total process energy consumption (heat and power) for the example mill is 2 200 kWh/t shippable paper. A breakdown at the level of the subsystems for this production is given in Table 6.27 to give an indication of the energy consumption of the relevant stages of the process. The values consist of summarised data deriving from process examinations and estimations [249, Blum et al. 2007].

Table 6.27: Energy consumption for the RCF example mill with deinking

Energy-consuming processes	Net shippable production		Subsystem-related		Base of specific subsystem value
	Heat (kWh/t)	Power (kWh/t)	Heat (kWh/t)	Power (kWh/t)	
Pulping, deflaking		50		40	RCF furnish
Screening		70		50	RCF furnish
Cleaning		30		20	RCF furnish
First deinking		70		50	RCF furnish
Thickening		10		10	RCF furnish
Dispersing	200	50	150	40	RCF furnish
First bleaching		40		30	RCF furnish
Second deinking		70		50	RCF furnish
Thickening		10		10	RCF furnish
Second bleaching		40		30	RCF furnish
Paper machine					
Approach flow		100		90	Gross production
Forming and web dewatering (including low vacuum)		60		50	Gross production
Pressing (including high vacuum)		150		130	Gross production
Paper drying (including hall ventilation)	1 100	60	1 000	50	Gross production
General mill services (WWTP, compressed air)		50		50	Net production
Total	**1 300**	**900**			
	2 200				

Cross-media effects
Positive impact on pulp quality can be achieved by a higher sticky removal capacity.

Technical considerations relevant to applicability
Applicable for RCF grades with or without deinking.

Economics
No information provided.

Driving force for implementation
Cost reduction by power savings and increase in production capacity.

Example plants
Some plants in Europe (including at least three in Germany).

Reference literature
[249, Blum et al. 2007].

6.3.10.3 Upgrade of stock preparation plants for decreased electricity consumption and emissions

The following description applies mainly for paper for recycling mills without deinking, e.g. paper mills producing case-making material (Testliner, Wellenstoff). However, the basic principles are valid for all mills processing paper for recycling. Deinking mills might have additional options in the deinking process units.

Description and achieved environmental benefits
There might be different aims for upgrading stock preparation plant concepts. They depend on the priorities set by a given company such as better removal of smaller impurities and

contaminants to improve the product quality and the efficiency of the paper machine, enhanced recovery of fibres from rejects thus reducing the fibre losses, or energy savings. Another aim can be simplification of the stock preparation system resulting in less energy consumption, less material loss, and less space being needed. In order to simplify the stock preparation, especially for brown grades, the possibilities for the removal of energy-consuming dispersion and traditional cleaning stages are discussed in this section. In contrast, extended process concepts with a higher number of process stages might be used to manufacture paper for special purposes or to meet the customer's needs (high-quality products).

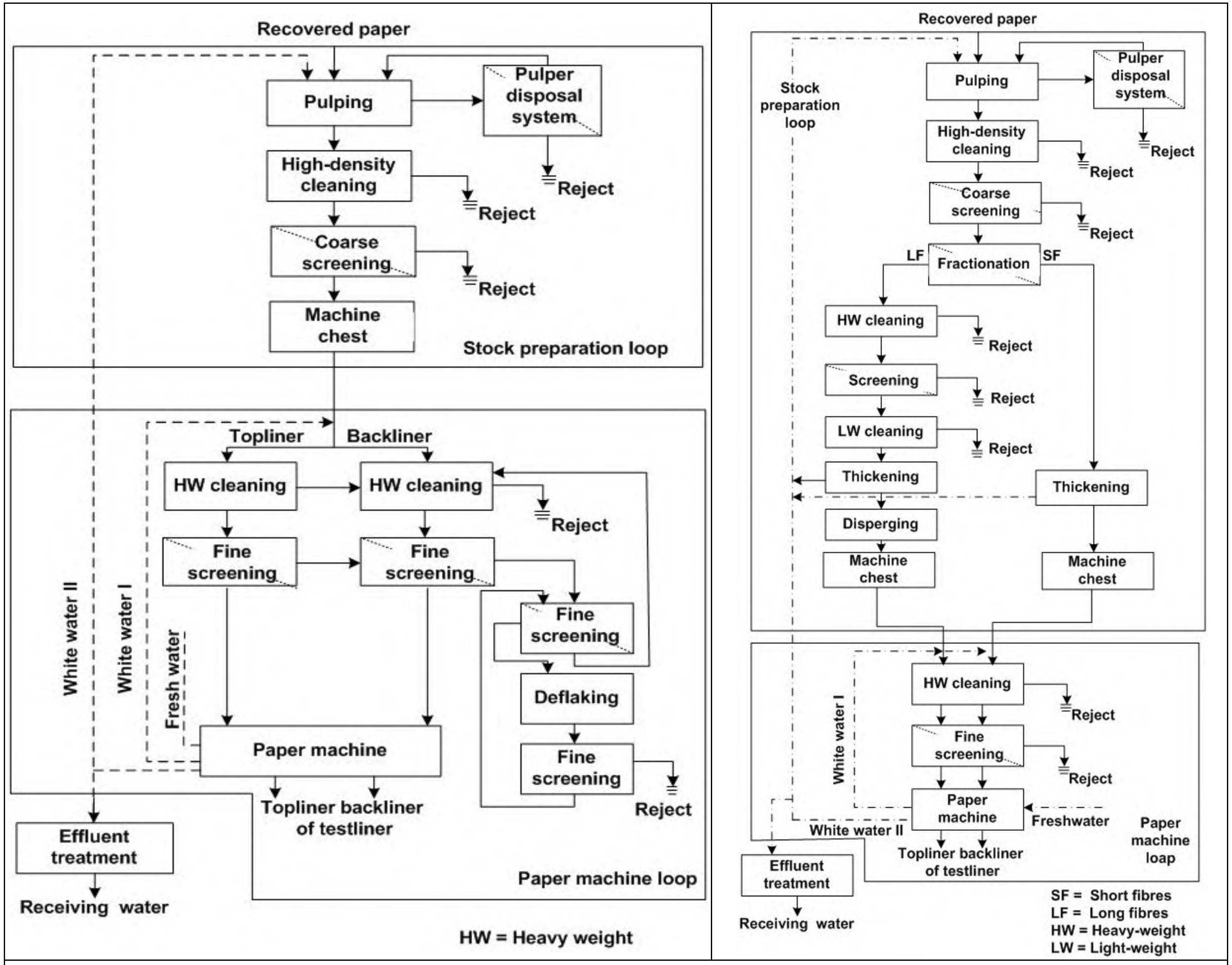
The processing of paper for recycling targets first of all the removal of non-fibre components (e.g. plastics, metal, wood, sand) and the elimination of detrimental substances such as stickies, wax or small pieces of undisintegrated paper (flakes) or wet strength paper. The second goal of pulp processing is the treatment of the fibres themselves to control the quality of the paper to be produced. To achieve this aim, fibres can be fractionated into long-fibre and short-fibre fractions and further treated. For example, low intensity refining improves the bonding ability of the recycled fibres, resulting in increased strength characteristics of the paper produced, and disperging improves the optical homogeneity of the paper.

For each specific treatment of recycled pulp, special machines are used in various ways. Thus, the screening and cleaning processes must operate in two to four stages in order to reduce the fibre losses in the final stage of each process. To realise an adequate runnability of the paper machine, it is also essential to operate additional cleaners and screens in the stock approach flow system. This prevents deposits released from chest walls or from pipes from entering the headbox and the wet end of the paper machine. These deposits would lead to web breaks and downtime of the machine.

A balance should be found between cleanliness of stock, fibre losses, energy requirements and costs, and depends to certain extent on the paper quality produced.

Below, some of the different technical options for stock preparation plant concepts are highlighted including their major advantages and drawbacks. Implications for the electricity demand are indicated.

Figure 6.44 shows two examples of stock preparation plant concepts for processing paper for recycling for two-ply Testliner (the reference presents four examples). This paper grade is used as an example because of its high importance in tonnage for paper and board mills in Europe and because information was easily available. Table 6.28 compiles for these two options the major characteristics, summarises the electricity demand, and gives some explanations concerning the layout of the stock preparation plant. The figures for electricity demand for the two different systems result from the values for specific energy demand for single process units as compiled in Table 6.28. They should be considered a realistic approximation. Real mills might have slightly lower or higher values.



Example 1 **Example 2**

Source: [69, IFP 1998]

Figure 6.44: Two examples of stock preparation plant concepts for processing paper for recycling for two-ply Testliner

Table 6.28: Major characteristics and electricity demand of two stock preparation plant concepts for processing paper for recycling for two-ply Testliner

	Major features of the different stock preparation plant concepts	Electric. demand range (average)	Explanatory notes
Example 1	Minimised cleaning and screening in the stock preparation plant without fractionation and without further fibre treatment like dispersion and additional cleaning and screening. The stock approach flow system is extended with respect to screening and cleaning in order to achieve sufficiently clean recovered pulp.	45 – 95 (70) kWh/t	Pulp is split without fractionation and is fed into two separate lines for separate cleaning and screening in both lines with different slot widths. The rejects of the topliner are introduced into the backliner for further treatment. In the backliner a deflaking process is established to disintegrate fibre flakes into individual fibres for the benefit of final screening efficiency and a reduced amount of rejects.
Example 2	Comprises fractionation and dispersion. After fractionation, screening and heavy- and light-weight cleaning of the long-fibre fraction are applied.	75 – 175 (120) kWh/t	Fractionation is carried out in order to save power of the following energy-intensive disperging by treating only a part of the recovered pulp stream (long-fibre fraction). Dispergers have to be fed with high consistency pulp (22 – 32 % dryness). Previously, dewatering (thickening) by means of, for example, a disc filter, belt press or screw press is necessary.
Source: [69, IFP 1998]			

Achieved environmental benefits

Enhanced recovery of fibres from rejects thus reducing fibre losses. Energy savings.

Environmental performance and operational data

The electricity demand for the stock preparation and stock approach flow system is between 20 % and 40 % of the total power demand of a mill processing paper for recycling without deinking. Therefore, the optimisation of the stock preparation plant with respect to the savings of electricity is worth considering. Reduced electricity consumption results in reduced airborne emissions, which depend further on the type of fossil fuel used.

The environmental advantage of Example 1 is related to the savings of electricity for the stock preparation and the stock approach flow system. A system installed in a German paper mill operates with an electrical power demand of 60 kWh/tonne paper produced. For comparison: the mean value of the electricity demand given in Table 6.29 results in a power demand between 45 kWh/tonne and 95 kWh/tonne (average 70 kWh/tonne) paper for the system shown as Example 1.

In comparison, with a concept where screening as well as light- and heavy-weight cleaning of the long-fibre fraction after fractionation is applied (Example 2: 75 – 175 kWh/tonne) the energy demand of Example 1 is significantly reduced.

Other, more 'extended' stock preparation plant concepts than Example 2 are also realised in Testliner mills. Their main positive effect on the environment is related to the high paper machine efficiency resulting from a very clean pulp with improved strength characteristics.

The electricity demand given in Table 6.28 results from figures for the specific energy demand of unit processes given in Table 6.29. As can be seen, the differences in electricity demand between the options discussed are significant: Example 2 requires between 75 kWh/tonne and 175 kWh/tonne compared to the 45 kWh/tonne to 95 kWh/t consumed by Example 1.

However, it should be borne in mind that the improved efficiency of the paper machine that is achieved by cleaner pulp results in lower specific electricity and steam demands for paper production, because during breaks the paper machine still uses electricity and steam. By contrast, techniques that are connected with the need for more frequent system washing (downtime) decrease energy efficiency and increase emissions.

Table 6.29: Specific energy demand and operating consistencies for unit processes in the production of Wellenstoff and Testliner

Unit process	Specific energy demand (kWh/tonne)	Operating consistency (%)
Pulping	10 – 20	3 – 6
Deflaking	20 – 60	3 – 6
Screening	5 – 20	0.5 – 4.0
Tail screening	20 – 40	1 – 4
Centrifugal cleaning	4 – 8	<0.5 ⇒ 4.5 (<6.0)
Fractionation	5 – 20	3 – 4
Thickening	1 – 10	0.5 ⇒ 5 (10)
Dewatering (Screw press)	10 – 15	2 – 5 ⇒ 15 – 50
Dewatering (Double wire press)	2 – 4	2 – 5 ⇒ 15 – 50
Disperging	30 – 80	22 – 32
Low-consistency refining	5 – 25 (per SR (1) unit)	3.0 – 5.5
High-consistency refining	10 – 60 (per SR (1) unit)	25 – 35
Washing	5 – 20	0.7 – 1.4 ⇒ 5 – 12
Dissolved air flotation (DAF)	10 – 20	<0.3 ⇒ 0.01
Storing	0.02 – 0.1	3.0 – 5.5 (12)
Mixing	0.2 – 0.5	3.5 – 4.5

NB: '⇒' = change of consistency; indicates range between inlet and outlet of the equipment concerned.
(1) SR = Schopper-Riegler freeness.
Source: [69, IFP 1998], data according to a machinery supplier, reference year: 1998; data refer to 100 % efficiency

Example 1 as shown in Figure 6.44 can be regarded as a 'minimised' stock preparation plant concept. It is running in one mill producing Testliner and Wellenstoff (RCF DE 6). With respect to the achievable paper machine efficiency and local limitations, this stock preparation plant concept should be regarded as an experiment. Because of limited experience, it is not yet possible to evaluate the success of this energy-saving concept. The system seems to result in slightly increased losses of fibres.

Screening in a conventional stock approach flow system protects predominantly against accidental contamination with low demands for maintenance. The maintenance required in the conventional stock preparation does not necessarily contribute to a paper machine shutdown because of the pulp storage capacity in available chests. By contrast, if finely slotted screen baskets (with a slot width of 0.15 mm) are applied in the approach flow system in order to achieve sufficiently clean recovered pulp (as in Example 1) those screens require more extensive maintenance for cleaning. This results in a shutdown of the paper machine and lost production. Therefore, the paper machine efficiency with the 'minimised' stock preparation is normally poorer than that of a well-equipped 'standard' stock preparation plant.

Worldwide a large number of mills are producing Testliner with fractionation and dispersion. Sometimes refining is also included in the stock preparation plant.

Cross-media effects

Paper machines running with increased efficiency have lower electricity and steam demands per tonne of paper. The improved recycled fibre quality results in an improved paper quality.

The rejects from different process stages can be collected separately and used for different purposes. For example, rejects containing high amounts of plastics can be incinerated with the benefit of considerable energy recovery, due to their high heating values (see Section 6.3.14). Rejects with high amounts of organic fibre material can be used for composting. The rejects of the high-density cleaner as well as of the pulper disposal system are usually disposed of by landfilling because of their high inorganic material content (e.g. stones, sands, staples, clips).

Technical considerations relevant to applicability
Rebuilds of stock preparation plants as well as of the stock approach flow system can usually be realised in existing mills.

A 'standard' stock preparation plant typically uses more machines than are required for the 'minimised stock' concept, the shutdown of only a part of the equipment is necessary and some new pipes and pumps for the connection to the machine chest are probably required. The stock approach flow system has to be extended. Existing screens from the stock approach flow system or from the stock preparation plant are usually not sufficient, due to the limited capacity when screen baskets with a narrow slot width of 0.15 mm are installed. Therefore, investments in advanced pressurised screens for the approach flow system would be necessary.

Economics
The investment and the operational costs of Example 2 are higher compared to those of Example 1 shown in Figure 6.44. However, the increase in costs for the operation of the stock preparation plant always has to be evaluated in light of improved paper machine efficiency. A lower number of shutdowns and web breaks as well as improved paper quality are also important factors.

Besides the higher investment for the equipment of stock preparation concepts with a higher number of process stages, increasing operational costs in terms of the electricity demand for stock preparation have to be expected.

'Minimised' stock preparation concepts (as in Example 1) require relatively low investment. Low electricity also reduces operational costs.

Driving force for implementation
The principal driving force for implementing stock preparation plant concepts with a higher number of process stages is the high quality requirements of the paper to be matched, which has to compete on the market with paper manufactured from virgin fibre. A further incentive is that paper machine runnability should be improved. The driving forces to implement stock preparation plant concepts with 'minimised' process stages are lower investment and operating costs, mainly saving in electrical power as a result of the fewer machines required.

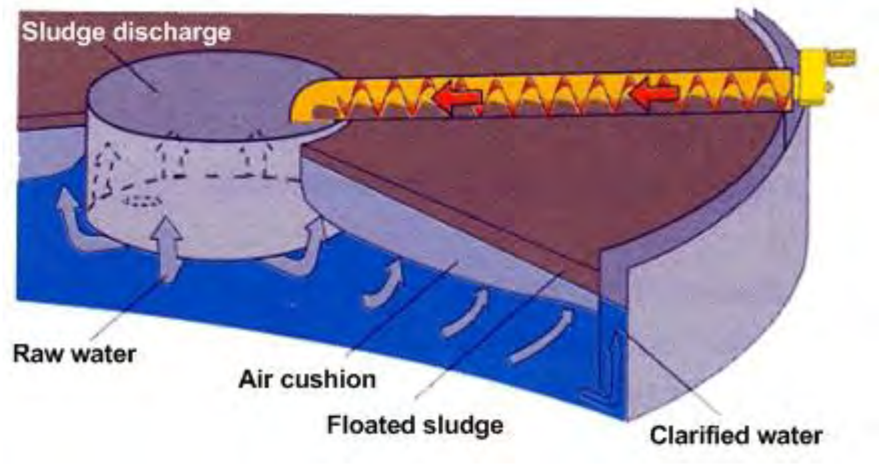
Example plants
Several mills in Europe are equipped with a stock preparation system similar to Example 2 including fractionation and dispersion. However, the equipment installed and the number of process stages vary and no exactly identical system appears to exist. Some mills have also implemented dissolved air flotation for process water treatment.

Reference literature
[69, IFP 1998]: This report contains many other references.

6.3.11 Clarification of white water

Description and achieved environmental benefits
The recycling of larger amounts of white water in paper recycling plants with deinking is only possible if there is a system for the clarification of white water. The systems for water clarification used almost exclusively in the paper industry are based on sedimentation, filtration (disc filter) and flotation. The best available technique at the time of writing (2013) is dissolved air flotation. Anionic trash and fines are agglomerated into physically treatable flocs by using additives. High-molecular, water-soluble polymers or inorganic electrolytes are used as flocculants. The generated agglomerates (flocs) are then floated off in the clarification basin. In dissolved air flotation (DAF), the suspended solid material is attached to air bubbles. These bubbles transport the material to the surface of a circular or rectangular basin where it is scraped

off and fed to sludge dewatering and incineration. The clarified white water is taken out from the bottom (see Figure 6.45).



Source: [125, Schwarz et al. 1995]

Figure 6.45: Operating principle of dissolved air flotation (DAF)

In a flotation system with a circular basin, the air bubbles are generated by mixing air into the circulation water at high pressure. When the pressure is reduced at the inlet of the basin, microscopic air bubbles are formed. The size of the bubbles is critical. Flocculation agents are usually added to the white water ahead of the flotation to improve separation.

The advantage of flotation is that, besides the removal of suspended material, small-size colloidal material can also be removed if appropriate DAF chemistry is applied. This is a great advantage in the paper recycling plants with deinking, where a large part of the solid material in the process water is colloid. In deinking systems, flotation is, at the time of writing (2013), the only way to purify the process water for recycling. In a deinking plant, the material is pumped to the sludge dewatering instead of being recycled in the process as in paper mills using virgin fibres.

The flotation systems generally give very pure water, but the efficiency is dependent on several factors, which have to be monitored and controlled, e.g. pH, volume flow, air bubble size and consistency flow. However, at optimum conditions the efficiency is very high. Another advantage of flotation is that the saturation of air (oxygen) in the process water creates less favourable conditions for the forming of anaerobic bacteria.

Environmental performance and operational data

By use of DAF at a suitable position in the water loops, the degree of water loop closure can be continuously adjusted to the requirement of the process water quality depending on the concentration of anionic trash, additive consumption and product quality requirements.

Cross-media effects

Chemicals are needed as flocculants. Electricity is required mainly as pumping energy to saturate part of the untreated water, or a corresponding amount of clarified water, with air after raising the pressure to 7 bar. Floated sludge which has to be dewatered is generated. The calorimetric value of the dewatered or dried sludge can be utilised for steam production in incinerators.

Technical considerations relevant to applicability

The measure can be adopted in new and existing recycled fibre mills. The upgrading of the water clarification system is often combined with rearrangements of the water loop systems. All components can be combined on a modular basis for optimal results for different applications.

Economics
No data available.

Driving force for implementation
The driving force for upgrading the water clarification systems with dissolved air flotation in deinking plants is that it allows optimal water management and adjustment of water loop closure as required (see Figure 6.3 and Figure 6.4).

Example plants
Numerous plants in Europe.

Reference literature
[14, CEPI 1997], [74, Pöyry 1994], [125, Schwarz et al. 1995].

6.3.12 Prevention and elimination of biofilms by using methods that minimise emissions of biocides

Description
A continuous input of microorganisms by water, fibres, air and paper additives leads to a specific microbiological equilibrium for each paper plant. One of the major problems is the forming of biodeposits also called biofilms. To prevent extensive growth of the microorganisms, various chemical additives are used in paper mills: biodispersants, oxidising and non-oxidising biocides. In recent years, a technique was introduced into the paper industry to eliminate biofilms and free germs in process water and paper slurry. The components of this technology are:

- a catalyst, which is a metallic catalyst in the form of knitting wire with a special surface;
- a 30 % solution of stabilised hydrogen peroxide;
- a dosing station.

In process water or slurry, the hydrogen peroxide solution is adsorbed and activated at the catalyst surface by an electron transfer from the catalyst to the hydrogen peroxide. As a result, the catalyst is positively charged. Free germs have a negative charge. For this reason, free germs are attracted to the catalyst. At the catalyst surface, the germs react with adsorbed hydrogen peroxide to form biotensides and water. Furthermore, adsorbed germs return the electrons to the catalyst, and are eliminated in the process. The formed biotensides remove the biolayers/biofilms from surfaces. The removed biolayers are biologically inert. The hydrogen peroxide is dosed sometimes per day and sometimes per week. The H_2O_2 concentration after dosing is between 10 g/m^3 and 100 g/m^3 water or slurry.

Achieved environmental benefits
- The 30 % solution of stabilised hydrogen peroxide is considerably less dangerous than other biocides as far as transportation, storage and application are concerned.
- No toxic products will be formed.
- The hydrogen peroxide reacts to form water and biotensides. The biotensides do not cause any undesirable side effects on human health or the environment.
- As a result of biofilm elimination, the formation of hydrogen sulphide and organic acids as well as the microbial-induced corrosion are stopped.

Environmental performance and operational data
The technology has positive effects, preventing pollution of all media. The 30 % solution of stabilised hydrogen peroxide reacts to formwater and biotensides without any other by-products. The biotensides are adsorbed in removed biolayers. The catalyst does not lose any metal cations into water. Its lifetime is at least five years. Any water treated by this technology is not dangerous for biological systems like waste water treatment plants or receiving waters.

The experiences of three German paper mills that use the solid surface catalysis with hydrogen peroxide for biofilm elimination is given in Table 6.30. The three mills use paper for recycling (sorted mixed paper and board) and have totally closed process water systems. The catalysts are installed in the white water circuit. The hydrogen peroxide must be dosed near the catalyst surface. It is necessary to control the hydrogen peroxide concentration in the receptacle.

Table 6.30: Application of catalytical disinfection with hydrogen peroxide in paper mills

Paper mills	**RCF DE 6**	**Vreden GmbH**	**RCF DE 7**
Paper quality	Cardboard	Raw paper for corrugating board	Raw paper for corrugated board
Paper output	12 500 t/year	75 000 t/year	60 000 t/year
Water volume (m^3)	700	1 000	No declaration
COD in the water circuits (mg/l)	25 000	40 000	25 000
Fresh water consumption (m^3/h)	3 – 4	12.5	No declaration
Waste water	Zero effluent	Zero effluent	Zero effluent
Catalyst	4 pieces of metallic catalyst in the form of knitting wire	10 pieces of metallic catalyst in the form of knitting wire	3 pieces of metallic catalyst in the form of knitting wire
Dosing station	Yes	Yes	Yes
H_2O_2 solution (30%) in the first six months	140 l/week	140 l/week	140 l/week
H_2O_2 solution (30%) after the first six months	28 l/week	21 l/week	-

Cross-media effects
No information provided.

Technical considerations relevant to applicability
The technique is applicable for the treatment of fresh water, cooling water and process water in new or existing paper mills.

Economics
For a paper production of 10 000 t/year, the annual costs (write-off and operation) for the application of the complete catalytic disinfection with hydrogen peroxide are between EUR 5 000 and EUR 10 000 per year. When the technology is used in an existing paper mill the consumption of hydrogen peroxide is considerably higher in the first year of operation than in subsequent years.

Driving force for implementation
When the technique is implemented, the use of other traditional biocides is not necessary. In this case, it is possible to reduce the consumption of retention aids and flocculants. The formation of toxic gases, especially hydrogen sulphide, is prevented.

Example plants
About 10 mills in Germany, the Netherlands and Austria are using catalytical disinfection with hydrogen peroxide thus substituting other traditional biocides.

Reference literature
[187, Bussmann et al. 2008]

6.3.13 Effective reject and sludge handling and processing (dewatering) on site

Description and achieved environmental benefits
In the processing of paper for recycling, the removal of impurities (mainly non-paper components) from the pulp slurry is one of the most important process steps. Impurities are removed by multistage cleaning and screening at various places in the stock preparation. The rejects generated can be subdivided into heavy-weight, coarse rejects and light-weight, fine rejects. Also, sludge (fibrous and biosludge) is generated and has to be handled.

Usually these rejects and sludge have no material recycling potential and are incinerated with energy recovery or disposed of by landfilling. In many countries, landfilling with rejects and residuals when the organic matter exceeds 5 % has been prohibited since 2005. Therefore, rejects, sludge and residuals are increasingly ending up at incineration plants, on or off site.

Regardless of the reuse or final disposal, dewatering of the rejects is an essential stage of waste handling. All commonly applied methods for energy recovery and disposal benefit from a high DS content of the rejects. Today, the ragger as well as the rejects from pulper disposal systems are mostly not subject to any special dewatering. Due to their material composition, 'draining off' results in a dry content of 60 – 80 %. For dewatering heavy and coarse rejects produced by high-density cleaning and prescreening, screen spiral conveyors, vibrating screens, screw and rake classifiers are used. DS contents of 60 – 80 % are achievable. The dewatering of light and fine rejects from forward cleaning and fine screening using screens, endless wires or vibrating screens is usually followed by a further dewatering by means of screw presses. The achievable DS content is in the range of 50 – 65 %.

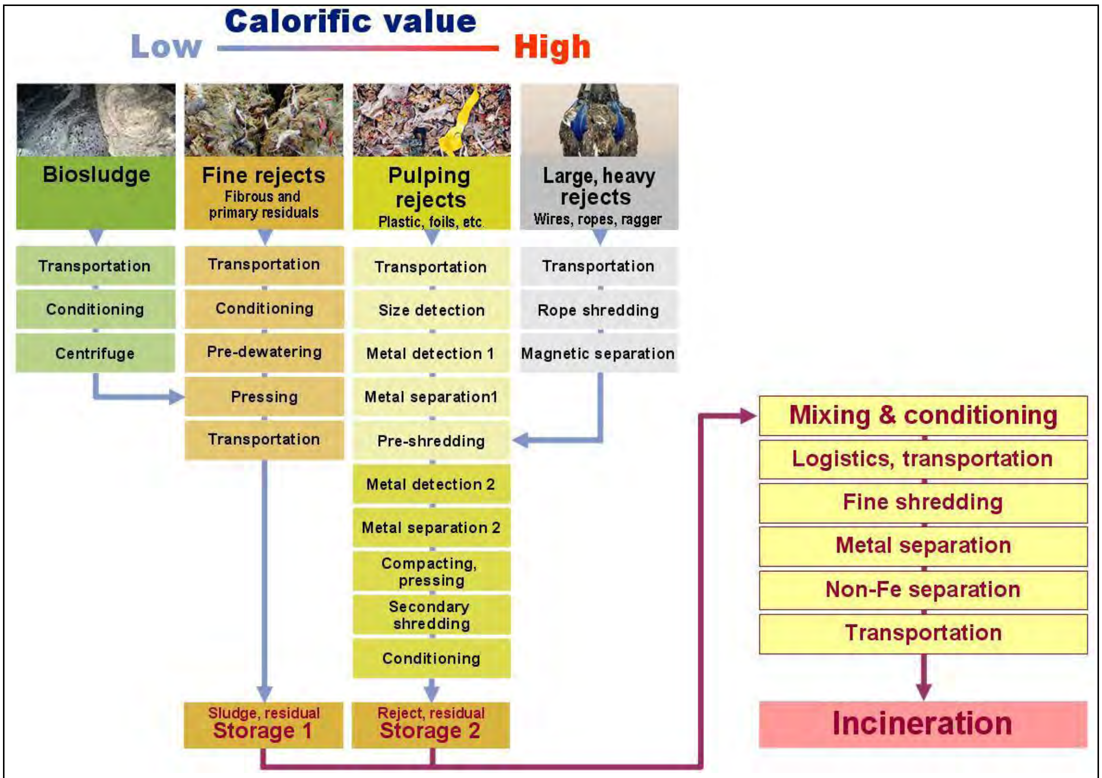
The excess sludge generated in biological waste water treatment plants in many paper mills producing Wellenstoff and Testliner is sometimes reused in paper production. As this biosludge is only a small volume, it can be used as a raw material for paper production without affecting the runnability of the paper machine and the paper characteristics. In this case dewatering facilities are not necessary. Other RCF-based mills manufacturing packaging paper that comes into contact with food do not send back the excess sludge to the production process (pulper or mixing chest). In this case, this sludge must also be handled and dewatered.

RCF paper mills with deinking always have to dewater the rejects and sludge (fibre sludge, deinking sludge, biosludge).

Environmental performance and operational data
To obtain a high dewatering efficiency, screw presses have become more and more common.

If the 'waste to energy' concept is applied at the mill, the preparation of rejects and sludge for fuel production (metal separation, separation of residues according to calorific values, shredding, pressing) is beneficial and often a prerequisite in order to run the process efficiently and to obtain a defined material to be burnt with a high calorific value and low levels of disturbing or contaminating substances. Rejects and other residues from production are thus prepared as alternative fuel and can be incinerated in special incinerators to generate energy.

An example of the generic process steps for separation and preparation of rejects and sludge into the two main composition groups for brown papers is shown in Figure 6.46. A similar system has recently been built in two large RCF-based mills in Germany that manufacture Testliner and corrugated medium [147, J.Sommer et al. 2009]. The design of each reject and sludge handling and processing system, the number of process steps, and their combination have to be determined specifically for each mill. Smaller mills may apply a considerably simpler approach.



Source: [148, Voith 2009]

Figure 6.46: Example of the generic process steps of an effective reject and sludge handling concept for a brown paper RCF mill

In Figure 6.46, it is indicated that the pulper rejects (plastics, etc.) have higher calorific values and fine rejects/sludge clearly have lower calorific values. The separation into two composition groups can be beneficial since the conditioning of fine rejects/sludge is simple but the preparation of pulper rejects requires multiple steps and special techniques to prepare it for use as alternative fuel. The latest techniques also allow for pulper ropes to be prepared for incineration.

After the rejects and sludge have been pretreated and are available in two compositions, they can be stored separately. The storage and handling system is more important if additional residues or fuels from other locations will be incinerated together. The boiler can then be fed with a specific mixture of the different compositions in order to allow continuous control and adjustment of the calorific value feeding the incineration process.

For DIP, the paper for recycling qualities used, the processes and arrangement of water loops, the removal of ash and other contaminants (e.g. micro-stickies) and consequently the reject handling system for effective preparation and treatment of rejects and residuals for utilisation, recovery or final disposal are different. The sludge and reject handling systems may however include similar building blocks to those described in Figure 6.46.

Cross-media effects

Reject and sludge dewatering results in an increased volume of water to be treated. The water squeezed out is normally sent to the waste water treatment plant. Dewatering is generally only performed by mechanical forces. The pollution of squeezed out water is equal to that of water attached to the rejects and sludge. When using screw presses, one has the possibility to heat the rejects by injecting steam, which affects the pollution of squeezed out water. This must be considered especially in cases where the waste water treatment plant has already approached its maximum capacity. Injecting steam requires thermal energy.

When the rejects and sludge are incinerated in power plants or in cement kilns, the energy demand for the evaporation of water in rejects and sludge decreases when higher dry solids contents are achieved by mechanical dewatering. This contributes to a higher energy recovery rate.

Technical considerations relevant to applicability

Reject and sludge dewatering facilities are common in new and existing paper mills. Retrofitting dewatering systems to run more effective equipment is possible.

Integrated concepts for reject, sludge, residue handling and treatment include the determination of the actual reject quantity and quality and the discharge points. The alternative recycling, recovery and disposal routes are assessed including machine concepts, logistics, costs and possible incineration.

Daily production output and the corresponding amount of rejects and sludge will determine the most appropriate disposal route. For smaller disposal quantities (e.g. up to 15 t/day), pressing or compacting with the highest possible dryness is often the most attractive alternative. Compacting with the latest techniques will enable the mill to reach a reject dryness content of 65 – 70 %.

For disposal quantities of up to 40 t/day, it may be useful to consider an additional drying process after compacting (see Section 2.9.6.1.4). For the drying process, appropriate pretreatment is necessary: metal separation, compacting, and multiple stages of shredding. By using the excess heat from the paper machine area or other waste heat sources, no additional energy input is required for drying. With excess paper machine heat, final dryness values of 90 % can be achieved. The 90 % dryness enables longer temporary storage of the residues without odour problems and offers advantages in logistics.

With large reject and sludge quantities of over 60 t/day, on-site incineration, e.g. in appropriate fluidised bed boilers that produce steam and power, can also be a feasible option.

Economics

No information provided.

Driving force for implementation

The driving force to implement effective reject and sludge dewatering and conditioning processes is the reduction of the waste volume to be handled. Since co-incineration with energy recovery has become a feasible and often preferred treatment option, effective dewatering and preparation of the alternative fuel is crucial for energy efficiency. This also applies to external co-incineration, e.g. in cement plants.

Example plants

Numerous plants in Europe. Very few plants use dryers for drying sludge and rejects before further treatment.

Reference literature

[8, Borschke et al. 1997], [69, IFP 1998], [81, Krieger 1998], [147, J.Sommer et al. 2009], [148, Voith 2009].

6.3.14 Environmentally sound residue utilisation and energy recovery

Description

For general aspects of waste management and options for material recycling and energy recovery in paper mills, refer also to Section 2.9.8.

In paper mills processing paper for recycling without deinking (e.g. Testliner, Wellenstoff, cartonboard or folding boxboard) coarse impurities from the pulper disposal system, rejects from various screening and cleaning stages from the stock preparation plant, and sludge from waste water treatment are the major waste fractions. The amount of rejects generated is from 4 % to over 10 % of the input raw material depending on the raw material source and its quality. Rejects from the stock preparation plant of brown packaging papers without deinking only have a limited material recycling potential because they consist of an undefined mixture of non-paper components that are removed from the paper for recycling.

Only for rejects from the final cleaning and screening stages of the paper machine loop is there a possibility for material recycling because they have a low content of plastics and other impurities. Therefore, in some mills this waste fraction is collected and dewatered separately and used as a co-substrate for composting. The practice of composting varies significantly between Member States. While in some countries the composting of sludge from RCF paper mills is encouraged, there are others (e.g. Germany) who discourage or ban the composting of waste from paper production.

RCF paper mills with deinking additionally produce high amounts of deinking sludge and sludge from process water clarification. The generated rejects and sludge amount to about 15 – 40 %, related to the input of raw material. In DIP plants, the deinking sludge, containing mainly short fibres, coatings, fillers and ink particles, is the crucial waste fraction to be handled. Alternatives include incineration, land reclamation, animal bedding, cement kilns, brick manufacturing and the manufacturing of other products. In a few countries, land spreading in agriculture or composting is practised whereas in other countries this option is discouraged or banned. In larger DIP plants, deinking sludge together with the sludge from waste water treatment can be incinerated. Different options exist for energy recovery of the various rejects and sludge and are given below.

- Incineration in an in-mill reject incineration plant (see Example 1 and Example 3 further below. Example 1 applies for Testliner and Wellenstoff, whereas Example 3 describes the incineration of rejects and deinking sludge from DIP plants).
- Co-incineration in an in-mill coal-fired power plant (see Example 2 further below)
- Co-incineration in the cement or brick industry. Rejects can be used as a substitute fuel in the cement industry replacing fossil fuels. Useful information can be found in the Reference Document on the Best Available Techniques in the Cement, Lime and Magnesium Oxide Manufacturing Industries [272, COM 2013]. Since waste incineration in general is not covered in this document, useful information regarding waste incineration can be found in the Reference Document on the Best Available Techniques for Waste Incineration [273, COM 2006]. Furthermore, the requirements of existing European and national regulations have to be considered, e.g. when co-incinerating waste, the requirements of the Waste Incineration Directive (WID) have to be met [203, Directive 2000/76/EC 2000].

To obtain a high surface area and good ignition behaviour, a pretreatment of the rejects is necessary. This comprises mainly primary crushing, screening and secondary crushing. Shredding and screening can be combined, e.g. with a magnetic separator and air separation, in order to recover ferrous metals and to remove impurities that could damage the post-crushing aggregates. Usually, in smaller mills, the pretreatment of rejects and sludge consists mainly of dewatering equipment. In larger mills, a more complete pretreatment and handling is often applied (see Section 6.3.13).

Reject utilisation techniques differ from paper mill to paper mill, mostly depending on local conditions. The ban on the landfilling of unprocessed waste with an organic content of more than 5 % DS in many EU Member States has promoted the development and start-up of a number of incineration plants. After suitable pretreatment, most waste fractions from RCF-based paper mills can meet the requirements for environmentally compatible energy recovery in incinerators. Recovery operations are considered the preferred waste treatment option. Possibilities to reduce the amount of waste to be landfilled should be identified and put into practice, where feasible.

Incineration combined with power and steam generation is regarded as an environmentally sound solution. Different technical options (pretreatment, boilers, abatement techniques) for the incineration of residues with energy recovery are realised in European paper mills. Four of them are described below.

The example includes: the combustion of rejects from RCF mills without deinking in an in-mill grate-fired incineration plant and flue-gas cleaning system (Example 1). Co-incineration of rejects in a retrofitted on-site coal-fired travelling grate combustion chamber and associated flue-gas treatment (Example 2) is another option. As in the case of Example 1, this grate-fired boiler is rather an example for retrofitting existing on-site boilers. Almost all more recent incinerators have been built as bubbled fluidised bed boilers. Example 3, the incineration of rejects and sludge from a DIP plant in a fluidised bed boiler is a more widely used option in European paper mills. Feasible options for smaller mills are also available (Example 4).

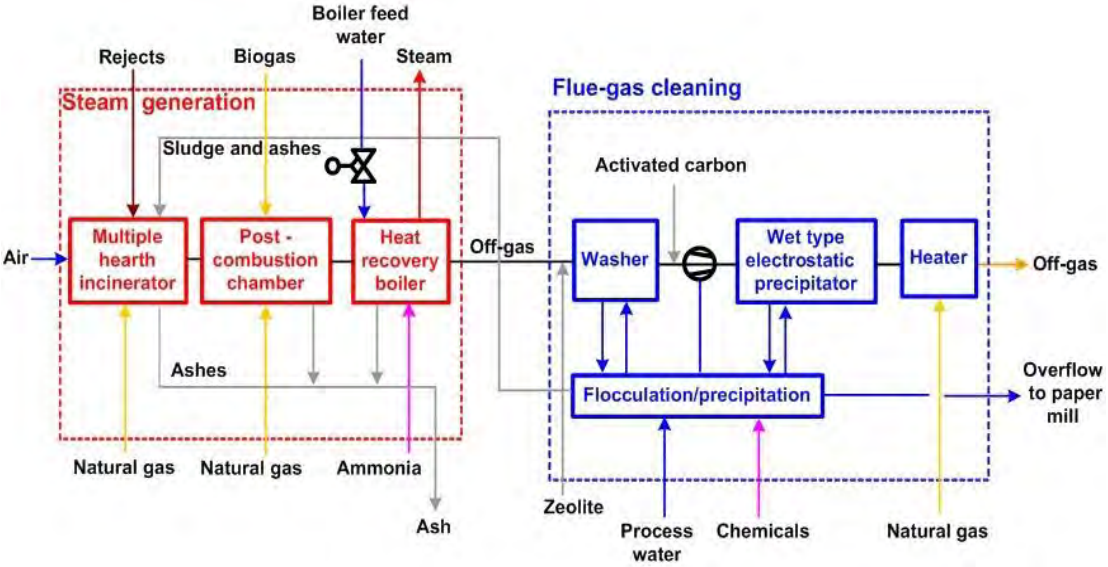
Example 1: Energetic utilisation of rejects from RCF mills without deinking in reject incineration plants

The description of this technique refers to 'brown packaging papers' manufactured from paper for recycling. However, similar systems are applicable for other mills processing paper for recycling (see Example 3).

Description and achieved environmental benefits

Before the entry into force of the recent legislation on landfilling that sets targets and limits on the amount of biodegradable waste that is allowed to be disposed in landfills, rejects from recycled paper processing in paper mills producing Wellenstoff and Testliner were disposed of by landfilling. Assuming that rejects account for a proportion of around 5 – 10 % of the paper for recycling input (depending on the quality of paper used for recycling), in many paper mills the volume of the separated rejects was not sufficient to operate a reject incineration plant economically. However, adapted combustion units are also available for smaller mills (see Example 4). Larger paper mills with a high production capacity have increasingly built stand-alone incineration plants for rejects from the processing of paper for recycling. A German paper mill (370 000 t/year), SCA Aschaffenburg, has operated an incineration plant with a good environmental performance since the early 1990s. A few other paper for recycling-based paper mills followed (SCA Witzenhausen, Klingele Papierwerke, Palm Wörth, Laipa Schwedt, Jass Schwarza). The more recent incinerators have been exclusively built as bubbled fluidised bed boilers.

The incineration plant employs multiple-hearth combustion and is integrated in the power plant of the mill. It is designed for a reject volume of 28 000 tonnes of rejects per year. The water content of the rejects is in the range of 45 – 50 %. After shredding and magnetic separation of ferrous material, rejects are fed onto the top hearth, where drying is carried out by upwards-directed hot flue-gases. The transport of the rejects to the next hearths is done with the aid of agitators. They transport the rejects through all burning zones, from top to bottom. Flue-gas from the furnace top is recycled into the combustion hearths and is reheated there. At 800 – 900 °C, the flue-gas from the combustion hearths is completely burnt. A separate combustion chamber is therefore unnecessary and the rejects are burnt economically. A post-combustion chamber prolongs the retention time of the flue-gas in the temperature zone of >850 °C. The chamber is equipped with a burner that is activated automatically when the temperature falls below a minimum value. Figure 6.47 shows a simplified scheme for the incineration of rejects in this incinerator.



Source: [227, SCA Aschaffenburg 2009]

Figure 6.47: Simplified scheme for the incineration of rejects in a multiple-hearth incinerator

The flue-gas purification unit is equipped with a two-stage wet scrubber (NaOH) for the removal of acidic pollutants, mainly sulphur dioxide and hydrogen chloride. The liquid from the wet scrubbing process is neutralised and treated with precipitation and flocculation agents to remove heavy metals. The sludge is mixed and burnt together with the rejects. The ash generated from the multiple-hearth incinerator is disposed of in a landfill. For minimising dioxin emissions, a mixture of activated carbon (around 17 t/yr) and zeolite (around 30 t/yr) is injected into the recycled flue-gas stream. The used adsorbents are also returned to the incinerator. Reduction of NO_X emissions is achieved by selective non-catalytic reduction (SNCR) using ammonia, which is injected into the combustion chamber. The dosage of ammonia is adjusted so that 160 mg NO_X/Nm^3 is achieved (the limit value is 200 mg NO_X/Nm^3). Solid particle emission is reduced by a wet electrostatic precipitator. After the flue-gas treatment, an additional burner is installed to maintain the stack exhaust temperature.

Environmental performance and operational data

Emission data of the reject incineration plant are summarised in Table 6.31. The values shown are average figures for the year 2008 for the continuously measured parameters dust, SO_2, NO_X and CO, and for all of the other parameters the results are from individual sample analyses that are carried out once a year.

Table 6.31: Emission data of reject incineration in a multiple-hearth combustion plant compared to German legal standards

Parameter	Unit	Measured yearly average value (calculated from daily means)	Measured daily average values (min.-max.)	Limit values (according to German standards)*
Solid particles	mg/Nm^3	1.2	0 – 10.8	10.0
SO_2	mg/Nm^3	4.4	0 – 20.7	50.0
NO_X	mg/Nm^3	150.7	62.0 – 177.3	200
CO	mg/Nm^3	9.2	6.3 – 14.1	50.0
HCl	mg/Nm^3	<0.4(1)	<0.4	10.0
HF	mg/Nm^3	-	-	1.0
Total-C	mg/Nm^3	5.4(2)	2.0 – 6.1	10.0
Cd, TI	$\mu g/Nm^3$	5(2)	2 – 7	50.0
Hg	$\mu g/Nm^3$	<1(2)	<1	50.0
Sum of Sb, Cr, CN, F, Mn, V, Sn	$\mu g/Nm^3$	64(2)	14 – 75	500
Sum of As, Cd, Co, benzopyrene, Cr	$\mu g/Nm^3$	8(2)	5 – 10	50
Dioxins/Furans	ng I-TE/Nm^3	0.037(2)	0.026 – 0.085	0.1

NB:
(1) According to the Seventeenth Ordinance on the Implementation of the Federal Immission Control Act (Ordinance on Incinerators for Waste and similar Combustible Material), of 14 August 2003, values refer to standard temperature and pressure (0 °C, 1 bar, dry) and to an oxygen content of 11 % per volume.
(2) Periodically measured parameters (once per year). Values from March 2009 measurement.
Source: [227, SCA Aschaffenburg 2009]

The operational efficiency of the incineration plant is satisfactory. Maintenance and inspection did not exceed the expected periods of time.

Cross-media effects

Incineration of rejects saves landfill capacities. The resulting ashes (3.13 kg ash/ADt net or around 1 000 t ashes in 2008) are suitable for reuse, e.g. for use in road construction. Fossil fuels for energy generation can be substituted, in this case around 66 000 MWh. The heat recovery steam generator of the reject incineration plant has a design capacity of 8.4 MW_{th} including added biogas and natural gas (see Figure 6.47).

Emissions to air are released from the incinerator and have to be treated. Achievable emissions can be found in Table 6.31. By contrast, potential emissions from landfill gases are reduced. Waste water is generated when wet scrubbers are used for waste gas treatment. The water is treated, the sludge returned to the combustion plant and the overflow is used in the paper mill.

Technical considerations relevant to applicability
Reject incineration in stand-alone waste incineration plants is only used in a few large-scale recently built or expanded mills. In many European paper mills, the volume of rejects produced in paper mills may not be sufficient to operate a waste incineration plant under economical conditions. Thus, this type of stand-alone plant is only feasible for larger mills.

The retrofitting in older paper mills is possible, but it is uncertain whether an incineration plant including the necessary flue-gas purification can be operated in an economical way. Taking into account the investment required of about EUR 20 million for a 15 000 tonnes/yr incineration plant and the fact that the specific costs for smaller plants increase, the economics are doubtful in the case of small paper mills. For them, the technique described as Example 4 can be a feasible option.

For that reason for instance in the province of Gelderland, the Netherlands, a group of mills operating at a relatively short distance from each other are incinerating residues in a commonly used fluidised boiler. The composition of the ash will be strictly controlled and it will be used in the construction industry.

Economics
In 1989, investments totalled about EUR 20 million. Specific operational costs are not available. The total costs for the incineration of 1 tonne of rejects (50 – 60 % dry substance) were around EUR 100. These costs include capital and operating costs as well as savings of natural gas, which is the energy source of the mill concerned. Investment costs in 2010 are unknown.

Driving force for implementation
In the case of this example plant, the landfill capacity near the paper mill became restricted resulting in increasing costs for landfilling.

Example plants
SCA Packaging Industriepapier GmbH, Aschaffenburg/Germany.

Reference literature
[227, SCA Aschaffenburg 2009].

Example 2: Co-incineration of rejects from RCF mills without deinking in coal-fired power plants including flue-gas treatment

This technique strictly speaking applies only to RCF-based mills manufacturing corrugating medium. However, it may be worth investigating case by case to see whether a similar system might be applicable for other mills processing paper for recycling.

Description and achieved environmental benefits

Because of their inhomogeneous composition, rejects from RCF mills without deinking were previously dumped in landfill sites. However, due to their high heating value in the range of 22 – 24 MJ/kg dry substance, caused by the high proportion of plastics, rejects are suitable for energy recovery, replacing fossil fuels (see also Example 1).

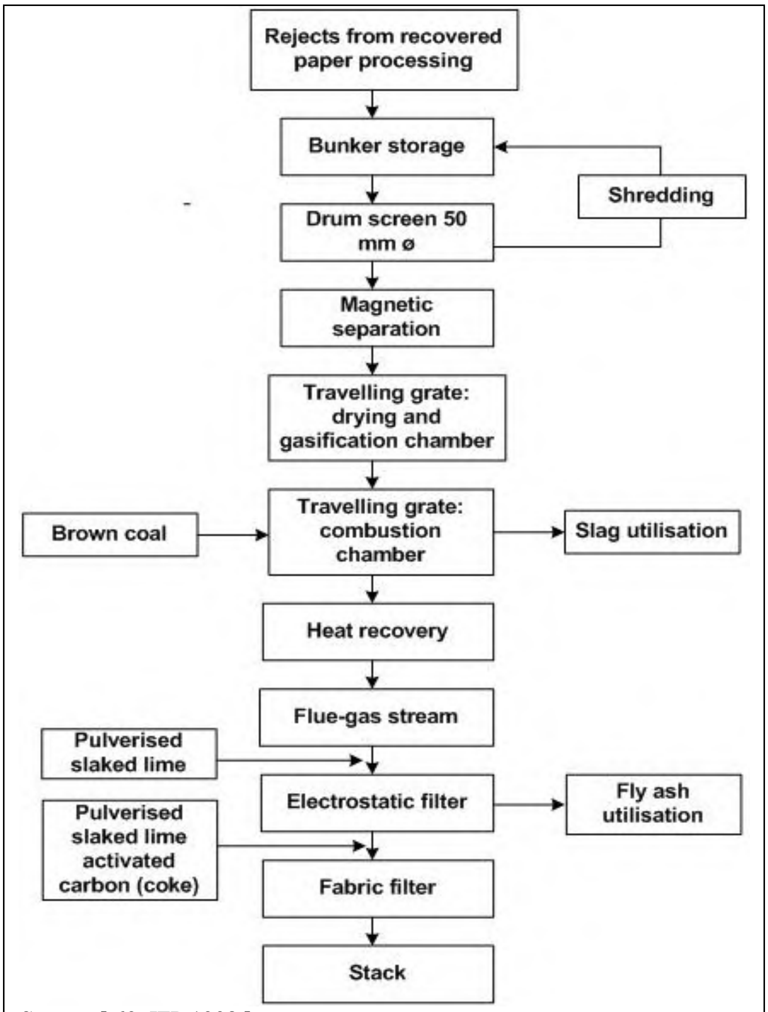
Table 6.32 shows the composition of rejects as averages from 18 analyses performed in different German paper mills producing Wellenstoff and Testliner.

Table 6.32: Composition of rejects from manufacturing of Testliner and Wellenstoff

Compound	Unit	Value
Plastic	wt-%	26.0
Fibres	wt-%	27.0
Glass and stones	wt-%	0.1
Metals	wt-%	0.9
Other organic material	wt-%	1.0
Water	wt-%	45.0
Heating value (100 % dry substance)	MJ/kg	23.8
Heating value (55 % dry substance)	MJ/kg	12.0
Chlorine content of plastic fraction	wt-%	5.5
Chlorine content of rejects	wt-%	1.4
Source: [69, IFP 1998]		

In paper mills firing solid fuels such as brown coal or hard coal in their power plants, the co-incineration of rejects is feasible. The installation of a drying and gasification chamber connected with the combustion chamber of the power plant is necessary. In the drying and gasification chamber the rejects are gasified by oxidation of the material containing carbon with air. The gases generated during gasification are burnt afterwards in the combustion chamber of the power plant. Proper combustion conditions (>850 °C and an oxygen level >6 %) have to be ensured to avoid problems with VOC and soot. As a control parameter, CO can be monitored (<50 mg/Nm^3).

Before drying and gasification, the rejects require the following treatment: in a first step, a classification in a drum screen is performed. Rejects with a size of more than 50 mm are shredded. Ferrous material is then removed by magnetic separation. A travelling grate is used for feeding rejects to the drying and gasification chamber. A simplified scheme of the technique described is shown in Figure 6.48.



Source: [69, IFP 1998]

Figure 6.48: **Simplified scheme for co-incineration of rejects in a brown coal-fired power plant**

Environmental performance and operational data

Co-incineration of rejects in existing power plants requires additional measures for flue-gas purification. Normally, this flue-gas treatment has to meet stringent requirements. To remove HCl that is caused by the high chlorine content of the rejects, pulverised dry slaked lime (calcium hydroxide) is injected into the flue-gas stream. By injection of dry lime in the right temperature zone, HCl, HF, and SO_2 can be minimised. Generally achievable emission levels are HCl <30 mg/Nm^3, HF <5 mg/Nm^3, and SO_2 <200 mg/Nm^3. Lower values are possible depending on the adsorbent dosage. The waste gases are subsequently treated in an electrostatic precipitator and additionally in a fabric filter. The solid particle concentration in the purified flue-gas does not exceed 10 mg/m^3. The concentration of HCl, particulate matter and O_2 in the purified flue-gas is measured continuously.

The removal of dioxins from flue-gas is achieved with activated carbon or coke. Generally achievable emission levels for dioxins/furans are <0.1 ng I-TEQ/Nm^3. Lower values are possible, depending on the dosage of activated carbon. The waste gas is subsequently treated in the dedusting facility mentioned above.

Cross-media effects

Co-incineration of rejects is considered to have a positive balance concerning achieved environmental performance compared to landfilling. When using rejects for energy generation, fossil fuels can be substituted. One tonne of rejects with a water content of about 45 % replaces about 0.7 tonnes of brown coal. Because the proportion of CO_2-neutral fibres in the rejects is in the range of 50 %, in relation to solid substances, the resulting fossil fuel CO_2 emission will be decreased. Co-incineration of rejects is an effective method to minimise waste normally disposed of by landfilling. In this case, the resulting ashes are suitable for reuse, e.g. in recultivation of brown coal mines. In other cases, dust, particle-bound heavy metals and the above-mentioned adsorbents are collected and have to be disposed of.

Technical considerations relevant to applicability

In principle, all existing power plants fired with solid fuels (brown coal, hard coal) should be suitable for the co-incineration of rejects. However, most of the large-scale European producers of Wellenstoff and Testliner use natural gas as fuel for their power plants. Therefore, this type of co-incineration of rejects is restricted to small and often older mills.

Economics

The investment required for a co-incineration plant including facilities for reject pretreatment and drying and the gasification chamber for a maximum reject volume of 3 tonnes/h is in the range of about EUR 2.5 million. Assuming costs for landfilling of EUR 50/t, an annual savings of EUR 0.6 million results. The substitution of brown coal saves EUR 0.3 million/yr. Costs for maintenance were not specified. The costs for depreciation and interest are not taken into account because they are not available.

Driving force for implementation

Bearing in mind that since 2005 in Germany it is not permitted to dispose of waste with an organic material content higher than 5 % in landfill sites, the implementation of this technique was a response to this requirement. High prices for sludge and reject disposal led to many paper mills today being interested in having their own incineration plants. Driving forces are also the saving of primary energy costs and the independence from external waste management companies.

Example plants

RCF DE 6; Schöllershammer Industriepapier, Düren, Germany; Oudegem Papier, Belgium.

Reference literature

[69, IFP 1998].

Example 3: Incineration of residues (rejects and sludges) from DIP plants combined with power and steam generation

Differing from Examples 1 and 2, this example refers to DIP plants or those using a mixture of deinked pulp (DIP) and mechanical pulp.

Description
Incineration of different kinds of sludge and rejects is widely used in the pulp and paper industry including rejects, deinking sludge, sludge from waste water treatment, etc. The two options for the incineration of rejects and sludge are given below.

- Co-incineration with bark in bark boilers (only for paper mills using a mixture of raw materials, e.g. a mixture of deinked pulp and mechanical pulp where debarking is applied): for co-combustion, particularly of rather low DS sludges, the fluidised bed boiler is predominant in new or more recent installations.
- Separate deinking sludge incineration. These incinerators are usually bubbled fluidised bed boilers and can be run with 100 % sludge, although the use of a support fuel such as natural gas, coal or oil is common. The need for the support fuel depends on the sludge's DS and ash content. Generally, a DS content of at least 35 – 40 % is required for self-supporting combustion (see Figure 2.29)

To be suitable for burning in a boiler, the sludge from the production of paper for recycling has to be first dewatered and dried with excess heat from the paper machine, if economically feasible (see Section 6.3.13). The dewatering filtrate can be treated in the WWTP of the mill. Some mills handle and reuse the pre-dewatering filtrate after micro-flotation in the pulping process.

Deinking sludge from the flotation cells can be burnt without pretreatment after being dewatered. Dewatered excess sludge from the biological waste water treatment can be added but only has a small share of the whole sludge volume (around 5 %). To ensure a high temperature (>800 – 850 °C), gas or bark is normally also burnt in the solid fuel boiler (fluidised boiler). There are mills that burn only the sludge, whereas others burn all residues including rejects or bark.

In cases where DIP rejects are also incinerated, they have to be processed first to be suitable for burning in a fluidised bed boiler (see also Example 2, Figure 6.48). The main purpose of pretreatment of the rejects from a deinking plant is to separate the incombustibles and crush the fuel particles to the proper size to obtain a high surface area and good ignition behaviour. After primary crushing and screening, the combustibles can be led to the fuel bin of the boiler. The remaining rejects can be separated into iron rejects and other incombustible rejects.

The pretreatment of these rejects may consist of the following stages:

1. prescreening 1 in order to separate large iron particles;
2. primary crushing that will reduce the particles to a suitable size for subsequent screening stages;
3. prescreening 2 that will remove the rest of the iron;
4. screening that will separate the incombustibles (metals, stones, glass, etc.);
5. secondary crushing that will cut plastic ribbons, strips and ropes that may have passed the primary crushing.

Environmental performance and operational data
The main achievement is the reduction of the amount of material to be landfilled by about 80 – 90 %. For the final disposal or use of the ashes, there are different options depending on the ash qualities achieved. In some cases, ash will be landfilled, others use it in the construction industry or other added-value products.

Emission data of incineration plants for deinking sludge, rejects and sludge from biological waste water treatment are summarised in Table 6.33. As support fuel, some natural gas and refuse-derived fuel is used. The values shown are yearly average figures for 2008.

Table 6.33: Emission data from a fluidised bed boiler incinerating deinking sludge, rejects, biosludge, biogas, natural gas and refuse-derived fuel

Parameter	Measured values in 2008 (1) (mg/Nm^3)	Limit value daily average(1) (mg/Nm^3)	Installed emission abatement techniques
Dust	5	10.0	Bag filters (Teflon)
SO_2	1	50.0	S content in the sludge is very low
NO_X	190	200	SNCR (injection of ammonia)
NH_3	Not detectable	20	No relevant ammonia slip
CO	2	50.0	Fluidised bed ensures good combustion
HCI	3	10.0	Injection of an adsorbent (mixture of calcium and activated carbon) before the bag filters
Total-C	1	10.0	

NB: Heavy metals and dioxins are well below the limit values. They are measured periodically, e.g. Hg <0.01 mg/m^3; PCDD/F: maximum value: <0.004 ng/m^3.

(1) The measured values and the emission limits refer to an oxygen content of 11 % per volume and are calculated as yearly average values.

Source: [Landesdirektion Leipzig, Abt. Umwelt, Stora Enso Sachsen: Continuous emission monitoring. Yearly emission report 2008]

Energy recovery may be a secondary reason for applying this technique. After dewatering, there is a slightly positive energy balance in the range of 4 – 5 MJ/t, referring to the incineration of dewatered sludge (at 58 % DS). However, for some paper mills applying wash deinking (e.g. RCF tissue mills), sludge incineration results in a net consumption of energy. This is typically due to the high ash content and thus the lower energy value of sludge.

The devolatilised chlorine from fluidised bed combustion will, besides occurring as HCl, also occur as potassium chloride (KCl) and sodium chloride (NaCl). These substances are known to condense on the tube surface and have a tendency to increase the possibility of molten phase corrosion. This type of corrosion can be encountered in superheaters when the steam temperatures are above 500 °C.

Cross-media effects

Emissions to air are released from the incinerator and have to be treated. Achievable emissions can be found in Table 6.33 below. By contrast, potential emissions from the landfill gases are reduced. Normally, the purification of waste gas from incinerators generates a certain amount of waste (retained dust from bag filters; ash from the combustion chamber) that has to be disposed of or recycled. In the case of wet waste gas treatment, waste water is generated.

Technical considerations relevant to applicability

The incineration of deinking and other sludges combined with power and steam generation is used in many modern mills, especially larger ones. However, the incineration of rejects is much more difficult and involves potential emission and corrosion problems. The possibilities in practice are dependent on the capacity and type of the boiler. This technique can be applied to a limited extent in smaller paper mills (see Example 4).

Incineration of residues (rejects and sludge) combined with power and steam generation can be applied to most new and existing mills. However, the applicability depends on the type and capacity of the boiler in each case. For instance, small mills cannot apply this technique. They have often only very simple oil or gas boilers with limited capacity or technical feasibility to burn solid materials. The higher chlorine content of the rejects requires special attention (corrosion, waste gas treatment).

When applied, fluidised bed boilers are generally more appropriate and can be retrofitted with fewer additional costs than grate-fired boilers (see Examples 1 and 2). From the operating point of view, the fluidised bed boilers have many benefits, including lower sensitivity to fuel quality or quantity variations and in most cases lower emissions, over the grate-fired boilers (see Section 2.6.1.2.3 on fluidised bed boilers), among other things.

Economics

No information provided.

Driving force for implementation

Legal requirements. Reduction of the transportation of sludge and rejects; reduction of landfilling; use of the energy content of the waste fractions.

Example plants

Some DIP plants in Europe for newsprint and tissue have installed fluidised bed incineration systems such as Stora Enso Eilenburg, newsprint (DE), Tela Papierfabrik AG, tissue (CH), UPM Schwedt, newsprint (DE), WEPA Giershagen, tissue (DE).

Reference literature

[1, Finnish BAT Report 1997], [16, CEPI 1998], [Landesdirektion Leipzig, Abt. Umwelt, Stora Enso Sachsen: Continuous emission monitoring. Yearly report 2008] in BATIS einfügen;

Example 4: Energetic utilisation of rejects and effluent sludge from a small RCF mill in a reject incineration plant (for smaller mills and lower amounts of rejects)

Description

The incineration plant consists of the following subsystems: fuel storage, which is separated for reject, wood, and effluent sludge; fuel preparation (a shredder) followed by a screening machine; storage silos for prepared fuel; fuel batching and fuel entry; an incinerator with an ash removal system; a heat recovery steam generator; a flue-gas purification plant and an exhaust gas monitoring system. Figure 6.49 shows the major building blocks of the reject incineration plant.

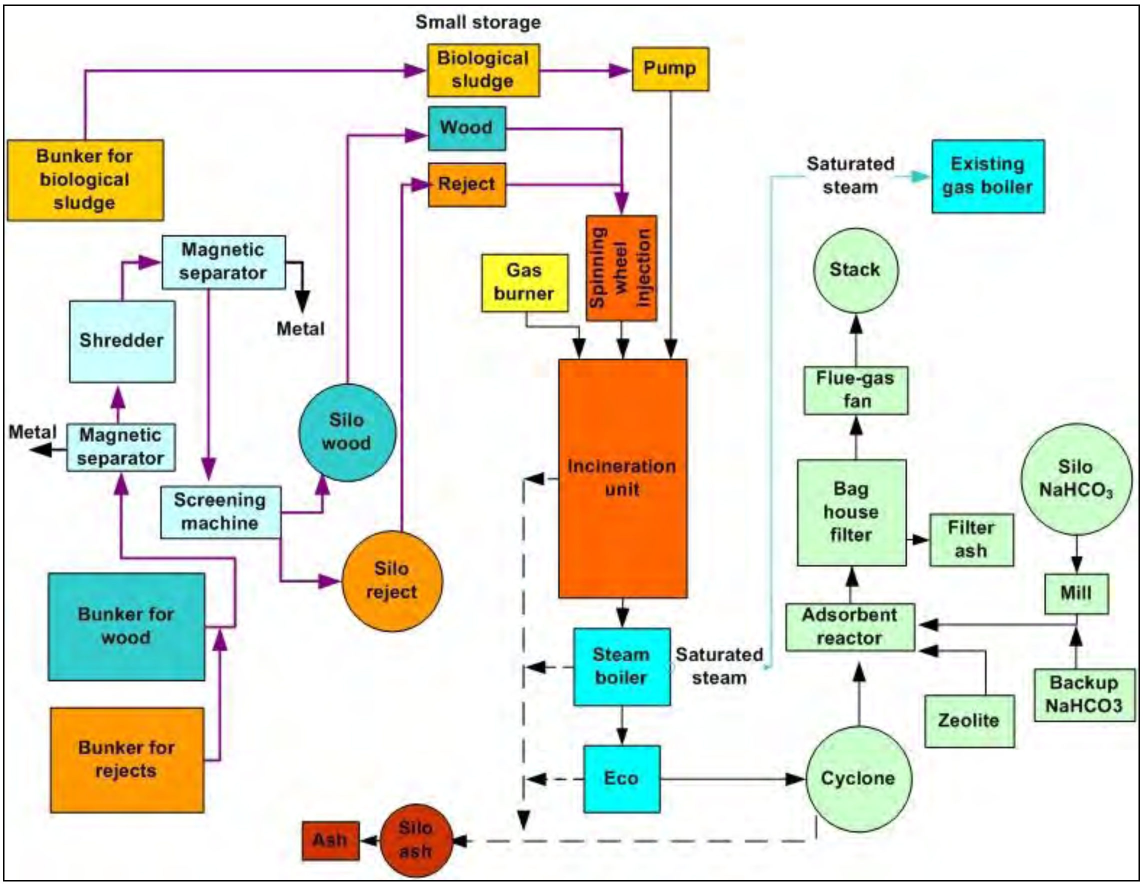


Figure 6.49: Plant flowsheet of the 'reject power' system

Three types of fuels can be used in the combustion plant simultaneously at different ratios: rejects from recycled paper, wood, and effluent sludge. Table 6.34 shows their typical composition and the mixture of fuels that is actually incinerated.

Table 6.34: Composition of wet fuel

Characteristics of the fuel	Unit	Fuel			
		Rejects	Wood	Effluents	Mixture
Fuel ratio	-	7.50	5.00	2.50	15
Composition					
C	wt-%	21.19	48.36	6.43	27.78
H	wt-%	2.98	4.09	0.98	3.02
O	wt-%	15.80	29.51	3.44	18.31
N_2+Ar	wt-%	0.05	0.12	0.80	0.20
S	wt-%	0.02	0.00	0.06	0.02
Ash	wt-%	5.07	2.92	3.29	4.05
H_20	wt-%	54.90	15.00	85.00	46.62
Cl	wt-%	0.26	0.00	0.01	0.13
Sum (without Cl)	wt-%	100.00	100.00	100.00	100.00
Lower calorific value	kJ/kg	5 898	15 700	340	8 239
DS content	%	45	85	15	53

Source: Data from example plant [231, Schwarz 2009].

A spinning wheel fuel injection system is used to load the incineration unit. Therefore it is necessary to chop the solid fuel using a shredder. Wood and rejects are cut up in sequence, screened, and then stored in separate fuel silos. In addition, metal separation units are installed before and after the shredder. Due to the cutting process, the fuels are mixed and a homogeneous effect is created. Every type of fuel component is stored separately; it is then possible to preselect the fuel ratio according to the fuel availability. Effluent sludge is pumped via a sludge pump to the incinerator without pretreatment. The output power is controlled directly by the amount of fuel injected, which leads to a more flexible incineration unit. Due to the fuel being distributed via the spinning wheel, a preheating zone as normally required for grate firing is no longer necessary. The burning process takes place over the entire surface of the glow bed. A burnout zone follows the incineration zone where the flue-gas remains for two seconds at a temperature above 850 °C. In this stage, a urea-water mixture is injected in the end zone of the incinerator in order to reduce the NO_X emissions. Steam from the incineration is generated in an upright water tube boiler. In the first two passages, the flue-gases are cooled down to 600 °C in a radiation zone, followed by contact surfaces (evaporator and economiser). The heating surfaces can be cleaned on-line with steam soot blowers. The high-pressure steam (83 bar(g)) generated from the waste incineration unit is mixed with the saturated steam from the existing gas boiler just after the steam drum of the existing gas boiler. The mixture is then brought to the required temperature in the existing superheater of the gas boiler.

For flue-gas purification, a system operating on a dry basis was chosen. $NaHCO_3$ and a mixture of coking coal and zeolite are added to the flue-gases to adsorb acid gas components and dioxins and furans, if they occur. The adsorbents together with the remaining ash particles are removed from the flue-gas in a bag filter. NO_X reduction measures are implemented through flue-gas recirculation and through the injection of a urea-water mixture into the burnout zone.

Achieved environmental benefits

With the incineration plant, fossil fuels for energy generation can be partially replaced (auxiliary fuel is still needed for start-up). Incineration of rejects is an effective method for minimising waste volume and recovering the caloric value of the organic fractions. The transportation of waste is avoided as the rejects are treated on site. The exhaust gas emission levels actually achieved are significantly lower than the required limit values (see Table 6.35).

Environmental performance and operational data

The achieved emissions of the incineration plant are shown in Table 6.35.

Table 6.35: Emission data of the example plant MM Hirschwang, Austria

Parameter	Unit	Daily average values, 2006 (range in %) (1)	Yearly average values, 2008	Measurement	Limit values as daily average (2)
Dust	mg/Nm^3	0.2 (± 50 %)	0.1	Continuously	10
SO_2	mg/Nm^3	2.7 (± 50 %)	3.9	Continuously	50
NO_X	mg/Nm^3	170.0 (± 15 %)	171.3	Continuously	200
CO	mg/Nm^3	4.6 (± 65 %)	2.3	Continuously	50
TOC	mg/Nm^3	0.8 (± 55 %)	1.8	Continuously	10
HCl	mg/Nm^3	4.9 (± 40 %)	5.3	Continuously	10
Dioxin and furans	ng/Nm^3	-	0.0054 (3)	Every 6 months	0.1 (3)
Hg	mg/Nm^3	-	0.0085	Every 6 months	0.05
Cd and Ti	mg/Nm^3	-	0.002 (4)	Every 6 months	0.05 (4)

(1) Data from measuring reports (typical values from 2006).
(2) According to the German Seventeenth Ordinance on the Implementation of the Federal Immission Control Act (Ordinance on Incinerators for Waste and Similar Combustible Material). Values refer to standard temperature and pressure (0 °C, 1 bar, dry) and to an oxygen content of 11 % per volume.
(3) Average value during a measurement period of 6 – 8 hours.
(4) Average value during a measurement period of 0.5 – 8 hours.

Source: [231, Schwarz 2009]

The plant can process different fuel compositions, fluctuating fuel water content and can automatically track these changing conditions. In the area of material transport and storage, the wet rejects show a tendency to harden, making it necessary to reinforce the silo discharging system. In addition, optimisations in the ash conveyor system are necessary; an upright conveyor screw is replaced by a bucket conveyor. During several manual boiler cleanings, which are carried out twice a year, no signs of corrosion have been observed, which proved the correct use of materials and the correct anticipation of temperature profiles in the boiler.

Cross-media effects

Ash from the incinerator, ash from the heat recovery boiler, as well as ash from the cyclone are collected and then transported to the ash silo (1.6 – 2.1 tonnes/day, mainly grate ash). Filter ash from the bag filter consists of reacted additives and dust (about 0.3 tonnes/day of reacted additives and 0.06 tonnes/day of dust). The filter ash is placed in large bags and requires further treatment to dispose of it at a residue landfill. In Austria, it is mixed with water and cement to harden, so that no eluate can emerge at the residue landfill.

Technical considerations relevant to applicability

This concept can also be applied for smaller mills starting with 5 MW_{th} firing thermal capacity. The system with spinning wheel injection can be used for various types of fuels. In this case, three different fuels can be used simultaneously, while fuel ratios may be varied. The fuel metering system of the incineration needs a fuel with a maximum size of 11 cm in the sum of length + width + height, whereas the maximum length of one side should not exceed 5 cm. The properties of the fuel must not be sticky and the water content should be lower than 50 %. The incineration units are supplied from 5 MW_{th} to 30 MW_{th} firing thermal capacity.

Economics

The investment required for the example plant that incinerates around 15 000 tonnes per year mixed fuel (53 % DS content) is about EUR 5 – 6 million, and operating costs are about EUR 0.5 – 0.6 million/year. Savings of around EUR 1.3 million can be expected (depending on disposal costs and costs for fossil fuel). The firing thermal capacity is 4.8 MW_{th}.

Driving force for implementation

The plant produces cardboard out of paper for recycling and had to find a solution for dealing with the rejects from the processing of paper for recycling (rejects and effluent sludge from the biological treatment plant). Until the end of 2003, the rejects were disposed of at the company's own dumping grounds and the effluent sludge was taken to a composting facility. Due to a new landfill regulation in Austria since the beginning of 2004 which does not permit the disposal of waste with a carbon content of more than 5 %, an alternative solution for the waste disposal was explored. The solution was discovered in the form of a waste incineration plant.

Example plants

Mayr-Melnhof Cartonboard plant in Hirschwang (Austria); Residual Waste Thermal Power Station Association plant in Böblingen (Germany).

Reference literature

[231, Schwarz 2009], [232, Symposium Slovenia 2007], [234, Schwarz 2007], [235, Schwarz 2007].

6.4 Emerging techniques

No emerging techniques were reported.

7 PAPERMAKING AND RELATED PROCESSES

This section describes paper and board production of the major grades being manufactured in European paper mills.

For integrated paper mills, the reader should also refer to the relevant process-specific information for the pulping processes or the processing of paper for recycling that applies (Chapters 3 to 6 of this document). Chapter 2 about general processes and techniques applies in addition to the process-specific chapters.

During the production of different paper grades, either virgin fibres (chemical or mechanical pulps) or recycled fibres are used as the main raw materials. In Europe, there are also a large number of mills manufacturing papers with a mixture of fibrous materials. At the time of writing (2013), the composition of the raw material used for paper is influenced more than ever before by the cost of the individual components. The composition of raw materials used for paper manufacturing (e.g. fibrous material, mineral fillers, coating) has a major effect on the total production costs, the product quality and the environmental impact of the process. The manufacturing of fibres used for papermaking has been described in Chapters 3 to 6. In this chapter, paper and board manufacturing is described independently from pulp manufacturing. This approach is considered to be reasonable because the same unit processes in the paper and board machine are required in every paper mill. The description of papermaking as a part of integrated pulp mills would increase the complexity of the technical description. Finally, in numbers, most paper mills in Europe are non-integrated mills.

Although there are a wide variety of paper products and different process layouts in paper mills almost all types of paper- and board-making processes have the following basic units:

- stock preparation;
- approach flow system;
- a paper and board machine consisting of:
  - a headbox that introduces the suspension of fibres to the wire and creates a uniform dispersion of fibres across the total width of the wire belt,
  - a wire section that drains paper web to around 12 – 20 % solids,
  - a press section that removes more water out of the web by pressing down to about 50 % moisture content,
  - a drying section that removes the rest of the moisture by heating the web with drying cylinders,
  - a reeler that reels the paper web into a roll;
- on-line aggregates (e.g. calender, sizer, coater);
- depending on the paper and board grade, there are additional process units (optional) like calenders, sizer, coaters, a coating colour kitchen, winders, rewinders, sheeting plant and a roll wrapping station.

In the following section, the basic units of paper manufacturing are described. The main papermaking additives and chemicals are included in these descriptions. Because papermaking is a sector that requires large amounts of water, a paragraph about water circuits is included. Coating and important finishing processes are also covered.

7.1 Applied processes and techniques

7.1.1 Stock preparation

Stock preparation is a process that converts raw stock into finished stock (furnish) for the production of paper. The furnish is prepared for the paper machine by blending different pulps, dilution and the addition of chemicals. The raw stocks used are the various types of chemical pulp, mechanical pulp, and paper for recycling and their mixtures. The quality of the finished stock essentially determines the properties of the paper produced. Raw stock is available in the form of bales, loose material, or, in the case of integrated mills, as suspensions.

Stock preparation consists of several process steps that are adapted to one another and include fibre disintegration, cleaning, fibre modification and storage and mixing. These systems differ considerably depending on the raw stock used and on the quality of furnish required. For instance, in the case of pulp being pumped directly from the pulp mill, the slushing and deflaking stages are omitted.

Stock preparation removes impurities and air and conditions the strength properties of the fibres (refining). Chemicals are added to the process to affect the final quality of the paper sheet (resins, wet strength agents, colours, fillers). In non-integrated mills the fibres are normally received with around a 10 % moisture content. They are suspended in a pulper to create a suspension that can be pumped. Undissolved impurities are removed from the slurry by screening (screens) and cleaning (centrifugal cleaners). The objective of screening is the removal of interfering substances from the fibres. The acceptable fibre suspension is passed through a screen with apertures in the form of slots or round holes, while the impurities are separated and rejected by the screen. Furthermore, the fibre suspension is cleaned in a centrifugal cleaner (hydrocyclones). A distinction is made between heavy-particle and light-particle cleaners, depending on the purpose of separation. Most cleaners are multistage systems (up to five stages).

To improve the bonding ability of the individual fibres in order to strengthen the paper, refining is usually carried out. Refining is also done to condition the fibres to create the required properties of the finished product. Refining is carried out in refiners equipped, for example, with rotating disks (or rotating disks combined with stationary disks) between which the stock is treated. The space between the disks can be adjusted, depending on the degree of refining desired and to control the fibre properties. The electrical energy consumed in refining as part of the papermaking process is usually in the range of 10 kWh/t to 500 kWh/t for most papers but can be up to 3 000 kWh/t for speciality papers. Thus for a non-integrated paper mill using chemical pulp, refining represents the largest use of electrical energy (drying being the largest use of heat). Practically all of the energy input to this refining will be turned into heat (heating the process water) and there is no option here for energy recovery, although this heat generated contributes to the elevated temperature sought in the process.

Complete stock preparation for a paper machine usually consists of several lines where different raw stocks are prepared. The processing of broke from the paper machine is also part of this process (see Section 7.1.4). Finally, the pulp is pumped to the storage chests or mixing chests. These chests serve as a buffer between the stock preparation and the actual paper machine, to secure process continuity. In mixing chests, prepared stocks are mixed in proportions for the particular grade of paper to be made, the required additives are added and the required fibre consistency is adjusted. Storage chests or mixing chests might be substituted by advanced stock tower controls and in-line mixing.

7.1.2 Paper machine

In the paper machine, the paper is formed and most of the properties of the paper are determined. The paper machine is actually a large dewatering device consisting of a headbox, a wire section, press section and dryer section. The most common machine design to date is the Fourdrinier forming process in which the sheet is formed onto a continuous horizontal wire or fabric onto which the suspension of fibres is supplied from the headbox. Also, twin wire formers are used for web formation. In twin wire formers, the fibre suspension is fed between two wires operating at the same speed where the water is drained in two directions. There are different types of twin wire formers (e.g. gap formers). In gap formers, the diluted stock is injected directly into the gap between the two wires. A third alternative is to combine the Fourdrinier and a top wire. These are referred to as hybrid formers.

Figure 7.1 shows the key features of a twin wire paper machine.

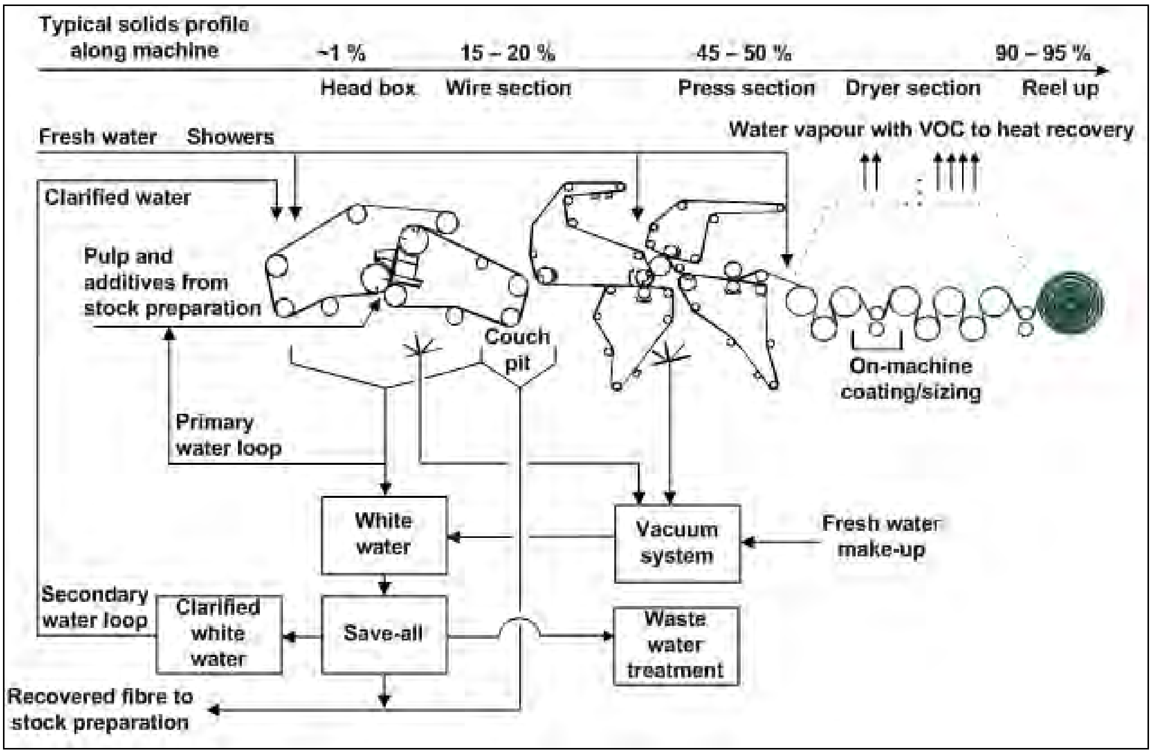


Figure 7.1: Key features of a twin wire paper machine

Paper is made by feeding a dilute suspension of fibres, fillers (optional), dyes and other chemicals onto a fine wire mesh through which the water drains away, leaving a web of fibres, fines and fillers on the mesh. The fibre slurry, which at the wet end of the paper machine is typically between 0.2 % and 1.5 % consistency, is pumped to the wire section via the headbox. The objective of the headbox is to create a uniform dispersion of fibres across the total width of the papermaking wire, in order to achieve a uniform paper formation and grammage distribution. The water drains through the wire aided by 'dewatering elements'. Examples of these are rolls, foils and vacuum boxes below the wire. After typically 10 m, the web of paper is formed. In a twin wire former, additional dewatering pressure is formed by the fabric tension over a curved surface of blades or a roll. By the time the paper web has drained to around 10 – 20 % solids on the wire, the web is self-supporting and can be carried away from the wire and on to the subsequent pressing and drying stages. Machine speeds vary considerably, with the web on the fastest machines, typically newsprint, travelling up to 2 000 m/min with a web width of 11 m. Tissue machines, although generally of narrower width, now run at speeds in excess of 2 500 m/min. Some machines operate with several forming sections for making multi-ply papers or boards.

The paper web passes into a press section supported on felts between rollers and through vacuum sections to remove more water (final dryness of about 50 % moisture content) and then through the drying section. The drying is normally done using steam-heated cylinders enclosed in a hood. In the dryer section, the web is dried to the final dry content of 90 – 95 %. Practically all the heat used for drying ends up in the hood as exhaust air. The temperature of the exhaust air is normally 80 – 85 °C and the humidity is 140 – 160 g H_2O/kg dry air. A part of the moisture (about 1 – 1.5 m^3/t of paper) is driven off to the atmosphere. For economic reasons, all paper mills have installed heat recovery systems. Figure 7.2 shows a schematic picture of an example of the drying and heat recovery section of a paper machine.

In the first heat exchanger of the heat recovery system, heat is recovered in order to heat the incoming supplied air. The next heat exchanger is for the heating of incoming fresh water. In some cases, heat is also recovered to the wire pit water to compensate for the heat losses at the wet end. The last heat exchanger is for circulation water. The circulation water is used to heat the incoming ventilation air. The supply air and shower water are heated to their final temperatures (90 – 95 °C and 45 – 60 °C respectively) using steam.

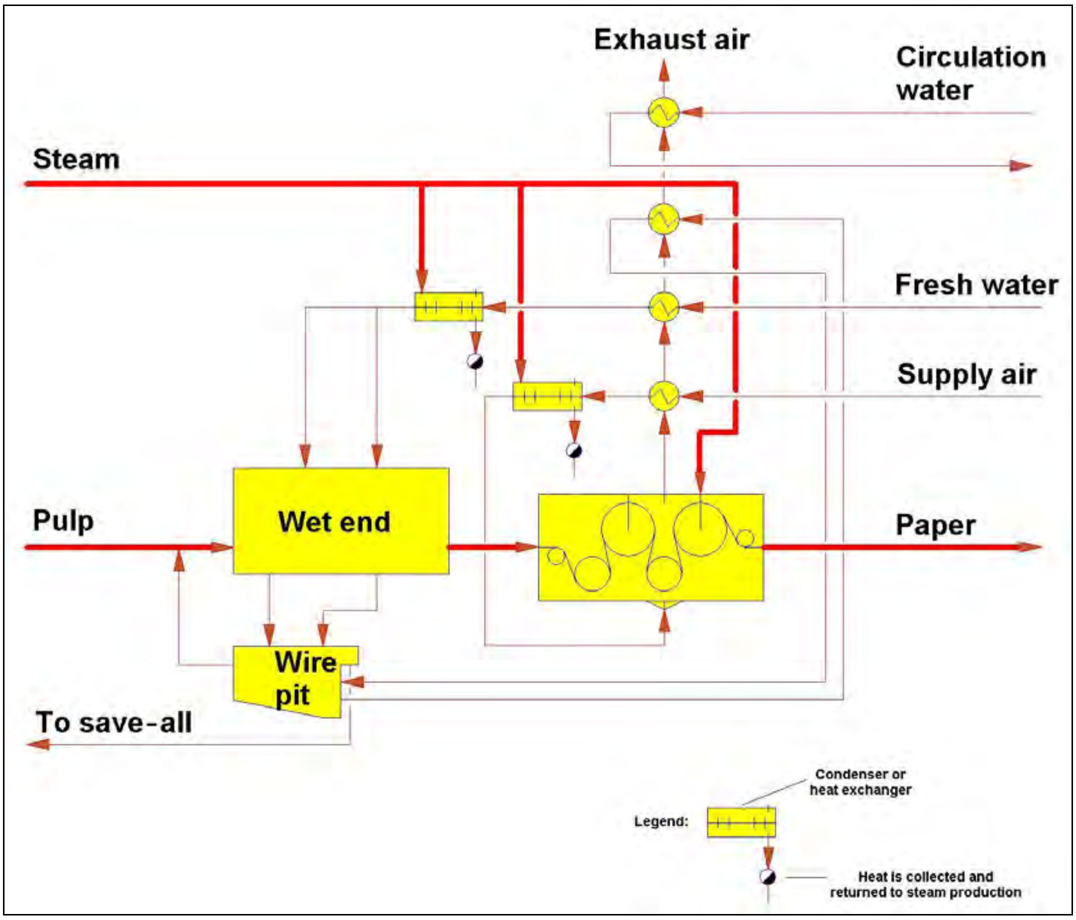


Figure 7.2: **Paper machine heat recovery system**

Table 7.1 shows an example of heat flows in a typical large, modern paper machine. The production capacity of the machine is 240 120 t/yr (667 t/d). The dry content of the web entering the dryer section is 44.5 % and leaving is 91 % dryness. The temperature of the exhaust air is 82 °C and the humidity is 160 g H_2O/kg dry air. The values are for Scandinavian winter conditions. In countries with a warmer climate, there is no need for the heating of circulation water that is used for machine room heating. Heat recovery to the circulation water decreases or disappears and the exhaust to atmosphere increases correspondingly.

Table 7.1: Example of heat recovery and heat losses of a paper machine with a production of 667 t/d

Sources of heat recovery	Destination of heat flow from the drying section	Distribution of heat (%)
Supply air	1.8 MW_{th} or 233 MJ/t	6
Wire pit water	3.6 MW_{th} or 466 MJ/t	11
Fresh water	5.5 MW_{th} or 712 MJ/t	19
Circulation water	8.0 MW_{th} or 1 036 MJ/t	27
Exhaust to atmosphere	10.8 MW_{th} or 1 399 MJ/t	37
Total (Exhaust air from hood)	29.7 MW_{th} or 3 847 MJ/t	100
Source: Valmet, 1998.		

One alternative to drying the paper for the production of light-weight machine-glazed paper or conventional tissue is the use of a large diameter, heated 'Yankee' cylinder on the machine. The drying of the paper web is carried out during one rotation of the cylinder.

In a simple papermaking set-up, the paper may then be reeled and sent for cutting and finishing. In more complex cases, a variety of different stages are incorporated within the machine, e.g. a film press where starch and other chemicals are applied on the surface of the paper by dipping or spraying, with residual water being removed in a short after-drying section.

In most applications, the edges of the web are continually trimmed with cutting water jets, into the couch pit, as it leaves the wire. Whenever the web breaks (it can happen a number of times per day), there is a considerable loss of paper. Similar losses occur on regular start-ups. All of this paper, termed 'broke', is repulped and returned to the stock chests in the stock preparation area. Losses of dry paper may be repulped immediately or stored and reintroduced later to the system. Coloured or coated broke is recycled if possible but sometimes needs to be bleached or chemically treated first (see Section 7.1.4).

There is a continuous need to prevent the build-up of solids on the fast-moving wires, felts or rollers as these would quickly lead to web breaks. The showers or sprays for this purpose are the primary consumers of fresh water and/or cleaned water in the system. Vacuum systems can also consume substantial amounts of fresh water. However, water-free vacuum systems are also available (see Section 2.9.6.2.1).

The retention of solids (fibres, fines and fillers) and solubles (added chemicals, organic material from the pulp, etc.) in the paper web, rather than passing them through the mesh and allowing them to remain in the water circuit, is important. It affects the likely destination of any substance – either to the product or to the effluent. On-line consistency monitoring is often used to stabilise retention. The retention of solids on the wire can be increased by the addition of retention aids (chemicals improving retention), and this is normal practice for most paper grades. However, this is constrained for some grades by product quality.

7.1.3 Water circuits and fibre recovery

The water system of a paper mill may consist of three water loops: the primary, the secondary and, in some cases (e.g. RCF packaging paper mills), the tertiary circuits. A scheme of the water circuits in a paper mill is shown in Figure 7.3.

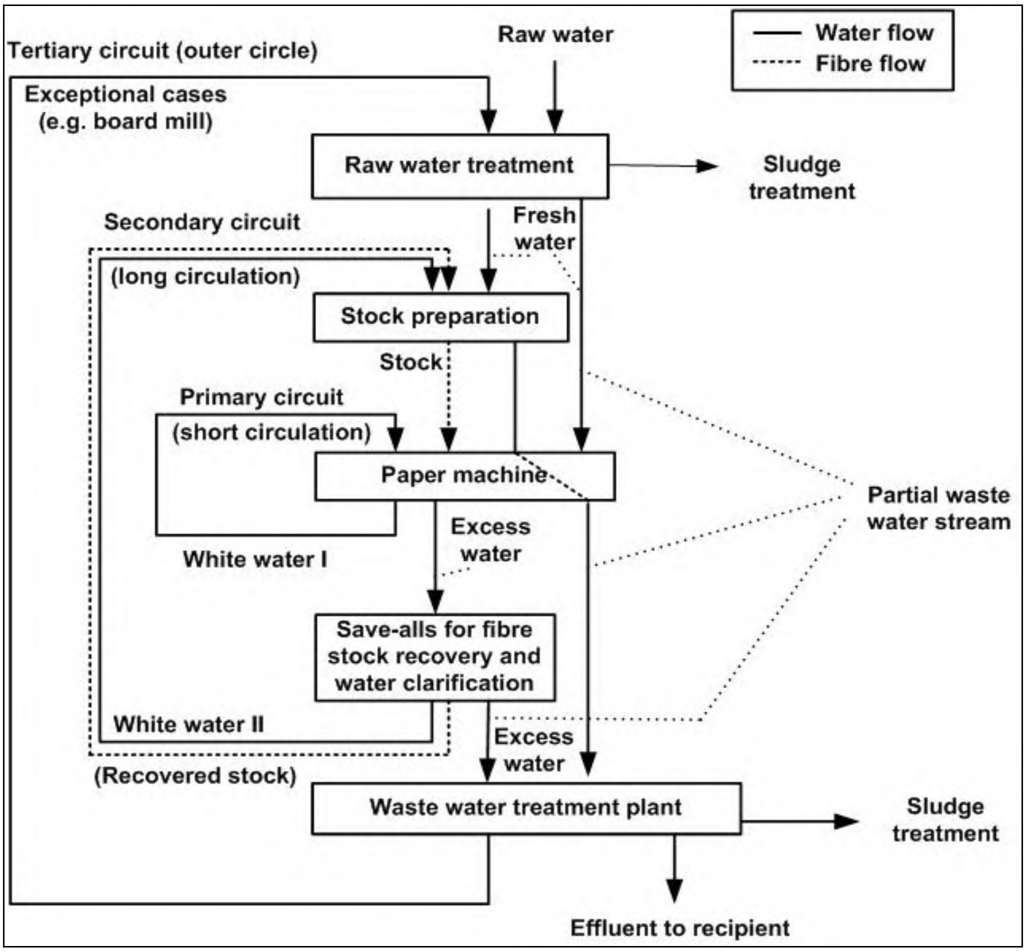


Figure 7.3: **Simplified scheme of water and stock streams in a paper mill**

In the primary circuit (short circulation), the fibre-, fines- and filler-rich water obtained in the sheet-forming zone of the wire section (white water I) is recycled for stock dilution in the stock approach flow system. The primary circuit is kept as closed as possible.

Excess water from the sheet-forming section, suction and press water, as well as cleaning water is called white water II and is circulated in the secondary circuit (long circulation). The white water draining from the wire is typically treated through a 'save-all', which may be a sedimentation plant, flotation plant or a filtration unit (a drum or disc filter). This water is called clarified water.

A disc filter precoated/conditioned with raw pulp produces stocks with the highest consistency (10 – 30 %) and is designed to produce a three-way (or four-way) separation of the white water into fibre. The first draw is cloudy water and the subsequent draws are clear and super clear filtrate. The cloudy filtrate is usually recycled back to the filter as dilution water, but can also replace fresh water in the process or be used for the dilution of the stock. A higher recycling rate of cloudy filtrate back to the disc filter results in a cleaner filtrate. The concentration of suspended solids in the clear filtrate (fines and fillers) is usually about 10 – 150 mg/l for virgin pulp or 100 – 400 mg/l for recycled pulp.

Flotation systems are also used as save-alls. Under operational conditions, the efficiency of flotation for solids removal is up to 90 %, resulting in a concentration of suspended solids of 10 – 50 mg/l (for virgin pulp). The consistency of the floated sludge is between 3 % and 10 %. Flotation plants consist of a clarifying basin with sludge removal, aeration equipment for a partial stream of clarified water, and a dosing plant for the flotation chemicals. The advantage of flotation is that small-sized colloidal material can also be removed (if suitably flocculated prior to flotation). This is a great advantage in paper recycling plants (see Section 6.3.11 with deinking, where a large part of the solid material in the process water is colloidal; in a deinking plant, the floated sludge is pumped to sludge dewatering instead of being recycled to the process).

Sedimentation installations are suitable for the clarification of filler-loaded process water but necessitate large volumes and therefore a large space requirement.

The fibre stream that is recovered in save-alls is returned to the stock chest and the different quality waters are returned to different uses relevant to their quality where replacing fresh water.

The tertiary circuit contains excess water from the secondary circuit and, in addition, all other process water which is not, or is not directly, reusable because of its degree of contamination. It is treated in chemimechanical and/or biological waste water treatment plants. The reuse of treated waste water is not applicable for all paper grades but mainly to some RCF packaging paper mills and in rare cases, to RCF newsprint mills (only one example mill). In those cases, purified water is partially returned to the process (5 – 30 %). Closed water circuits are only realised in a few paper mills producing corrugated medium-based on processing paper for recycling (see Section 6.3.4) or board.

This description shows that a very large quantity of water is involved at the wet end of a paper machine and there is usually a high degree of water recirculation in different water loops. About 1 – 2 m^3 of process water per tonne of paper is usually evaporated in the dryer section of a machine and is lost from the process. 'Dry' paper in equilibrium with the normal atmosphere is around 6 – 10 % water.

7.1.4 Broke system

The term 'broke' refers to any paper formed from the beginning of the papermaking process to the finished product that has never been shipped to the customer. Broke will exist in many forms and varying quantities and it will always be generated by the papermaking process.

The main goal of a broke system is to return the paper fibre back to the process with no disruption in the uniformity and quality of the stock flowing to the paper machine. Every paper machine is different. There are no two paper machines that are exactly the same, even machines producing the same paper grades. It follows, therefore, that no two broke systems are alike (from a chemical point of view).

The amount of broke produced during papermaking is normally 5 – 20 % of the machine's capacity. Sometimes it can even reach 50 % of normal production.

Depending on the particular case, machine broke will be generated at different locations. Broke is produced during web breaks. Wet broke is even generated during normal operation in the form of edge trimming at the wire section, and dry broke is produced during start-ups, grade changes and during all finishing operations. The broke pulps originating from the wet and dry ends of the paper machine are not identical in terms of their papermaking characteristics.

On coated paper machines, the broke system needs different storage towers for uncoated and coated broke. Figure 7.4 shows a possible layout for a broke system of a paper mill manufacturing coated paper. Broke pulp is pumped from the storage towers to the thickeners, where excess water is removed. Thicker broke is fed to the broke dosage chest, where the coated and uncoated broke are mixed together. After the broke dosage chest, the broke is cleaned in several stages to minimise the waste broke which cannot be recirculated to the process. The cleaned broke is discharged to the main line mixing chest, from where the final papermaking furnish is pumped through additional cleaning to the paper machine. Uncoated and coated broke are stored in separate tanks.

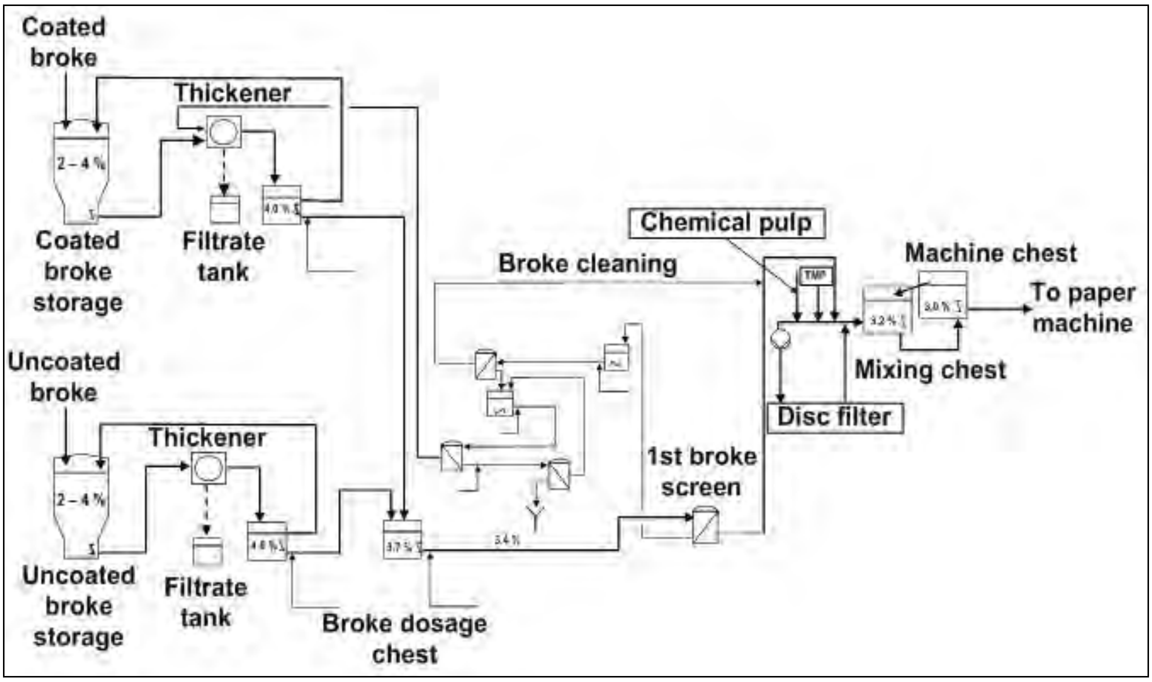


Figure 7.4: **Possible layout of a broke system in a paper mill manufacturing coated paper**

7.1.5 Sizing (optional)

Usually sizing means wet-end sizing where starch or synthetic sizing agents are added directly to the furnish to reduce the natural absorption capacity of the paper. In sizing, starch or other sizing agents are applied to the fibre matrix to increase the strength of the base paper web and to modify the surface properties with respect to liquid uptake during writing, printing or coating. Wet-end sizing is applied for instance to fine papers and some special paper grades.

The potential environmental impact of size application is mainly the releases to water. If sizes are added to the paper stock, a significantly higher concentration of COD in the water circuits can be measured. Also, the repulping of sized broke somewhat increases the COD in the water circuits. For instance, the repulping of starch-coated broke is one of the main sources of COD effluents in the writing and fine paper sector.

Sizeing may also be applied to the surface of the paper sheet (surface sizing) to avoid dusting (linting) of the paper in offset printing processes. Surface sizing also increases the surface strength of the paper. In surface sizing, the web is passed through the sizing liquor pond, which is located above a roll nip that presses on the web (size press). As a result, the paper web absorbs the sizing liquor. The amount of sizing agent taken up depends on the dry content of the web which can reach 98 % before the size press.

Size press technology has advanced, with the film size press becoming the norm in preference to the older flooded pond two-roll technology. Film size presses involve the application of a controlled amount of water-based size mixture evenly to the paper sheet by first creating a uniform film thickness on an adjacent roll and then transferring the film onto the paper sheet as if printing the size film onto the paper. The water applied in the size press is evaporated in the after-dryer section. Film size presses are mainly used for printing and writing papers and packaging grades made from recycled fibre. If size is applied by a film size press, only relatively small amounts of concentrated size have to be discharged when operational conditions are changed.

Although size press treatment is a form of paper coating to improve its surface properties, the term 'coating' is usually reserved for the application of a pigmented slurry to the surface of the paper in order to improve printability or for other specialist applications.

7.1.6 Coating (optional)

Paper composed only of individual fibres has a relatively rough surface. Since this roughness has a negative effect on print quality, a large amount of paper and board is coated in order to attain a smooth surface for printing. The term 'coating' describes the application of a mixture of water, white pigments, binder, and various additives to one or both sides of the surface of the paper in order to create specific surface properties. Paper may be coated either with equipment that is an integral part of the paper machine (on-machine) or on separate coating equipment (off-machine). The coated sheet is first dried by infrared radiation, by hot air or by a combination of an infrared and a hot air dryer and finally a short steam-heated cylinder section.

The composition of the coating colour is largely determined by the demands made on the surface of the paper by the particular printing process. Coatings can be complex mixtures of ingredients and usually require preparation before use. The coating colour preparation is carried out in the 'coating kitchen' where the coating chemicals are mixed and adjusted. The finished coating colour is screened before entering the coating machine. Some raw materials may be received wet for easier handling and to avoid any dust problems. All coatings will contain some sort of binder, which is mainly carboxylated styrene-butadiene, styrene-acrylonitrile, or acrylic latexes. Starch may be used for added stiffness and will typically be cooked prior to use. Stearates (Ca and NH_4) are used to provide lubrication during the calendering process and to provide surface texture. Pigments such as fine clay, talc, or calcium carbonate will be used, as will colours, brighteners and other low volume speciality chemicals.

Coating machines consist of an unwinder, a coating station or stations (coating application unit), a drying section (infrared, hot-air and heated cylinders) and a reel. For optimal operation, various control measurements are installed.

Nearly all coatings are water-based and applied with a roller, air knife, size press, blade and bar and more recently curtain colour coating systems. The objective is to apply a consistent and uniform thickness of coating material to the paper sheet. Every coating system needs a specific coating colour in which solid content and viscosity have to be settled for reaching the best runnability and paper quality results. Air knives work at about 30 – 50 % solids, others about 50 – 70 %. The coating slurry is generally recirculated through the system with constant filtering to remove fibres and other contamination in order to maintain the slurry quality. These filters will be cleaned at regular intervals thus generating a concentrated waste stream.

There are different grades of coated paper and boards. However, the classification of coated grades has not yet been standardised. Certain terms for describing the major types of coated paper and board are used throughout Europe. They are described below.

Art paper
The term refers to wood-free or paper containing only a small amount of wood that is coated on both sides. The weight of the coating exceeds 20 g/m^2 per side, resulting in the complete coverage of the fibre structure of the paper. Up to three coats are applied to each side to obtain the high quality required. This paper is used for high-quality printed products.

Machine-coated papers
This grade includes both wood-free paper and wood-containing paper with a coat weight of up to 25 g/m^2 per side. Higher weights are often obtained by applying a double coat. The coating formulations are normally simpler than those for art paper. Machine-coated papers are used mainly for printing purposes.

Light-weight coated (LWC) papers
These papers contain high amounts of wood fibres and have coat weights in the range of 5 – 12 g/m^2 per side. They are mass-produced papers and are used for the production of catalogues, magazines, advertising pamphlets, etc. The weight ranges have been extended below these limits (ULWC = ultra-LWC) and also above them (MWC = medium-weight coated and

HWC = heavy-weight coated). Today the heavy grades are often provided with a double coat and are, consequently, grouped with machine-coated grades.

Folding boxboard and chromoboard

In these grades of board, the white topliner is coated on the board machine. The remaining layers of board can consist of bleached or unbleached pulp or of paper for recycling. The coating weight is in the range of 12 – 33 g/m^2 and the coat is normally comprised of a precoat and a topcoat. More recently, three coating layers have also been applied. The board is rarely coated on the reverse side.

Depending on the operation of the coating kitchen, the coating application and the measures in place for recovery or separate treatment of effluents which contain coating colour, relevant releases to water can occur (see Sections 7.3.5 and 7.3.6). In some applications, somewhat increased concentrations of volatile organic compounds (VOC) can be measured in the exhaust gases of the drying hood.

Potential releases to water can be caused either by a spill of concentrated coating components (approximately 50 % consistency) from the coating kitchen or coater station or by a spill of diluted coating components from the washing water of tanks and piping. The concentrated discharges can be collected in tanks or mobile containers for solid waste treatment or for recovery of minerals as fillers, after removing the excess water by sedimentation. The diluted streams are collected in tanks, from where they are led to the effluent treatment. Usually, effluents from coating require a separate pretreatment in a flocculation plant (see Section 7.3.6). Otherwise, coating waste water may cause disturbances in the performance of the biological waste water treatment plant. In recent years, the membrane filtration technology described in Section 7.3.5 has produced good results in the recycling of coating colour. Applications in Finland, Sweden, France and Germany recover coating colour back to the coating kitchen where it is proportioned to the fresh coating colour. Coated broke is normally repulped so that some of the coatings are returned to the water circuit.

7.1.7 Dyeing of paper (optional)

Coloured papers are obtained by dyeing the paper stock or the paper surface (size press, paper coating). Optically brightened papers can be produced in the same manner.

Stock dyeing is the most widely used type of paper dyeing. Dyes, pigments, and optical brighteners are added either batch-wise in the pulper or mixing chest or introduced continuously into the stock flow. Continuous addition has the advantage of a shorter zone in the stock line that must be cleaned when the colour is changed. However, because of the lower contact time compared to batch addition, a lower colour yield is obtained for intensely coloured papers and more complex equipment is required for this dyeing process.

When the surface of the paper is coloured in the size press, the dyes are added to the size press liquor. Surface dyeing has gained acceptance only in individual cases because uniform dyeing of the paper is difficult to achieve. However, this process has the advantage of the absence of dyes in the water circuits.

Surfaces of papers can also be coloured by coating. In normal coating (see Section 7.1.6), the surface of the paper or board is covered with a pigment coating. In the case of coloured coatings, the starting material is the white coating mixture, and the desired shade is attained by adding a dispersion of an organic or inorganic pigment.

Depending on the fibrous material to be dyed and the intended purpose of the paper, different types of pigments and dyes are used as basic dyes (cationic dyes), direct dyes, and acid dyes. Additionally, fixing agents and other additives are used to improve dye fixation and to obtain better dyeing results. Inorganic pigments or organic pigments (e.g. azo and phthalocyanine types) and carbon black are pigments used for paper dyeing.

The potential environmental impact of dyeing is mainly the releases to water. Especially in mills with several changes of tints or shades per day, the water circuits have to be cleaned after a certain time. Usually, the paper mills work in campaigns producing first the paler tints, changing step by step to the deeper tints. The colouration of the water then just has to be readjusted. However, when for instance deep green is reached, the water system has to be washed. The coloured waste water is sent to the external recipient via the waste water treatment plant. Several times per month, the piping is subjected to a chemical treatment to remove deposits and colour in the piping. In some mills, elemental chlorine and hypochlorite are used as cleaning agents.

7.1.8 Addition of chemicals

Apart from the main raw materials, i.e. fibrous material and fillers, papermaking requires the use of various admixtures of chemical additives and auxiliaries. One part serves as a means to achieve certain paper properties (e.g. sizing agents, wet strength agents, dyestuffs, coating colours); the other part improves operations in the production process (e.g. retention agents, anti-foaming agents, cleaning agents, and slimicides).

Chemical additives may be delivered to a site ready for use or prepared on site. Typically, low volume speciality chemicals will be delivered ready for use whereas the higher volume chemicals may be delivered or prepared on site. This holds true for coatings as well as those added to the paper stock.

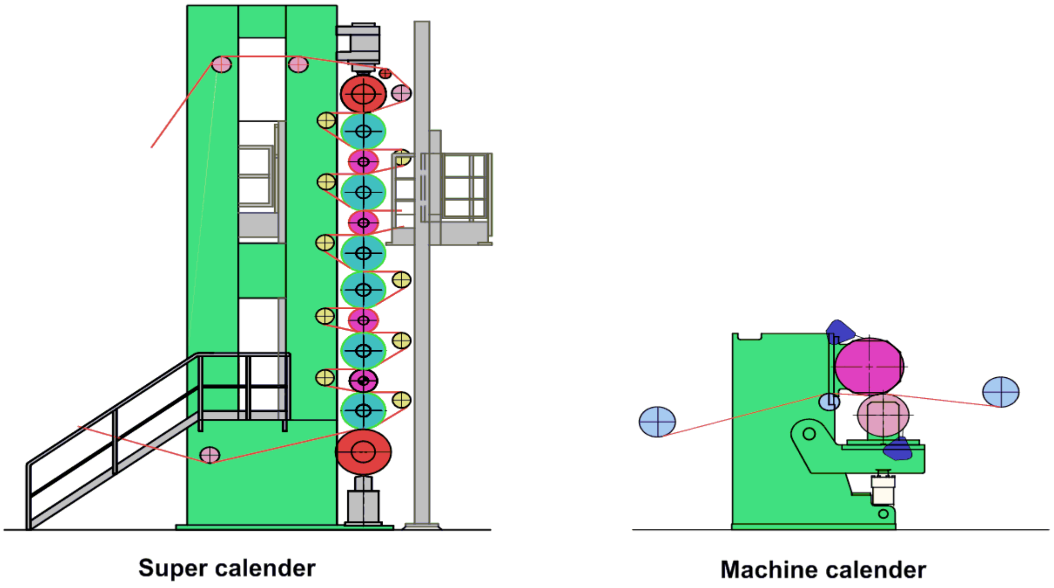
Chemical additives can be added at the wet end with the dilute feedstock or sprayed onto the wire, whereupon they are mixed into the body of the paper, or alternatively by the size press or the coater at the end of the machine where they are added to the surface. In the former case, the chemicals which fail to be retained in the paper web will remain in the water circuit, probably ending up in the effluent. The chemicals remaining in the water circuit may hinder the closing up of the water cycle and may thus have a negative impact on the effectiveness of the waste water treatment plant. However, it depends on the type and quantity of applied chemicals.

Adding chemicals to the surface by spray or by dipping is potentially more controlled and requirements only involve water for washing out and cleaning. However, this is only possible for a few applications. In these few cases, any wash water could be segregated for separate treatment. For example, liquid residues from coating can be treated separately in a precipitation step or by use of ultrafiltration (see Section 7.3.5 and Section 7.3.6).

The main papermaking additives and their environmental properties are discussed in more detail separately in Section 7.2.2.3. and in Section 2.3.2.1.

7.1.9 Calendering (optional)

The objective of calendering is to produce a smooth paper surface that meets the printing and writing requirements for the intended use. In calendering, the web is fed through counteracting press rolls and in this process the surface roughness of the paper is influenced by the action of pressure and temperature. A machine calender consists of two or more chilled cast-iron rolls with very smooth surfaces that are arranged one on top of the other as shown in Figure 7.5. Through calendering, smoothness is gained, but at the same time some other properties like thickness, strength and stiffness are reduced.



Source: Valmet

Figure 7.5: Example of two different calenders: supercalender and machine calender

The web is passed through the nips of these rolls (hard nips). Nowadays, calenders have a heated cast-iron roll combined with a roll with a soft plastic cover (soft nip). Two or more of these are arranged one behind the other. The rolls are heated internally with hot water, steam or heating oil.

For paper grades that require a more smooth and glossy surface, a further finishing is carried out in the supercalender (Figure 7.5). Supercalendering improves the print quality and is used to increase printability, which is necessary in the case of picture printing. Before supercalendering, the web is for some grades checked in rewinders for paper qualities like SC paper and LWC paper. The supercalendering system consists of the reel-off stand, the actual supercalender, and the reel-up stand. The environmental impact of supercalendering is mainly the energy consumption needed for running the machine and heating the rolls.

7.1.10 Reeling/cutting/dispatch

The final paper product will be made to customer specifications such as in rolls or sheets, and with a particular paper weight, colour and finish. The paper machines produce large rolls of paper where the width of the paper web is determined by trimming the sides of the web at the wet end of the machine. Sharp rotary knives or guillotines trim rolls or sheet sizes to the required specifications before wrapping for dispatch. The moisture content of the paper is adjusted to balance with the atmosphere in the print room. The environmental consequences of these operations are relatively small, but there is the potential for dust generation in cutting. The processes involved consume little energy. Waste is generated from trimmed paper, which is normally recycled as broke back to the papermaking process.

7.1.11 Examples of non-integrated paper mills in Europe

Paper and board manufacturing processes can take place at the same site as pulp production (integrated mills) or separately at a site of their own (non-integrated mills).

Different paper and board grades are manufactured from different raw materials with machines that are designed for each grade. However, until now there has been no common understanding in Europe as to which paper grades have to be distinguished from an environmental point of view to describe achievable emissions of paper mills that have implemented BAT. The classification systems of trade statistics (e.g. national statistics, CEPI statistics) are not the same as those used by the Member States for setting legal requirements for the paper industry. The classification of paper mills varies from country to country. As a consequence, there is no existing classification that can just be adopted.

In Europe, the largest number of non-integrated paper mills are manufacturing fine paper, tissue or speciality papers. However, it has to be borne in mind that in some countries these paper grades are also produced in integrated mills. For instance, in the Nordic countries, the fine paper mills have in most cases been built adjacent to a pulp mill. Tissue is also either produced in integrated paper mills (mainly using recovered fibres) or in non-integrated paper mills.

7.1.11.1 Uncoated wood-free printing and writing papers

Printing and writing papers include products like magazine printing papers containing wood (see Chapter 5) and wood-free natural printing papers.

Wood-free natural printing papers consist almost exclusively of bleached hardwood and softwood chemical pulp. Between 10 % and 30 % (or even more) may be made up of fillers. These uncoated papers are usually sized internally and further upgraded by surface sizing and calendering. Wood-free printing papers yellow very little and have a high strength.

During the cleaning and screening of the stock, only small quantities of rejects are purged, as the raw materials are largely pure. The refining operation shortens and fibrillates the fibres to suit the paper quality in question. During fibre fibrillation, a small part of the organic material is dissolved.

Other wood-free paper products consisting primarily of chemical pulp include tissue, cellulose wadding, filter paper, decorative paper, base paper for lamination or parchment base paper. They also include those products where size is added to the mass to reduce the natural absorption capacity of the fibre web, e.g. poster paper, carbon paper, kraft papers and drawing papers. Sizing increases the organic substances in the water circuits and during repulping of the broke. Most of the additives can be redissolved (e.g. converted native starch).

7.1.11.2 Coated wood-free printing and writing paper

Coated printing papers represent the largest group within printing and writing papers. The largest part of this group, coated printing papers containing wood, is described in Chapter 5.

The base paper for wood-free, coated paper consists predominantly of chemical pulp. A layer of coating colour is applied to both sides of the paper web. These papers may be additionally calendered to produce a matte or glossy surface. In addition to printing paper and art paper, the production of chromoboard (the white topliner of board) is also included in this group.

During the stock preparation process, only small quantities of rejects are purged, as the raw materials are largely pure. Coated paper is dried twice, in the usual drying section and again after application of the wet coating. Depending on the paper type produced, additional additives are added in the mixing chests which can result in waste water contamination. Coating and finishing consists of both surface sizing and application of coating colour (one or several coats on one or both sides). The preparation of the coating colour and the repulping of the broke result in additional waste water contamination, consisting of undissolved substances as well as dissolved oxygen-consuming substances.

7.1.11.3 Tissue paper

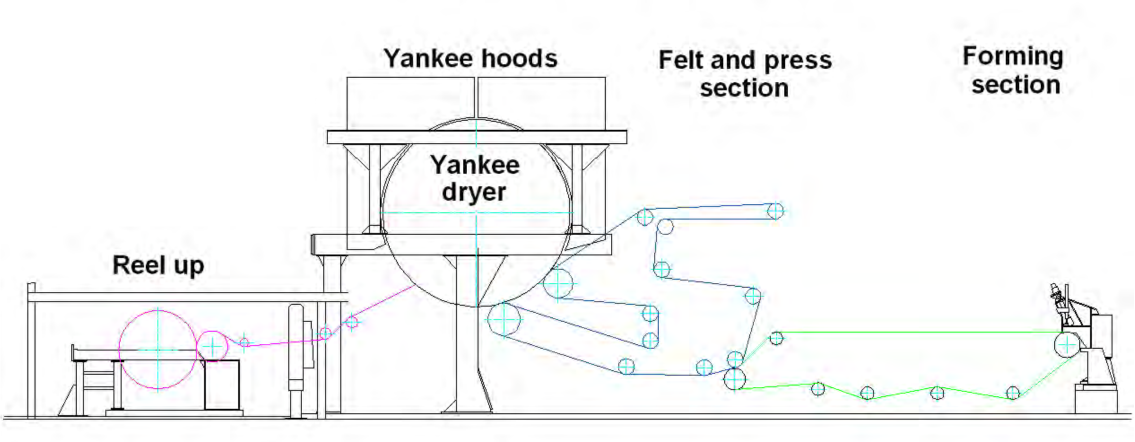
Tissue is usually a product where the single layers produced in the paper machine are combined in a multi-layer product after the paper machine in a separate unit. This is because of its low basis weight sheet (down to 12 g/m^2 on the wire). The main product properties are softness and smoothness, cleanliness, high absorption capacity and strength. The conversion into finished products is often integrated with the tissue production, i.e. tissue mills often sell their products to the end-consumer (including packaging).

Tissue is predominantly made of bleached chemical pulps or deinked recovered fibres (see Chapter 6). In the case of using paper for recycling, the fillers and fines (very small fibres unsuitable for tissue manufacturing) have to be removed. Normally, a mixture of different shares of virgin and recovered fibres is used. For the processing of paper for recycling with deinking, the reader is referred to Section 6.1.3.4. If virgin fibres are used, the paper mill can be integrated or non-integrated into pulp-making. For non-integrated tissue-making mills, additional water is required to repulp the virgin fibres.

In tissue-making, different processes are used to manufacture different types of tissue products with different characteristics. The way of drying the tissue determines most of the tissue characteristics. There are three main types of processes:

- conventional tissue-making,
- through-air drying process (TAD),
- hybrid processes.

The most common process is the conventional tissue paper machine with a conventional Yankee dryer (see Figure 7.6). The tissue sheet is formed on a moving fabric, where water is removed by drainage. The sheet is then transferred to a felt where more water is removed by pressing and vacuum. Here the tissue sheet is compressed. For full drying, the sheet is transferred to a Yankee cylinder and dried by adding steam to the cylinder and blowing hot air onto the tissue surface. Finally the tissue is removed from the Yankee cylinder by a creping blade and the sheet is reeled up.

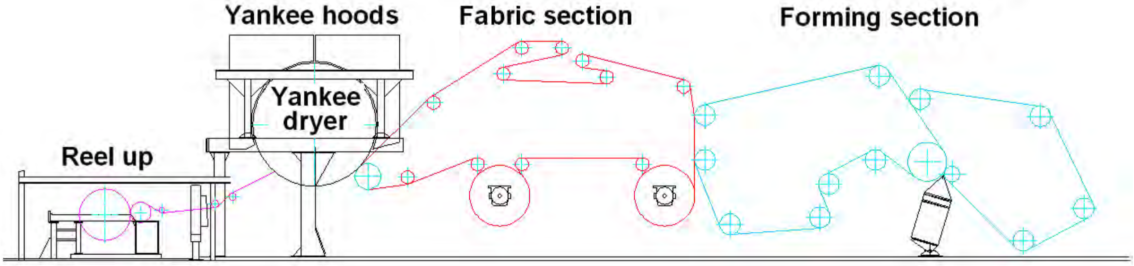


Source: ETS

Figure 7.6: CWP tissue process with conventional Yankee dryer

To make bulkier tissue with high absorbance and softness, the TAD process was developed about 20 years ago. In the TAD process, pressing of the tissue web is minimised. The tissue sheet is formed on a moving fabric where water is removed by drainage and vacuum. Because of the high moisture, the sheet is moved to a second fabric using a vacuum. To obtain the bulkier characteristics, the sheet is dried by passing it over one or two TAD dryers where hot air

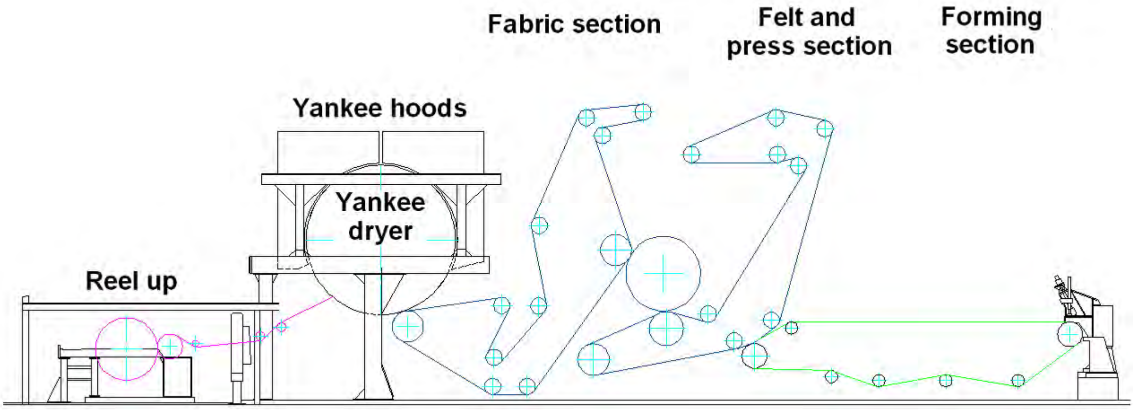
(>350 °C) is blown through the sheet. Finally the sheet may be transferred onto a Yankee cylinder for further drying with steam and hot air. The TAD process (Figure 7.7) is more energy-intensive but it delivers a very soft and bulky sheet that can absorb up to twice as much water as conventional tissue while utilising less fibre. The higher energy needs are linked to the reduced pressing and multistep drying with TAD and Yankee dryers while power use is higher due to the vacuum requirement and large airflows (fans).



Source: ETS

Figure 7.7: TAD tissue process with two TAD drying cylinders and Yankee dryer

During the last decade, new hybrid technologies have emerged that also enable small machines to produce a higher bulk tissue than conventional machines with a texture or structure similar to that produced in a TAD machine. In terms of energy consumption, these hybrid tissue technologies are somewhere in between conventional and TAD tissue: they have lower energy consumption than TAD tissue, but higher than the conventional tissue machines referred to. Hybrid technology deployment in Europe is still limited but is increasing. Figure 7.8 gives an example of a patented hybrid tissue-making process.



Source: ETS

Figure 7.8: A patented hybrid tissue-making process

Each tissue-making process produces a specific kind of tissue suitable for different applications. Kitchen towel requires high strength and good absorption while for facial tissue softness is most important. Premium bathroom tissue requires high softness and strength while low-quality/cost bathroom tissue has less softness and lower strength. The surface structure of the tissue is the basis for these characteristics. Multilayer products are made to further improve the above characteristics [CEPI comments WD Chap 7].

During the stock preparation process there are only small quantities of losses of fibrous material (1 – 2 %). Air emissions depend mainly on the energy supply and the layout of the drying process. Tissue mills tend to use somewhat higher volumes of fresh water on showers than other paper mills because the cleanliness of wires and felts are crucial for the very light-weight sheet formation. Many tissue machines make frequent changes of grades and/or colours for different products, reducing somewhat the efficiency of the use of raw materials, water and energy. This phenomenon is more pronounced for small mills with only one paper machine. Depending on the product properties, chemical additives are used which may result in waste water contamination. As an example, the use of organic halogenated resins for wet strength improvement leads to higher levels of AOX in waste water.

7.1.11.4 Speciality paper

Paper and boards for technical and speciality uses cover a wide range of grades. Speciality papers have to fulfil very specific properties defined by their particular end use. Some of these properties are similar to those for commodity paper grades, but at a significantly higher level or within much closer tolerances (e.g. dry strength, porosity, thickness, optical properties). Other characteristic properties are very particular, such as cleanliness, high absorption and porosity, hydrophobicity, barrier properties, anti-soiling, resistance to certain chemicals, electrical conductivity, wet strength, abrasion resistance, defined pore size distribution, chemical reactivity, high opacity, transparency, appearance and texture.

Some examples for speciality papers are (with this list being far from complete):

- banknotes and security paper,
- decor and overlay paper,
- highly absorbent papers/boards,
- labels and release papers,
- wet laid nonwovens and filter papers/boards,
- thermal printing paper,
- photographic and digital imaging paper,
- technical drawing paper,
- creative paper for advertising and luxury packaging, mostly coloured (with a great choice of colours, finishes, textures and grammages),
- papers for cigarettes,
- carbonless copy paper,
- filter paper for laboratory use,
- flexible or luxury packaging papers,
- tracing and glassine papers,
- thin printing papers,
- papers with special barrier properties against water, water vapour, grease, etc.,
- electrical papers (cable paper, capacitor tissue, transformer board),
- building papers (wallpaper, barrier papers),
- artist's papers/board, luxury papers/boards, coloured papers/boards, etc.,
- bioactive papers/board,
- parchment paper and fuel, oil and other liquid filter paper,
- other.

Speciality papers are in general lower quantity products and therefore are typically produced on smaller paper machines starting at production rates of a few tonnes per day. Because of the low quantities and the very specific demands from the customer side, a further typical feature in speciality paper production is the high frequency of grade changes of at least one change of produced paper grade per paper machine and day as a yearly average (often significantly more), leading to higher overall changeover losses (higher broke levels and material losses). Together with the small size of the paper machines, this leads to significantly higher specific consumption values of water, materials and energy. It is therefore necessary to take account of these special circumstances for speciality paper mills.

Strict requirements regarding cleanliness and/or incompatibilities between furnish components of different grades (also some of the chemical additives) may necessitate a more or less complete emptying of the stock and water system when changing paper types. Due to the high cleanliness requirements in the production of most speciality papers, in many cases water can only be recirculated to a limited extent. The specific waste water flow of speciality paper mills varies from 13 (30) m^3/t up to 200 (150) m^3/t depending on the product and the specific production conditions. The concentration of the organic load of the waste water for example is often low but together with the comparatively higher flow may result in relatively high specific emission loads per tonne of product.

The production of speciality papers often requires costly fibrous materials and/or specific fibre-processing equipment. For instance, some speciality paper grades contain, besides chemical pulp, other fibres such as synthetic fibres, cotton, abaca, flax, sisal, etc.

To achieve the demanded high strength values or specific characteristics, such as transparency or greaseproof properties, intensive refining of the fibrous raw materials is often required, which also increases the specific electric energy demand. During refining, the fibres are shortened and strongly fibrillated. During fibre fibrillation, a part of the organic material is released to water. Refining also leads to significantly slower dewatering on the wire section. In order to achieve a high level of retention of costly, special inorganic filler pigments and various chemical additives, gentle dewatering in the wire section is necessary with many speciality paper grades. The high degree of refining and/or the gentle dewatering often result in a comparatively low dry content of the paper web after the press section, which causes a higher energy demand in the drying section. Filter paper also requires more energy for drying as these papers cannot be pressed before the drying section or else they will lose porosity. \

Depending on the speciality paper type, various chemical additives are introduced in the furnish and/or applied in surface treatments (e.g. sizing, coating, dyes, speciality chemical additives), which may partly end up in the waste water.

The possibilities for closing up the water circuits may also be limited by the production technique for this product group (e.g. increased heat because of intensive refining) or by qualitative demands placed on the individual paper types (e.g. electric conductivity, sensory characteristics, cleanliness).

Table 7.2 gives examples of some of the speciality paper types produced in Europe, some of their product characteristics, environmental aspects and examples of specific BAT to be considered for these paper grades. Given the variety of grades in the group of speciality papers, this list is not exhaustive.

Table 7.2: Examples of major characteristics, environmental aspects and specific environmental techniques to be considered for various speciality paper types

Type of speciality paper manufactured	Major characteristic of the paper	Specific environmental concerns during manufacturing	Specific environmental techniques applied
Paper grades from highly refined fibres (e.g. glassine, parchment, transparent, greaseproof, baking papers)	Transparency and greaseproof, resistance, strength properties, stiffness	High energy demand for refining and calendering; more COD dissolved from virgin pulp, higher energy demand in paper drying due to lower dry content after press section	Refining optimisation, heat recovery from the refiners; biological WWTP with/without flocculation
Paper grades that need special chemical additives and/or fillers or need them in higher amounts (e.g. filter paper, fire-retardant paper, carbonless, wet strength papers, coated paper for full colour inkjet, base papers for lamination (extrusion or metallisation), security papers, release (base) papers and label (base) face papers, thermal papers)	Wet strength, hydrophobicity, barrier properties to prevent migration of chemicals, high absorption of liquids, porosity, chemical reactivity, optical properties (opacity), water or oil resistance, etc.	Higher waste water load and sometimes poorly biodegradable substances; higher energy demand for paper drying and for chemicals drying; use of AOX-containing additives depending on the additives applied, not all broke may be repulped; often highly specified paper grades (very specific demands of the customer) and small batches leading to lower efficiency levels; often higher energy consumption	Special chemical assessment and management system; adapted waste water treatment plant (WWTP); use of fewer AOX- /lower AOX-containing chemicals; heat recovery drying section; optimisation of mill broke and management of its further use
Small quantity paper grades with frequent changes(1) of produced paper grades (e.g. more than once a day – up to twelve times/day)	Very specific demands of the customer for smaller quantities also have to be met; often produced on various smaller machines	Higher water consumption; higher pollution load because of complete emptying of stock and water system several times per day; higher broke levels (depending on the additives applied, not all broke may be repulped)	Improvement of paper production planning to have a longer run of each product; adapted management of water circuits; adjustment of broke system, chest capacities, adapted WWTP, optimisation of mill broke and management of its disposal
Example: decor paper, i.e. printed and usually coated paper; impregnated with melamine resins	High wet strength, high cleanliness requirements, highest demands on colour accuracy	Use of AOX-containing chemicals, high specific energy consumption; after drying the paper, wet strength resins need to be cured; downtime at the start of each production to adjust the colour on melamine board with power consumption but not production; high specific water consumption	Use of fewer AOX-containing chemicals
Example: thermal paper	Light-weight; high mechanical strength; high brightness; highly sized; requires a low level of contamination and holes in base paper	Very low level of broke reuse; large number of organic additives associated with increased COD; extensive refining which means greater electricity consumption in refining and steam consumption in drying	Special chemical assessment and additive management system; adapted waste water treatment plant (WWTP); IT systems to optimise production batch combinations and length.

(1) Frequent change of produced paper grade (or type) means one or more changes in a product on a paper machine per day as a yearly average, meeting one or more of the following features: (i) grammage changes equal to or over 5 g/m^2; (ii) changes in more than one measurable product characteristic, i.e. whiteness level, moisture content, porosity level, etc.; (iii) changes in pulp composition (different types of pulp or softwood/hardwood ratio); (iv) switch between functional paper chemicals (changing functionality of the product bulk and/or surface) during production.

7.1.11.5 Paperboards

Paperboards are classified into three categories: cartonboards, containerboards and speciality boards. There are some common features for all three.

- Basis weight is usually higher that 150 g/m^2, but there are also lower weights, e.g. in liners and corrugating medium, even below 100 g/m^2.
- Most of the paperboard grades are multi-ply products like folding boxboard and liquid packaging board.
- Packaging is the most common end use of paperboards and this emphasises the need for strength as the key functional property in competition with other packaging materials.

Multilayer forming of paperboard consisting for example of three white water circulation systems typically leads to higher specific water consumption compared to single layer papers. However, this is compensated by the optimum combination of properties and the overall functional efficiency of the products in the packaging chain. The same analogy with the adaption of multilayer techniques applies to on-machine coating and in-house sheeting: board mill-specific environmental loading may be higher than average but the overall efficiency is improved and the total impacts are reduced.

Folding boxboard (FBB), solid bleached board (SBS) and liquid packaging board (LPB) are the primary fibre grades that are especially extensively used in food packaging and which are therefore governed by stringent requirements concerning hygiene, purity and odour and taint-free characteristics. These end use requirements often limit the possibility of recycling process waters to a certain extent due to increasing odour and tainting risks. Food-contact end uses also set strict requirements for all process chemicals used.

Cartonboards are divided into various subgrades: folding boxboard (FBB), white lined chipboard (WLC), solid bleached board (SBS), solid unbleached board (SUS) and liquid packaging board (LPB). For good printing properties, most of the cartonboard grades are pigment-coated. The top side is typically double or triple coated and the reverse side may also be coated. LPB is coated in web form by a functional barrier on both sides in the conversion process and used even in aseptic packages.

FBB machines typically utilise a MG cylinder (Yankee) in order to obtain good surface smoothness without deterioration of bending stiffness. FBB and WLC in particular are for the most part sheeted in the board mill and delivered in sheets to the customer, because sheet-fed offset is the dominating printing method in carton production.

Containerboards are divided into linerboards and corrugating mediums. Linerboard is typically a two-ply product and the top side may also be coated. It may consist of primary fibre, unbleached, bleached or a combination and in this case it is usually called kraftliner or white topliner. Linerboard consisting of recycled fibre may have up to four plies and it is called Testliner. Corrugating medium is used as the middle layer of corrugated board. It may consist of semi-chemical pulp (in this case often called fluting), of semi-chemical pulp and recycled pulp combined or of only recycled fibre (in this case often called Wellenstoff). Containerboards are delivered in reels for corrugated board production plants. [CEPI comments WD Chap 7]

7.2 Current consumption and emission levels of paper mills

7.2.1 Overview of input/output for the production of paper and board

An overview of raw material and energy input and the output of products, residues for further utilisation and major releases (emissions, waste, etc.) of the manufacturing of paper and board is presented in Figure 7.9.

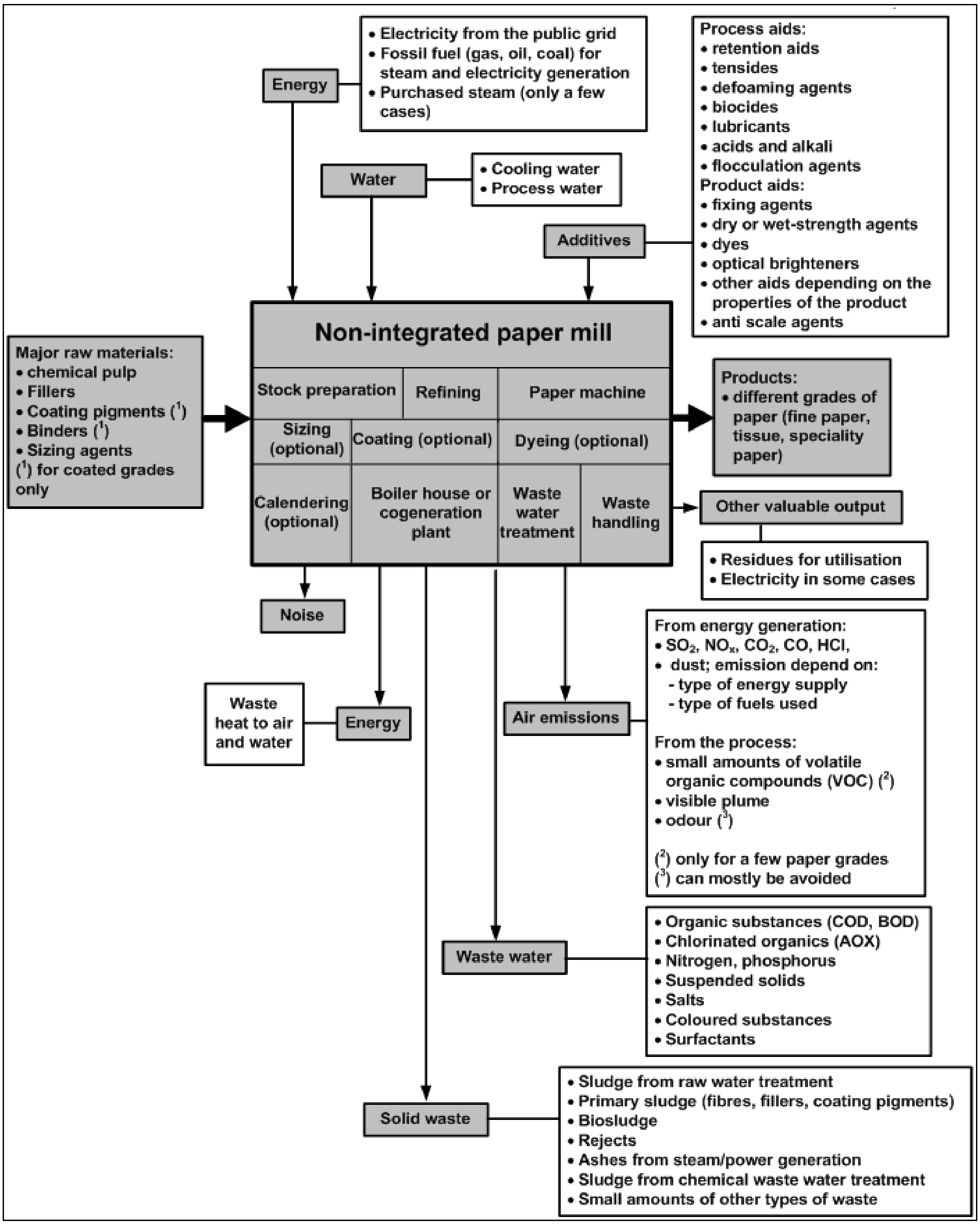


Figure 7.9: Mass stream overview of a paper mill

The presence of some substances depends mainly on the paper grade and properties to be achieved, the type of raw materials used and the type of energy supply.

Using the mass stream overview, specific raw material consumption and specific emission per tonne of product can be calculated. Table 7.3 shows data from the largest fine paper mill in Europe because no other data were available. This example represents a mill that is among the best performers.

Table 7.3: Annual average input/output data from the largest non-integrated wood-free fine paper mill in Europe (coated and uncoated grades) manufacturing about 1 228 Mt/year (updated 2012)

Input			Output		
Raw materials	**Value**	**Unit**	**Product**	**Value**	**Unit**
Chemical bleached pulp (5 % moisture)	576	kg/t	Fine paper (coated and uncoated)	1 000	kg
Fillers and coating pigments (73 % DS)	385	kg/t	**Emissions**		
Starch, binders and other additives	74	kg/t	CO_2 (1)	229	kg/t
			NO_X (1)	0.120	kg/t
			CO (1)	0.02	kg/t
			SO_2 (1)	Negligible	kg/t
Energy			Dust (1)	Negligible	kg/t
Natural gas for steam generation	4 082	MJ/t	Noise: at two points of measurement (2)	40 (600/1 200 m)	dB(A)
Purchased electricity (3)	566	kWh/t	COD	0.181 60	kg/t mg/l
Total energy consumed	1 700	kWh/t	BOD_5	0.035 12	kg/t mg/l
Total primary energy (4)	2 674	kWh/t	Suspended solids	0.059 20	kg/t mg/l
			AOX	0.0008 0.28	kg/t mg/l
			$N_{inorganic}$	0.011 4	kg/t mg/l
			Tot-P	0.003 1	kg/t mg/l
			Water vapour	1.5	m^3/t
			Waste water flow	3.0	m^3/t
Water demand			**Residues**		
Raw/fresh water	4.2	m^3/t	Sludge (utilised in the brick industry)	11.7	kg/t
			Other waste	4.5	kg/t
			Hazardous waste	0.1	kg/t

(1) Air emissions from purchased electricity are not included. Steam is produced on site in a gas-fired steam boiler. Air emissions from non-integrated paper mills depend mainly on the type of fuel used.
(2) The distance from the paper mills to a commercial area is about 600 m; the distance to a residential area 1 200 m.
(3) The consumption of power includes the delivery of raw water pumps.
(4) The contribution of purchased electricity to the specific primary energy consumption is calculated assuming an energy yield of the electricity-generating companies of 36.75 %, i.e. purchased electricity of 1 kWh corresponds to primary energy of 2.75 kWh. In this case, 566 kWh/t corresponds to 2 673 kWh/t primary energy (e.g. coal). Conversion factor: 1 MJ = 0.2778 kWh and 1 kWh = 3.6 MJ.
[CEPI input BATIS 25-1-12], [CEPI comments WD Chapter 7]

The emission data for waste water discharges represent the situation after two-stage biological treatment (high-load trickling filter plus activated sludge).

Table 7.3 refers to a very large paper mill. Smaller mills often have higher specific energy consumption values and also higher water consumption than large mills. Some reasons for differences in environmental performance between larger and smaller paper mills are given below.

- The amount of fresh water needed for continuously trimming the edges of the web is the same for wider and narrower machines. Thus, paper machines with a larger width use relatively less water for that purpose.
- Large machines usually produce bulk grades and have a very large production capacity compared with smaller machines, but, at the same time, large machines are not flexible. Focusing on bulk production with fewer changes of grades helps in achieving more economical and a better environmental performance.
- The economies of scale facilitate investments in clean technology for larger mills.
- Larger mills have more financial and human resources for research and development.

In Table 7.4 consumption and emission levels for typical tissue mills are compiled. Emissions are given as typical values after flue-gas and waste water treatment. The main difference between virgin and secondary fibre mills is solid waste. While virgin fibre mills generate 10 – 40 kg waste/t of paper (100 % DS), amounts of 400 – 600 kg waste/t of paper result from recycled fibre processing (see Section 6.2.2.6). Some of the value ranges in Table 7.4 are quite wide because they cover:

- different tissue-making processes (conventional, TAD, hybrid);
- small and large tissue mills;
- old and new paper machines;
- mills with and without cogeneration (higher natural gas consumption);
- mills with many grade changes (more stop-start);
- mills with many colour changes (higher water consumption for cleaning);
- mills in different geographical locations (no water restrictions in Nordic countries).

Table 7.4: Consumption and emission levels for typical tissue mills

Input			Output		
Raw materials	**Value**	**Unit**	**Product**	**Value**	**Unit**
Chemical bleached pulp	1 010 – 1 020	kg/t	Tissue	1 000	kg
Wet strength resins	0 – 80	kg/t	**Emissions**		
Starch, dry	0 – 30	kg/t	CO_2 (1)	300 – 1 800	kg/t
Colour agents	0 – 2	kg/t	CO_2, regenerative		kg/t
Other additives	0 – 20	kg/t	NO_X (1)	0.5 – 5	kg/t
			SO_2 (1)	0.07 – 10	kg/t
			Dust (1)	NA	kg/t
Energy				**After on-site biological waste water treatment**	
Fuel for sheet drying	4 600 – 21 000 (2)	MJ/t	COD	0.3 – 4.5	kg/t
Total electricity consumed (3)	900 – 3 100 (2)	kWh/t	BOD_5	0.1 – 0.5	kg/t
Total energy consumed (4)	2 000 – 10 000	kWh/t	Suspended solids	(0.02)(*) 0.1 – 0.7	kg/t
			AOX	1 – 16	g/t
			Tot-N	(2)(*) 10 – 480	g/t
			Tot-P	(0.3)(*) 0.4 – 30	g/t
			Water vapour	1 – 3 (up to 8 for TAD machine)	m^3/t
			Waste water flow	4 – 70	m^3/t
Water demand			**Residues**		
Raw/fresh water	5 – 71	m^3/t	Solid waste	10 – 40 (at 100 % DS)	kg/t

(*) Data in brackets from recent data collection/questionnaires.

(1) The emissions include all fuel types for the generation of steam. Emissions do not include purchased energy.

(2) The upper end of the range refers to tissue mills using through-air drying (TAD) or re-creping techniques. To operate TAD, enormous volumes of air need to be moved by large fans.

(3) No allowance is made for the efficiency of electricity-generating companies.

(4) The specific primary energy consumption can be calculated from this figure by taking into account the energy yield of the electricity-generating companies. Conversion factor: 1 MJ = 0.277 8 kWh and 1 kWh = 3.6 MJ.

NB: Data are from ETS for 2008, updated to 2012 by [CEPI comments WD Chap 7]. Energy data are from a total of 53 mills including some with TAD. Mills include virgin fibre and secondary fibre. Waste water data are from a total of 25 mills with on-site biological treatment, again using virgin and secondary fibre. Data for the water vapour flow provided by Assocarta.

In Table 7.5, consumption and emission levels for a non-integrated wood-free speciality paper mill (coated and uncoated specialities for graphical and industrial applications) are compiled.

Table 7.5: Annual average input/output data for a non-integrated wood-free speciality paper mill (coated and uncoated) manufacturing 212 500 tonnes net saleable paper

Input			**Output**		
Raw materials	**Value**	**Unit**	**Product**	**Value**	**Unit**
Chemical bleached pulp (5 % moisture)	709	kg/t	Speciality papers, coated and uncoated	1 000	kg
Fillers ($CaCO_3$, 73 % DS)	313	kg/t			
Coating pigments ($CaCO_3$, kaolin, 73 % DS)	7.0	kg/t	**Emissions**		
Starch, dry	49	kg/t	CO_2	661	kg/t
Binders, dry	0.3	kg/t	NO_X	0.45	kg/t
Sizing agents, 20 % DS	10.5	kg/t	CO	0.14	kg/t
Other additives and dyes	57	kg/t	SO_2	0	kg/t
			Dust	Negligible	kg/t
Energy			Noise	NA	dB(A)
Natural gas for steam generation	7 180	MJ/t	COD	1.13 (87)	kg/t (mg/l)
Gas for forklift trucks	0.019	MJ/t	BOD_5	0.30 (23)	kg/t (mg/l)
Consumed electricity from CHP plant	683	MJ/t	Suspended solids	0.20 (16)	kg/t (mg/l)
Purchased electricity	4.8	kWh/t	AOX	0.0026 (0.2)	kg/t (mg/l)
Total energy consumed	2 682	kWh/t	$N_{inorganic}$	0.005 (0.4)	kg/t (mg/l)
Total primary energy	2 690	kWh/t	Tot-N	0.066 (5.1)	kg/t (mg/l)
			Tot-P	0.015 (1.2)	kg/t (mg/l)
			Waste water flow	13.0	m^3/t
Water demand			**Residues**		
Raw/fresh water	13.4	m^3/t	Sludge (utilised in brick industry)		kg/t
			Other waste		kg/t

NB: Waste water emissions given as annual average values after biological treatment.

Source: [CEPI comments D1]

7.2.2 Consumption and emission levels

The following aspects associated with paper manufacturing are of concern:

- the consumption of raw materials,
- water use,
- use of chemical additives,
- energy demand,
- waste water and emissions to waste water,
- solid waste generation,
- air emissions from paper machines,
- air emissions from energy generation,
- odour from vapours and from waste water treatment plant (local),
- noise from paper machines (local).

Low frequency vibrations and emissions of visible plumes can also be local aspects of concern. No information was provided on these issues and therefore they are not further described here.

7.2.2.1 Consumption of major raw materials

Paper is made from fibres, water and chemical additives. The consumption of raw materials in papermaking depends strongly on the paper grade manufactured and the final product properties and qualities to be achieved. In Table 7.6 examples of raw materials used are compiled. Some product characteristics are also given.

Table 7.6: Examples of major raw materials used for the manufacturing of different types of paper

Paper grade	Major raw materials used	Some product characteristics and product examples
Newsprint	Few added chemicals; sometimes pigments added; very little colour; uses mechanical pulp or RCF	Narrow weight range: 40 – 52 g/m^2 a) 100 – 70 % RCF-based + 0 – 30 % TMP b) mainly TMP + 0 – 50 % DIP
Kraft wrapping	No added fillers; coloured; uses mainly unbleached kraft pulp	High strength product; 70 – 100 g/m^2
Kraftliner or Testliner	No added fillers; uses unbleached kraft pulp and RCF or RCF only	Heavier weight: 110 – 160 g/m^2 Testliner: 90 – 100 % RCF
Board	Often different compositions in different plies; mostly multi-ply sheet; all fibre types including RCF	Higher basis weights: 175 g/m^2 + (up to 2 000 g/m^2)
Writing and printing	All grades of fibre, mainly bleached; fillers, sizes, colours, brighteners; may be coated; wide range of basis weights	Precise specification for user; specific weight from 30 g/m^2 to 50 – 60 g/m^2 (LWC) up to 90 – 150 g/m^2
Tissue	No added fillers; wet strength additives; uses chemical pulp and RCF in different mixtures	Light-weight product (^{1}), e.g. handkerchiefs: 15 g/m^2 (for three sheets), napkins: 20 g/m^2 (for two sheets)
Speciality papers	Specific fibre processing; the pulp used can vary considerably in type and quality	This group covers a wide range of grades

(^{1}) The sheet made on a tissue machine rarely exceeds 40 g/m^3. The higher basis weights of tissue products are achieved by plying up in converting.

7.2.2.2 Water use

In paper mills, fresh water is mainly used in the ways that follow.

- As cleaning water for the paper machine, called shower water. The function of showers is to lubricate and to clean forming fabrics and wet press felts to maintain a satisfactory dewatering performance of: 5 – 20 m^3/t.
- As sealing water and confining in stuffing boxes, suction boxes, vacuum systems and cleaners: 1 – 6 m^3/t.
- As a solvent and dispersant for fillers and additives: 1.5 – 3 m^3/t.
- For some paper grades, e.g. speciality paper: make-up water in stock preparation.
- Cooling of process equipment: 3 – 10 m^3/t. These waters are often recirculated and used as process water. Other mills discharge them separately. Therefore, this water is normally not included when the water consumption of paper mills is reported.
- Power plant: 2 – 3 m^3/t. This water is normally not included when the water consumption of paper mills is reported.

The simplified scheme in Figure 7.10 shows by use of an example the major positions where fresh water is used. It assumes that cooling water is reused in the process. Paper mills discharging cooling water would need correspondingly more fresh water. When comparing figures on water use in paper mills, one has to make sure that the compared figures include the same positions for water use. Most of the water used by the paper mills is discharged, and only a minor part is consumed, being retained in the product as humidity content.

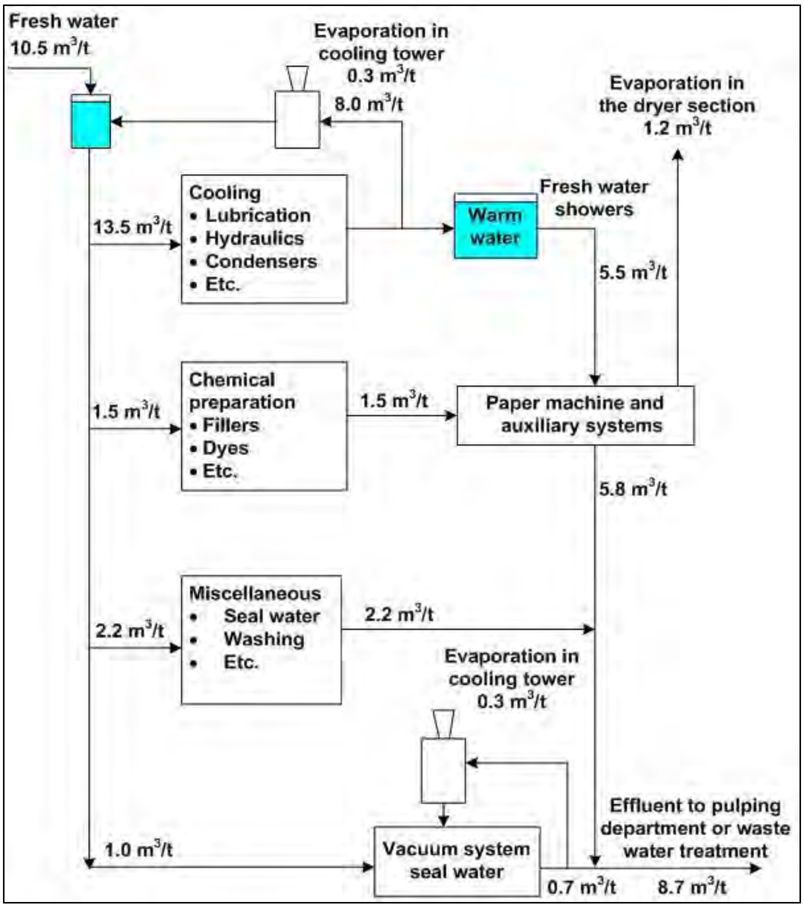


Figure 7.10: Positions of fresh water demand in a paper mill

Figure 7.10 shows an example paper mill using 10.5 m^3/t fresh water. Cooling water is recirculated by use of cooling towers (open recirculation system, see Section 2.4.2.1). The figure shows only the average water flows (input/output) under continuous operation. Unbalances of the water flows, e.g. during start-ups where usually a greater amount of water is used, are not taken into account. 'Miscellaneous' is a somewhat 'grey area' but is not negligible (e.g. the recirculated water flow from the liquid ring pump vacuum systems is in the range of 1 – 3 m^3/t).

Fresh water is normally introduced in the papermaking process mainly through the paper machine forming section and press section showers after which it is fed upstream to various washing and diluting processes in the mill.

In the stock preparation, usually no fresh water is required to dilute incoming fibre raw material, except for speciality papers, high-quality papers and for start-up and during production changes. If different qualities of white water are available, the water with the highest fibre content (cloudy filtrate) could be used in pulping units. However, most of the cloudy filtrate is used in the short circulation for adjusting the consistency of the incoming fibre slurry. The need for fresh water is limited to dilution of chemicals and to sealing water for some of the equipment. Most chemicals must be diluted with fresh water before entering the paper machine system because otherwise quality problems may arise and the dosages have to be increased. For the dilution of fillers, it is sometimes possible to replace the fresh water with clarified water if there is no risk of anaerobic biological activity.

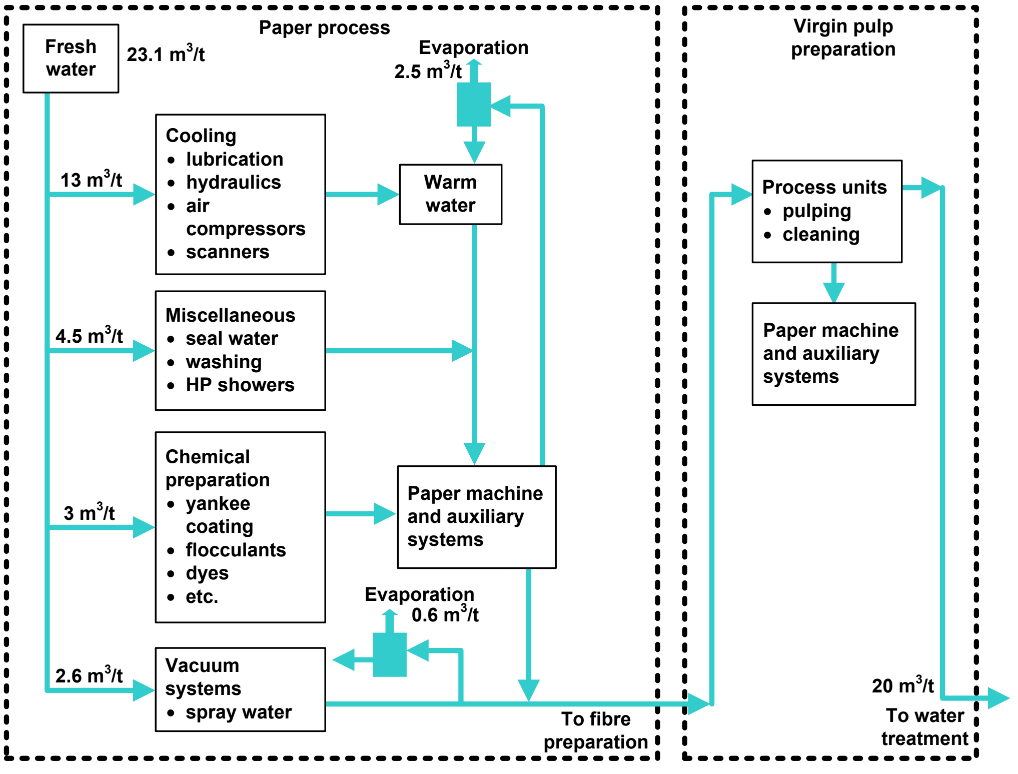
As fibre passes through a pulp or paper mill, different consistencies are required at different stages of the process. Each increase in fibre consistency creates an effluent at that point with the amount and type of contamination depending on the particular unit operations upstream. The ability to recycle that water to another point in the process may be constrained by the chemistry at different stages.

The amount of fresh water used in paper production varies depending on the paper grade produced, the nature of the raw materials used and the final quality level within each paper grade.

Some additional explanations on specific water consumption for tissue mills
In considering fresh water use, there are two main factors to bear in mind with regard to tissue mills. One is the need for high levels of cleanliness of both the product itself (hygienic use) and the tissue machine clothing. The other is the very low production rates due to the light basis weight products made (varying between 12 g/m^2 and 48 g/m^2 on the wire compared to 40 – 50 g/m^2 for newsprint, 50 – 100 g/m^2 for writing papers and several hundred g/m^2 for packaging grades).

Although the absolute volume of water used in a tissue mill may not be significantly higher than some other mills, these two factors can combine to make the specific water consumption appear high.

In a tissue mill there are a number of areas where fresh water is required; shower water to keep the felt surface free from contaminants, high-pressure shower water for cleaning the wire, and for miscellaneous purposes. The latter will vary from machine to machine depending on the operator's activity, white water arrangements and storage volume and degree of automation and information available for the operator. Miscellaneous purposes include uses such as chemical make-up, lubrication showers (inside pressure rolls, etc.), vacuum pumps, etc. Some of these such as chemical make-up may be proportional to production rates. In a mill applying BAT, clarified water as opposed to fresh water should be suitable for all other uses. Figure 7.11 shows the water flows of a typical tissue mill using virgin pulp.



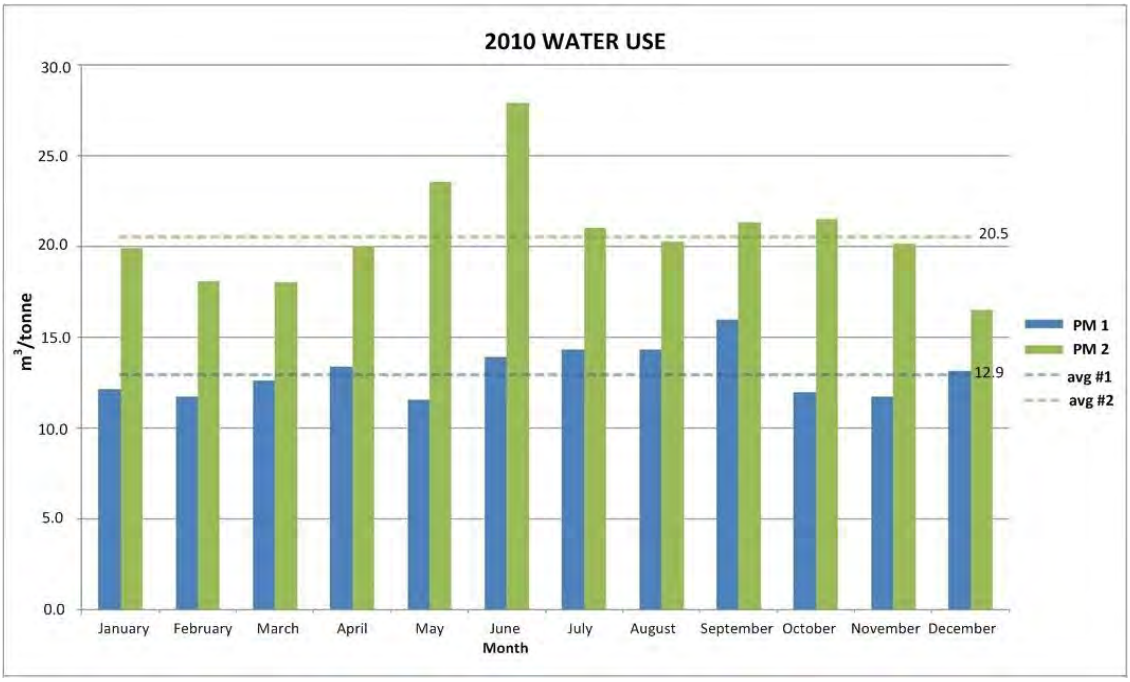
Source: [CEPI Comment WD Chap7], changed by EIPPCB

Figure 7.11: Typical water flow chart for a non-integrated tissue mill using virgin pulp

Where there are grade changes, colour changes, machine shutdowns, several machines in one mill, etc., figures on specific water consumption will be increased. These influences are site-specific but could increase water consumption by 25 % or more. Generally, in mills that manufacture less variety of products, fewer colours, fewer wet or dry strength agents, on large machines, the water consumption will be lower and vice versa. Reported values for fresh water use in 29 non-integrated tissue mills ranged from 2 m^3/tonne to 42 m^3/tonne [ETS data 2008]

Figure 7.12 shows the water consumption of two similar tissue machines in the same mill. Paper machine No 2 produces only coloured tissue with many colour changes: it uses 5 – 15 m^3/tonne water more on monthly average due to many colour changes. The variance over the months for both paper machines is due to:

- more or fewer stops,
- more or fewer grade changes on PM No 1 (difference of up to 5 m^3/tonne or 40 %),
- more or fewer colour changes on PM No 2 (difference of up to 10 m^3/tonne or 60 %).



Source: CEPI comments WD Chap 7

Figure 7.12: Difference in water consumption on two similar tissue machines due to colour changes

Even on the same machine a change of basis weight and speed of the paper machine can have a significant effect on the specific water consumption. Tissue machines generally run much greater ranges of basis weight and speed than most other paper machines. The same machine can make a basis weight range that varies by a factor of 4, e.g. from 12 g/m^2 to 48 g/m^2, and could run at speeds from 500 m/min to 1 200 m/min. Throughout this range, the specific water consumption may vary significantly.

It can be stated that there are no fundamental differences in the water reduction measures in use at tissue mills and other paper mills. However, because of the large variations possible on a tissue machine, the main difference is in the degree to which tissue mills can reduce their specific water consumption.

7.2.2.3 Use of chemical additives

Examples of the main additives and their application are given in Table 7.7. A number of processes and functional chemical additives are based on synthetic polymer compounds and are not readily biodegradable; others are classified as hazardous to the environment or to watercourses. This may apply for some fixing and retention aids, wet or dry strength agents, polymer-based size or coating binders. The vast majority of these chemical additives that are introduced to the pulp prior to the sheet formation remain almost entirely in the paper due to their cationic charge or by fixation with cationic polymers. Thus, the concern with regard to protection of water bodies is reduced. Sizing agents and coatings are applied directly on the surface of the finished paper web either by means of an aqueous solution of size (size press), or in a closed circuit in the case of coating colours. Only during changes of paper grades or recipes are the rest of these concentrates of chemicals discharged via the waste water treatment plant.

Chemical additives contribute to the effluent load or may have the potential to accumulate in the environment and organisms. For more details concerning the regulation concerning the registration, evaluation, authorisation and restriction of chemicals [200, REACH Regulation (EC) No 1907/ 2006] which is designed to provide updated facts about all chemicals, the reader is referred to Section 2.3.2.2.

If the additives are used as directed they should not cause significant negative impacts on the efficiency of the waste water treatment plant. Sudden changes in loads because of system cleaning or batch-wise additive adjustments to fulfil product requirements might have a negative impact on the performance of the waste water treatment plant. In this case, the biomass may require a certain period for adapting to the additives appearing in the effluents. During this limited time period the efficiency of the treatment plant may be reduced and the settling of the sludge may deteriorate (increase of the sludge volume index). Therefore, additives should be handled carefully and as directed. This is how the remarks in the right-hand column of Table 7.7 should be interpreted.

Table 7.7: Main process and product aids and their application in the paper industry

Product aids	Purpose	Examples	Remarks
Fillers	Improve printability properties, opacity, brightness, smoothness and gloss; replace (saving) fibres	Kaolin or clay, talc, lime, gypsum, titanium dioxide, calcium carbonate	
Sizing agents	Improve surface quality; make paper hydrophobic	Modified starch, modified natural resins, wax emulsions, synthetic products like alkyl ketene dimers and maleic acid anhydride copolymers	Some may be toxic to bacteria when they are cationic; however, they have high retention to the fibre
Fixing agents	Improve adsorption of additives to fibres	Alum [$Al_2(SO4)_3$], cationic amines	Mostly cationic products which may be toxic to bacteria
Dry strength agents	Improve strength properties in dry conditions	Modified starch	Some may be toxic to bacteria when they are cationic
Wet strength agents	Improve strength properties under wet conditions	Urea formaldehyde polymer, melamine formaldehyde polymer, Epichlorohydrin condensates	Usually toxic to bacteria, some increase the AOX
Dyes	Give paper a certain colour and/or brightness	Azo compounds, quaternary ammonium compounds	Difficult to eliminate; some are toxic; may contain heavy metals
Optical brighteners	Give paper a white impression	Chemicals based on 4,4-diaminostilbene-2,2-disulphonic acid	Some cationic substances may be toxic
Coating chemicals	Give paper certain surface properties	Pigments, binders, wet strength agents, dispersion and lubrication agents, defoaming agents, slimicides	Binders must be destabilised before mixing with other WW, otherwise they may disturb the clarification
Greaseproof or waterproof agents	Give paper grease- or water-repellent properties, e.g. baking papers, coated drink cups, fast food wrappers and pizza boxes	Perfluorinated compounds (e.g. based on fluorocarbon resins (FC) and perfluoropolyether (PFPE)) are applied to impregnate some papers; for adhesive labels, fluorocarbon resins are used to prevent the penetration of the adhesive. The fluorochemicals are designed so that they bind to the fibres	Persistent and bioaccumulative; PFCs used for paper impregnation do not contain PFOS but may contain FTOH and PFOA in the lower ppm range, trace contaminants
Retention aids	Retention of fibres, fines and fillers; increased production by improving dewatering; decreased emission of pollutants	Alum, sodium aluminate, polyaluminiumchloride, starch products, gums, anionic polyacrylamides, nonionic polyacrylamides, cationic polymers, bentonite	Mostly cationic products
Surfactants	Cleaning of felts, wires and machinery; cleaning of water circuit system; dispersion of substances	Acidic and alkalic surfactants	May cause floating sludge
Defoaming agents	Prevention and destroying of foam	Fatty acid ethoxylates, poly-oxi-ethylene, fatty acid derivates, higher alcohols, phosphoric acid esters, vegetable oil products	De-aeration agents may lower the oxygen input in WWTP
Biocides (slimicides)	Prevention of growth of microorganisms	Organic bromine, sulphur or nitrogen compounds, quaternary ammonium compounds, chlorine dioxide, hydrogen peroxide	Some contain AOX, they are toxic when reaching the WWTP in higher concentrations

For more details on the storage and handling of chemical additives, the reader is referred to Section 2.3.2.

7.2.2.4 Energy demand

The paper industry could be generally described as energy-intensive. Energy is one of the highest contributors to the total costs in the papermaking process, accounting for approximately 10 – 25 % or more of the total production costs.

The development of reliable sector-wide and paper grade-specific energy consumption benchmarks is a complex task [194, Francis 2007]. An international effort to harmonise data collection is needed to allow for reliable energy intensity comparisons [197, IEA 2007].

When comparing energy consumption for paper mills of a certain grade or quality, the major influences on the specific energy consumption (SEC) of a given mill should be taken into account (see Section 2.5.1), e.g. the system boundaries, the energy generation (power and steam supply, cogeneration of heat and power), the process areas operating in the mill (e.g. pulp production, RCF processing, papermaking), the process used (e.g. refining, coating, calendering), the specific product quality, the product mix and some other factors. The explanations and figures presented in Table 7.8 may give a first idea about the energy-relevance of the main processes and the energy improvement opportunities in papermaking.

The papermaking processes can be divided into the main process areas:

(i) stock preparation,
(ii) wet end,
(iii) dry end, followed by
(iv) optional finishing and coating.

These can be further subdivided into main process units. Table 7.8 shows the role of energy use in each process and the potential for energy savings in these stages.

Table 7.8: Role of energy in the main papermaking stages and potential for improvement

Main processes	Main process units	Type and role of energy in each process	Potential for energy savings (installed base versus state of the art)
Stock preparation	Slushing	Up to 30 kWh power/t to break up dry pulp including pumps	Moderate
	Cleaning/ screening	The amount of pumping energy and stock heating depends on the consistency, the number of stages required and the type of fibre (recycled fibre requires more energy than virgin); about 10 kWh/t is used for virgin stock including pumps	Low for virgin fibres; moderate for RCF
	Refining	Very energy-intensive. Electrical energy is mostly used to drive the rotor in the refiner. Depends strongly on the raw material and the paper properties to be achieved: Standard paper grades (newspaper/LWC, etc.): 50 – ~400 kWh/t; Special grades (tracing paper, etc.): up to 3 000 kWh/t	Low - moderate for standard grades; high for special grades
Wet end	Forming and draining	Uses large amounts of electricity for machine drive and vacuum processes. Drives: energy-efficient design of the headbox (flow resistance, headbox supply pump) and twin wire machine (less vacuum) leads to power savings. Vacuum: about 80 kWh/t is used for vacuum systems (varies with grade and porosity)	Low. High, with heat recovery (if there is a use for recovered thermal energy, e.g. hall heating, heating of shower water and white water)

Main processes	**Main process units**	**Type and role of energy in each process**	**Potential for energy savings (installed base versus state of the art)**
Dry end	Pressing	Efficient dewatering (shoe press technology) can result in very large energy savings in the dryers (increased dryness also allows the machine to be speeded up)	High
	Drying	Apart from refining, it is the most energy-intensive process in papermaking. Mainly heat energy, even with shoe press	High - very high
	Size press and second dryer section	Heat energy for after size press drying	Low
	Calendering	Electrical energy for machine drives and pressing, thermal energy for heating	Low - high, depending on paper grade (higher gloss requires higher temperatures)
Coating	Coating and dryer	Electrical and heat energy for redrying	Low
Auxiliaries			
Power plant	Boiler(s), turbine	Heat energy (steam pressure)	Moderate - high
Waste water treatment	Aerobic techniques	Aeration, pumps. Efficient aerators, energy-efficient design concept and operation of the WWTP	Moderate. Thermal energy (biogas generation) depending on waste water characteristics
Machine air handling	Fans/heat exchangers	Electrical and heat energy (high dew point hood)	Moderate
HVAC ([1])	Heat exchangers	Thermal energy from heat recovery from the exhaust air cap, the turbair vacuum or the dryer hood	Moderate - high
Steam & condensate system	Heat exchangers	Thermal energy recovery from drying cylinders	Low
Lubrication	Heat exchangers	Thermal energy	Low
Hydraulic	Pumps	Electrical energy	Low
Chemicals, starch preparation	Grinders, pumps, heat exchangers	Thermal, electrical energy	Low
Converting	Drives	Electrical energy	Low
Transport	Drives	Electrical energy	Low
Wrapping	Drives	Electrical energy	Low

([1]) HVAC = heating, ventilating and air conditioning.

Source: Unpublished data from a supplier, 2010. Data are taken from results of energy audits that were carried out between 2005 and 2010.

Reporting energy use by process area instead of for the entire mill allows for meaningful comparison of energy use across mills and countries with widely varying processes and product mixes. A comparison for a specific process area can be performed with similar process areas in other mills. This methodology would allow for more precise estimations than the entire mill approach [194, Francis 2007], [197, IEA 2007]. An entire mill approach always needs a careful assessment of the relevant influences and a precise definition of borderlines in order to avoid misinterpretation.

Table 7.9 is an example for the energy consumption in the form of heat and electric power for an entire non-integrated fine paper mill with on-line coating. The figures represent a mill with a technical age of no more than five years. The values include all the stages from disintegration of fibre raw materials to the final paper product and also include necessary service departments. Energy consumption for the coating process is included in the case of the production of coated paper (the mill has a capacity of 150 000 t/yr of coated fine paper from market pulp; the paper has a pigment content of 25 % and a moisture content of 4.5 %).

Table 7.9: Example of energy consumption (actual consumption figures for steam, gas and electricity at 100 % efficiency) in a non-integrated coated paper mill with a production capacity of 150 000 t/yr

Department	Process heat (kWh/t)	Electric power (kWh/t)
Stock preparation (pulper, refining, storage tower)	0	206
Paper machine • steam • gas (coating machine included)	1 090 130	583
Coating kitchen (preparation of coating colour slurry; energy demand depends on the recipe and combination of the coating colours)	575	36
Total paper mill	**1 795**	**825**
Effluent treatment	**0**	**4**
Total consumption per tonne of paper	**1 795**	**829**
Turbine generator		0
Total external supply	**1 795**	**829**

Source: Unpublished data from a supplier, 2010. Data are taken from results of energy audits that were carried out between 2005 and 2010.

The external supply figure shows the amount of the total demand that is purchased from external sources as fuel oil, coal and gas and electricity. For more examples, the reader is referred to Section 2.5.2.

Process heat in the paper industry
Process heat is mainly used for four purposes:

- heating of water and liquors, wood or pulp, air and chemicals to the temperatures required by the process;
- evaporating water;
- covering the heat loss to the surroundings;
- conversion of heat into electric power.

Heating of water and liquors, wood or pulp, air and chemicals to the temperatures required by the process
Pulp and white water systems can often be kept warm enough without the addition of steam. It is essential to minimise the use of fresh water and increase the use of white water from an energy point of view. In non-integrated paper mills, exceptional addition of warm fresh water and/or circulation of the white water through heat recovery are often necessary to keep the temperature at a sufficient level in the white water system.

Evaporating water
In papermaking, paper drying is the most energy-demanding stage during which the majority of heat is consumed to evaporate water in the paper sheet. It is important to minimise the amount of water to be evaporated by mechanical measures (pressing). Development of the press section (use of twin wire and an extended nip press) has resulted in somewhat lower moisture levels of

the paper entering the drying section (this does not apply to tissue paper). In the case of surface sizing or coating, the dried paper has to be dried again after adding surface starch or coatings to the paper web. Higher concentrations and temperatures of these coating colours result in reduced heat consumption, given that the coating process allows for the use of higher temperatures.

Covering the heat loss to the surroundings
The majority of warm humid exhaust air discharged from the drying section is compensated by inlet dry air that has to be heated again (the heat losses to the environment after having passed several heat exchangers are called total heat loss). The heat requirements can be minimised by reducing the airflow through the drying section. The precondition for this is a high dew point hood (state of the art is 60 – 62 °C). This also gives a higher humidity of the outlet air, which increases the value of air as a source of secondary heat. Heat recovery through heat exchangers, e.g. for the incoming air, the process water and for building heating, also reduces heat consumption. Also, the entire heat recovery equipment such as ductwork, heat exchangers and fans can be sized down.

Conversion of heat into electric power
An increasing number of mills have installed cogeneration of heat and power plants, which is a conversion of primary energy into steam and electric power. In most cases, steam is produced at a high pressure and temperature, and reduced by a turbine to a pressure level which can be used in the dryer section of the paper machine.

Electric power in the paper industry
Electric power is mainly consumed for the operation of various motor drives and for refining in stock preparation.

- The motors are used for running fans, pumps, compressors, agitators, paper machine main drives, vacuum systems, various conveyors, etc.
- For refining, the electrical energy is primarily used to drive the rotor in the refiner. The energy usage varies by product with filter and blotting papers requiring the least energy and tracing papers requiring the highest input. Typical net power consumption for refining is shown in Table 7.10. The data relate to net electrical energy, i.e. the absorbed energy per fibre (kWh/tonne) which is inserted as grinding capacity into the fibres. Each refiner increases the pressure in the system, named the idle load, that is taken up by mechanical drag and turbulent forces and this is therefore not available to treat the fibres. The gross power needed is the net energy plus the idle load and is 30 – 50 % higher than the net energy.

Table 7.10: Typical power consumption in refining by product

Type of paper	Net energy (¹) for refining (kWh/t)	Remarks
Tissue	Up to 30	Refining in bypass mode, not total volume, see Table 7.15.
Printing and writing	60 – 200	Depending on mixture of long and short fibres, see Table 7.15.
Carbonless papers	150 – 200	Depending on mixture of long and short fibres, see Table 7.15.
Glassine/Greaseproof papers	450 – 600	Depending on mixture of long and short fibres, see Table 7.15.
Tracing papers	800 – 1 200	Depending on mixture of long and short fibres, see Table 7.15

(¹) Net energy is derived from the gross power minus the idle load or free running power. Gross energy is the total electrical energy consumed including the losses. Gross energy = Net energy × 1.3 – 1.5. The idle load of a refiner is the power that is taken up by mechanical drag and turbulent forces and is therefore not available to treat the fibres.
Source: Unpublished data from a supplier, 2010.

The potential for energy savings will be high in some cases. For example, many refiners are incorrectly sized. This results in a high idle power which reduces refiner efficiency. Incorrect refiner fillings or dimensioning will cause an increased use of energy to achieve a desired freeness (savings potential of up to 20 % more than a standard solution). Compared to the possible savings by optimised refiner sizes and inserts, the other losses such as idle load or free running power are small.

Below, the consumption of electricity in paper mills is discussed in more detail to shed light on the technical background that provides the basis for improvements and the application of energy-efficient technologies.

The total electrical energy consumption at paper mills is summarised in Table 7.11. All electric power inside the paper mill building is included, i.e. all power usage inside the paper mill starting from the pulp storage towers (in integrated mills) and ending at the finishing operations is included in these figures. For non-integrated paper mills, all processes starting from the mixing chest are included, i.e. for the whole mill energy consumption, consumption data for pulpers that increase specific power consumption must be added (up to 30 – 60 kWh/t) and refiners, if applied. Waste water treatment is not included and consumes between 4 kWh/t and 10 kWh/t (see Section 2.5.4). The values in Table 7.11are based on 100 % efficiency at the reel. The 100 % efficiency rate is used to make paper machines comparable, as the actual efficiency is a function of various inputs of the mill such as mechanical age, maintenance, operating skills, paper grade, etc. It should be noted that the mill efficiency changes the figures: the lower the efficiency of a paper machine, the higher the deviation from the dimensioning figures. The correction of the figures by the efficiency rate achieved plays a greater role at old machines or multi-grade machines with a lot of grade changes. These mills normally have less automation, measurement, control and documentation of the processes which are required to achieve very high efficiency rates. In contrast, modern mills that produce bulk grades of similar quality have reached 94 – 95 % efficiency (or even 96 % in a few cases).

Table 7.11: Typical electrical energy consumption at modern paper mills based on the dimensioning capacity (= 100 % at reel) of the paper machine

Paper grade	Power consumption in kWh/t (based on dimensioning capacity (¹), Paper machine without stock preparation)(*)	Power consumption in kWh/t (data refer to the whole paper mill)(**)
Newsprint	480 – 630	500 – 700
LWC paper	550 – 750	500 – 800
SC paper	600 – 700	450 – 700
Fine paper (uncoated)	450 – 650	450 – 650
Fine paper (coated)	600 – 850	600 – 750
Multi-ply board	~ 680	
Sack paper	~ 850	700 – 850
Testliner	~ 550	
Tissue	500 – 3 000 (²)	

(*) *Source:* Unpublished data from a supplier, 2010.
(**) *Source*: [CEPI comments D1, 2010]
(¹) For paper mills that are equipped with a modern process control system, the measurement of the electrical energy demand is relatively simple to determine and can usually be read directly from the DCS (distributed control system). The determination of the real production (compared to the dimensioning capacity) and the method for calculation of the actual process efficiency often vary between mills but are part of the daily business.
(²) The different drying systems used in tissue mills such as conventional Yankee cylinders, through-air drying or hybrid technologies have a significant effect on the energy consumption of the mill (according to ETS). The range reflects the full range of possibilities and is not typical in this sense.

The electricity consumption of the paper machine depends on the paper grades produced (e.g. higher grammage leads mathematically to better specific energy consumption), the speed of the machine (see Table 7.12 and Table 7.13) and the raw material mix used (e.g. coatings are easier to dry than fibres, i.e. a high share of coating improves the SEC). The lowest values for power consumption correspond to packaging paper or corrugated base paper which consume about 400 – 600 kWh/t, whereas printing and writing paper (e.g. wood-free uncoated, WFU) consume about 450 – 650 kWh/t (electrical energy, 100 % efficiency). The highest power demand, up to 5 600 kWh/ADt, is needed for some special paper grades (e.g. tracing paper, older and smaller machines). For these special cases, the power is mainly consumed by more intensive refining. More detailed information on electricity consumption is given further below.

The total figures in Table 7.11for the power consumption of paper mills represent a number of energy-consuming subsystems that are explained below. The sum of the subsystems of Table 7.12 and Table 7.17 (*Source:* all data from a supplier of paper mill equipment, 2010) correlates with the total power consumption figures of Table 7.11. The data are based on 100 % efficiency and are guaranteed values that are taken from the results of energy audits.

Table 7.12: Typical specific energy consumption at the approach flow system of paper mills

Type of machine	Power consumption	Remarks
Fast machines (>1 300 m/min)	70 – 130 kWh/t	Headbox feed pump energy increases to the second power when paper mill speed is increased
Slow machines	50 – 100 kWh/t	Slow machines below 1 200 m/min have in general no de-aeration system

Table 7.13: Typical specific energy consumption at the vacuum system of the wet end at paper mills

Type of machine	Power consumption	Remarks
Fast machines (>1 300 m/min)	70 – 100 kWh/t	Fast machines have bigger production; therefore specific power consumption is lower than for slow machines
Slow machines	80 – 110 kWh/t	

Table 7.14: Typical specific energy consumption at the under machine pulpers of the paper mill

Position	Power consumption new machines	Power consumption old machines	Remarks
Couch pit	2 – 5 kWh/t	3 – 7 kWh/t	Older paper mills (before the 1990s) typically had concrete vats or the tank shape was not optimised for slushing; technical development resulted in decreased power consumption
Press pulper	5 – 8 kWh/t	7 – 12 kWh/t	
Dry-end pulper	7 – 18 kWh/t	10 – 20 kWh/t	
NB: Under machine pulpers are tanks under the paper mill where paper web is slushed with water. These pulpers operate only during web breaks except the couch pit which operates continuously due to the trim. It collects drained water and wet wire trim.			

Table 7.15: Typical specific energy consumption for new machines at the refiners per tonne of refined pulp

Pulp grade	Power consumption per tonne of refined pulp	Remarks
Long fibre (bleached)	150 – 250 kWh/t	Manufacturing of pulp is not included in these figures; the higher end of the range refers to lower CSF levels. The actual power consumed per tonne of end product depends on the amount of refined pulp used per tonne of end product (e.g. if only 30 % of refined pulp is required, the values have to be multiplied by 0.3)
Short fibre (bleached)	75 – 150 kWh/t	
Long fibre (unbleached)	100 – 200 kWh/t	
Short fibre (unbleached)	Typically not refined	
RCF	60 – 100 kWh/t Typically not refined	

Table 7.16: Typical specific energy consumption at the stock preparation and white water systems per tonne of paper (excluding refining, pulpers and approach flow system)

Type of process	Power consumption	Remarks
White water system	20 – 30 kWh/t	Water storage towers, save-all, chests, pumps
Broke system (¹)	5 – 50 kWh/t	Broke tower, broke screens, tanks and pumps depend highly on paper grade (uncoated/ coated). Coated grades need more energy (e.g. separated system for dry, wet and coated broke)
Mixing	5 – 15 kWh/t	Mixing chest, machine chest, pumps and agitators
Bale pulping (only for non-integrated mills)	20 – 35 kWh/t	Bale pulpers and conveyors, tanks and pumps
Pulp dosing (integrated mills)	5 – 10 kWh/t	Pulp line from storage to mixing chest; tanks, pumps, pumps strongly depending on location of stock preparation
Paper mill showers	10 – 20 kWh/t	Paper mill shower water system consisting of pumps, filters, screens
(¹) Except the couch pit and the trim systems of the winder, the broke system is only operated in case of paper breaks. For the calculation of total energy consumption of entire mills, a time factor (<10 %) has to be considered for the broke system.		

Table 7.17: Typical specific energy consumption of paper mill drives

Type of process	Power consumption	Remarks
Paper machine	150 – 300 kWh/t	Paper mill drives, former, press, dryer, sizer, reel; machine speeds up to 2 000 m/min
Ventilation, paper mill	30 – 60 kWh/t	Hood air supply, hood air exhaust, air to runnability components, wet-end ventilation, machine room ventilation, fans and pumps depending on the paper grade
Ventilation (finishing): includes coating machine, calenders, slitter winder, packaging	50 – 80 kWh/t	All equipment after the reel (e.g. coating, calendering, winding area), depending on the paper grade
Steam and condenser	2 – 6 kWh/t	Condensate and vacuum pumps
Lubrication and hydraulic pumps	10 – 40 kWh/t	Lubrication units and hydraulic pumps
Coaters	15 – 25 kWh/t	Per coater station, depending on applied coating weight
Calenders	30 – 120 kWh/t	This wide range is caused by • finished paper weight • heating energy for heated rolls (steam/electricity/gas)
Winders	20 – 50 kWh/t	Machine speeds of up to 3 000 m/min, wide range of paper weight
Finishing	10 – 15 kWh/t	Wide range of paper weight
Chemicals	5 – 50 kWh/t	Chemical mixers, feed pumps, screens, grinders, strongly depending on paper grade and kind of raw material supply

A great deal of the electric power that is consumed is transferred to energy in the form of mechanical work, and is finally transferred into heat. This heat is useful in many cases, since the heat contributes to keeping the systems at the required temperature levels.

Due to the high energy amount needed for paper production, the paper industry started very early to optimise the energy consumption of the production process. Forced by technical reasons (e.g. savings through more energy-efficient equipment were compensated by higher energy demand because of machine speed increases), the amount of electrical energy remained at almost the same level for decades. At the same time, the amount of steam was reduced by nearly 60 %. This was mainly achieved by installing higher dew point hoods and the intensive use of heat recovery systems.

More data on the energy consumption of pulp and paper mills can be found in Section 2.5. The measures for reduction of energy consumption in pulp and paper mills applicable to most paper grades are discussed in Section 2.9.6. For measures for reducing the use of thermal and electrical energy in papermaking, the reader is referred to Section 7.3.15.

Some additional explanations on specific energy consumption for tissue mills

As mentioned in Section 7.1.11.3, there are different papermaking processes in place to make tissue depending on the required tissue characteristics (softness, absorption, etc.) The main difference between the tissue-making processes is the way of drying the tissue and thus the energy consumption. Apart from the tissue-making process, there are additional processes that can significantly influence the energy consumption of a tissue mill:

- integrated deinking will require more energy;
- CHP/cogeneration will require more natural gas consumption;
- electrical steam boilers will require more electricity;
- biomass boilers will require less fossil fuel.

In Table 7.18 the total energy consumption is compared for mills with various tissue-making processes and raw materials.

Table 7.18: Energy data range for conventional tissue mills

Type of mill	Heat consumption (MJ/tonne)	Electricity consumption (kWh/tonne)
Virgin fibre mills	5.4 – 10.5	887 – 1 422
With additional processes (1)	5.4 – 18.04	887 – 2 012
Mills with TAD process (2)	11.6 – 21	1 432 – 2 730
Recycled fibre mills	7.3 – 11.4	987 – 1 805
With additional processes (1)	6.7 – 12	987 – 3 130

(1) Additional processes can be on-site CHP, cogeneration, electrical steam boiler or biomass boiler.
(2) These are full mill consumption figures from 8 mills that have TAD machines. Most of these mills also have conventional paper machines on site and may have RCF processes.
Source: [ETS, data 2008]

7.2.2.5 Waste water and emissions to waste water

There are different sources of waste water discharges from paper mills which are described below (see Figure 7.3).

Rejects from stock cleaning

Pulp is cleaned ahead of the paper machine for the removal of impurities. The rejects from the cleaners contain the impurities (e.g. shives and sand) and also some valuable fibres, suspended in water. These rejects are usually discharged to the effluent treatment, but may also be discharged directly to the sludge dewatering.

Excess white water
The process water together with the chemical additives applied are drained off in the wire section of the paper machine to the main part, and are then finally removed from the paper in the press section and the drying section. The white water also contains the spent shower water from the cleaning of wires and felts. The main part of the white water is recycled within the paper machine as dilution water and shower water. The excess of white water (a certain amount of fresh water is added continuously to the paper machine which displaces white water) is discharged to the effluent or for use in stock preparation in integrated mills. This water usually passes through a fibre recovery unit before being discharged.

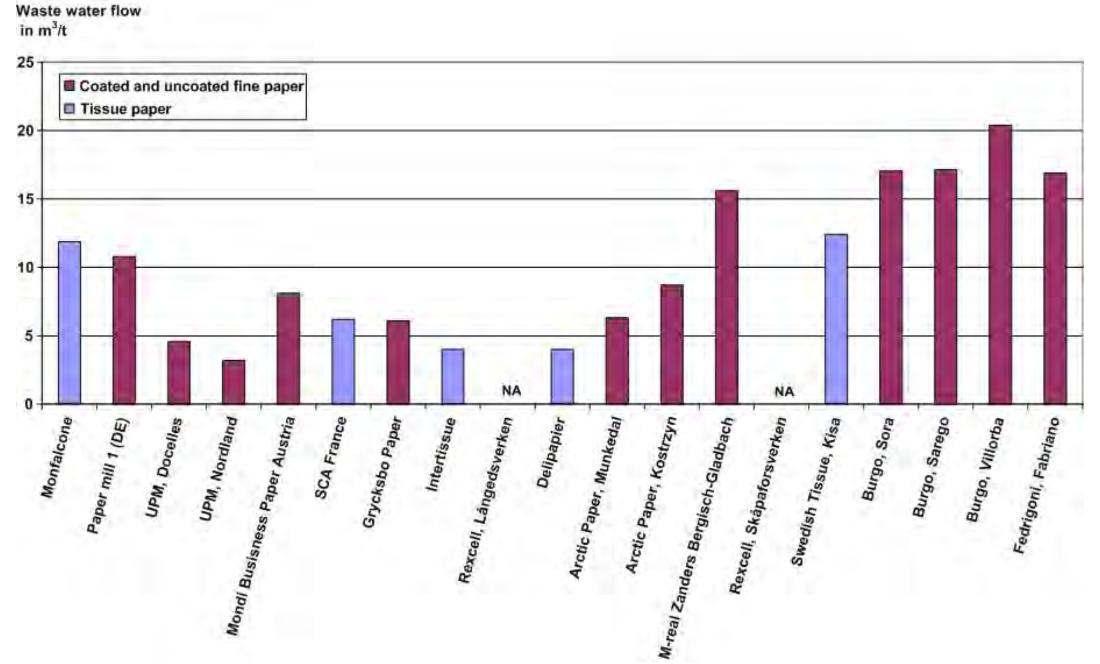
The amount of discharged white water depends on the degree of closure of the water circuits. It contains the majority of the continuous discharges of suspended solids and dissolved organic substances normally expressed as COD and BOD.

Temporary and accidental discharges
These discharges are not directly connected to the process and occur intermittently. Examples of such discharges are overflows of white water or even pulp from tanks or other equipment with a poor level control, spent wash water from the cleaning of equipment and flushing water from flushing of floors, etc.

Emissions to water or soil from storage and handling of potentially hazardous chemical additives should be prevented by appropriate design and operation of the facilities in such a way that potential pollutants cannot escape (see Section 2.9.2.3).

Cooling and sealing waters
The spent cooling waters and sealing waters from the vacuum system and pumps do not usually contain suspended solids. These waters are often recycled to some extent. Clean cooling waters should be separated from the other effluents in order to minimise the load on treatment plants and to maintain their efficiency.

Waste water flow
Coated/uncoated graphic and tissue paper
Figure 7.13 shows the specific waste water flow of a number of non-integrated paper mills that responded to the EIPPCB survey (reference years 2006 and 2008). Coated and uncoated fine paper mills reported waste water flows between 3.5 m^3/t and 20 m^3/t. Six mills (out of twelve examples) discharge less than 10 m^3/t. The tissue producers that provided data for the EIPPCB survey (five mills) reported waste water flows between 4 m^3/t and 12 m^3/t, while calculated waste water flows from data provided by the European Tissue Symposium (ETS) for 2008 (yearly average loads and concentrations) yield waste water flows ranging from 1 m^3/t to 42 m^3/t. [CEPI comments WD Chap 7, 2012]

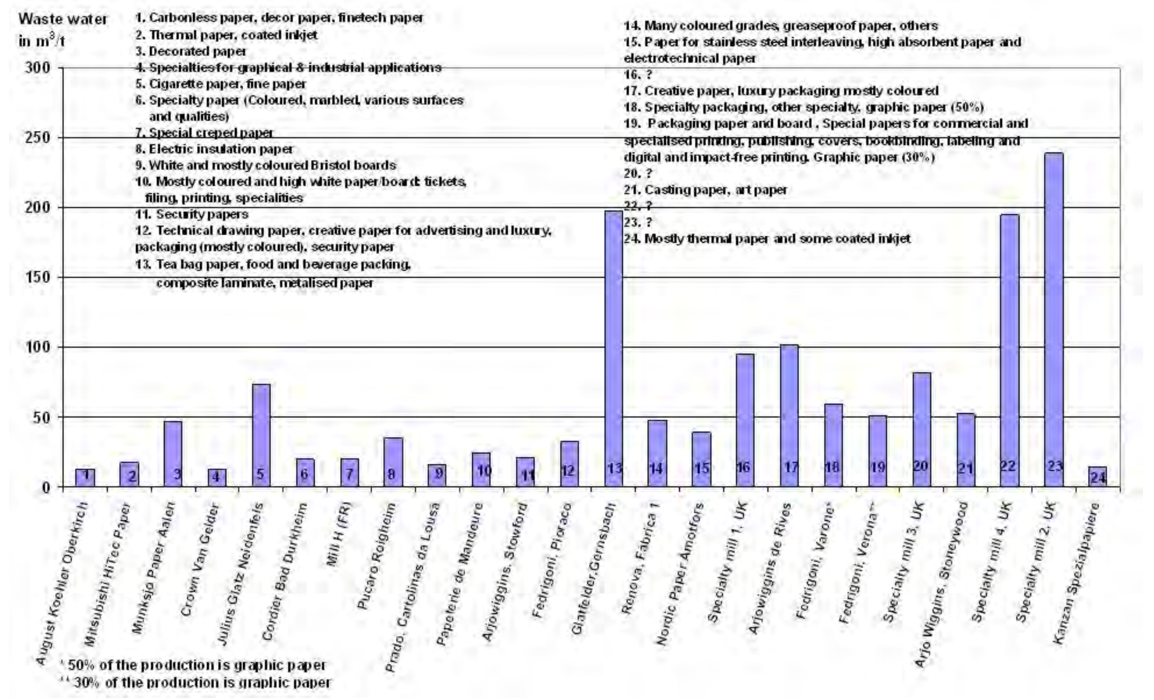


Source: Data collection/questionnaires [Swedish statistics 2008]

Figure 7.13: Examples of specific waste water discharge from non-integrated European paper mills (excluding speciality paper)

Speciality paper

Figure 7.14 shows the specific waste water flow of some speciality paper mills (EIPPCB survey, reference years 2006 and 2008). The reported waste water flows varied, depending on the product manufactured and the specific production conditions, between 13 m^3/t and 100 m^3/t, with three mills reporting values around 200 m^3/t. Speciality papers are typically produced on smaller paper machines and with frequent grade changes leading to higher overall changeover losses and potentially higher specific water use. Strict requirements regarding cleanliness and/or incompatibilities between furnish components of different grades often require a complete emptying of the stock and water system when changing paper grades. Due to the strict cleanliness requirements in the production of speciality papers, water can in many cases only be recirculated to a limited extent.



Source: Data collection/questionnaires

Figure 7.14: Examples of specific waste water flow from non-integrated European speciality paper mills

Pollution parameters

The most common parameters used to characterise final effluent discharges from paper mills include total suspended solids (TSS); BOD_5 or BOD_7; COD; total N and total P; AOX; and sometimes individual metals. More recently, whole sample toxicity has been used for single mills (e.g. in Germany, toxicity to duckweed) or as parameters in an ordinance for paper mill waste water (e.g. in Austria, toxicity to fish) because of the complexity of effluents containing a wide range of substances.

In the following sections, more detailed information on the emissions of individual waste water parameters relevant for papermaking is given. The data are provided, where available, as load (kg/t), concentration (mg/l), yearly and daily average. Values are presented as reported (e.g. with regard to decimal places, regardless of the uncertainty factor close to the detection limit). When interpreting the given concentration data, one should bear in mind the corresponding waste water flows. Due to efforts being made in some mills with regard to reducing water use and closing water loops, the concentration of pollutants might have increased. The plants with higher concentration values do not necessarily emit high emission loads.

Chemical oxygen demand

The discharge of organic matter from non-integrated paper mills originates mainly from organic matter released from the purchased pulp during repulping and processing, from the organic matter dissolved from the pulp in the refining stages above the paper machine, and from the organic chemical additives applied as product or process aids in papermaking (e.g. organic polymers). Those that are not retained in the paper web (see Figure 2.8) end up in the waste water. The significance of the contribution of chemical additives to the organic load of the paper mill depends on the amount and type of chemicals used. At least for some paper grades (e.g. speciality paper), the share of chemical additives in the total organic load discharged to the receiving water body is significant. Generally, there is a lack of knowledge about the contribution of chemical additives to the total waste water load.

Paper mills' emissions to water have become generally lower after efficient biological treatment.

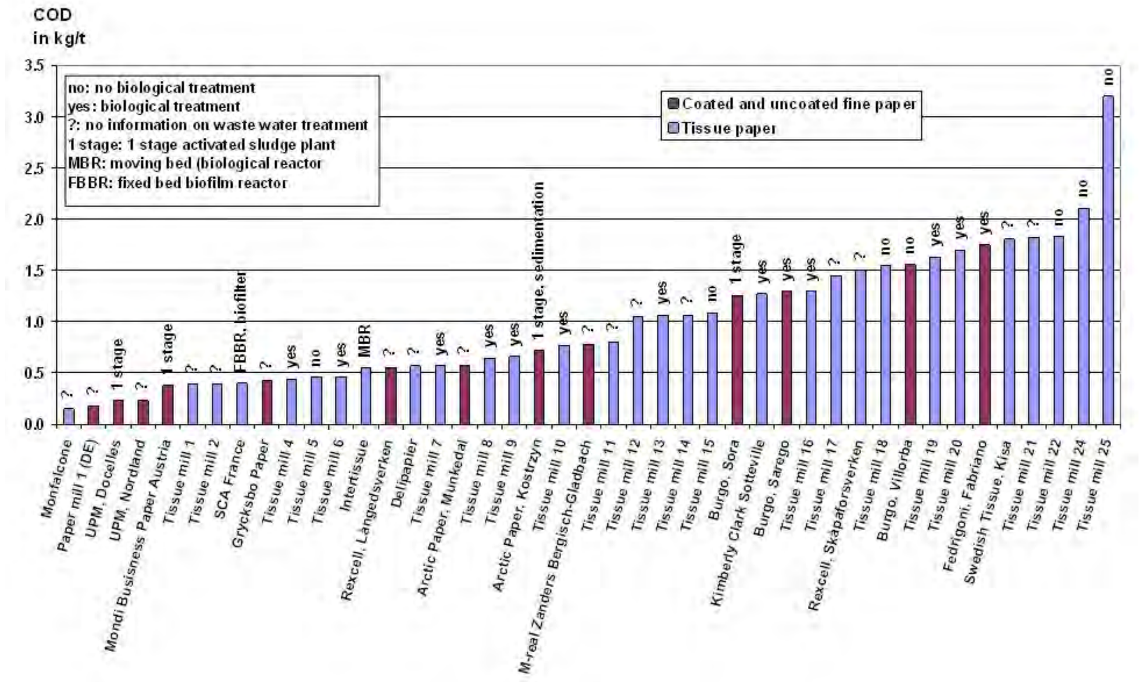
In an older investigation of a few mills in Germany, the share of additives in the total COD load after biological treatment was assessed. In the investigated example mills, it amounted to about 26 % for coated printing and writing paper, 20 % for newsprint from recovered fibre, 43 % for hand towels from recovered fibres and 35 % for coated cartonboard from recovered fibres [68, IFP 1997]. However, these results may have great uncertainties (e.g. limited number of mills investigated; retention factors obtained in laboratory tests). The values therefore give only an indication of the possible share of chemical additives that may be released via waste water. They should not be generalised.

Coated/uncoated graphic and tissue paper

In Figure 7.15, the specific COD load for several non-integrated wood-free paper mills manufacturing coated or uncoated graphic or tissue paper is shown as a yearly average (*Source*: EIPPCB survey (reference years 2006 and 2008) and ETS data (reference year 2008) for tissue mills No 1 to No 25). As many paper mills produce coated paper as well as uncoated fine paper, a distinction between these paper grades was not possible.

Data provided range from 0.18 kg COD/t to 1.90 kg COD/t for graphic paper and from 0.15 kg COD/t to 1.80 kg COD/t for tissue mills (with two mills reporting values above 2 kg/t). Most of the 20 mills of the EIPPCB survey discharge less than 1 kg COD/t as a yearly average, seven of them less than 0.5 kg COD/t. Only seven of these mills discharge organic loads above 1 kg/t. Values for tissue mills reported in the ETS data were mostly higher, with values of up to 3.2 kg COD/t. However, the upper range (mills > 1.8 kg COD/t, e.g. tissue mills No 22 to No 25) refers to mills without biological waste water treatment.

The yearly averages of COD concentration values for non-integrated paper mills obtained via the EIPPCB data collection ranged from 17 mg/l to 119 mg/l for coated and uncoated graphic paper and from 27 mg/l to 140 mg/l for tissue paper. ETS reported daily averages of COD concentrations with values for tissue mills from 27 mg/l up to 500 mg/l after biological treatment.



Source: Data collection/questionnaires [CEPI comments 2012, ETS 2008 data]

Figure 7.15: Examples of specific COD emissions as a yearly average after waste water treatment from non-integrated European paper mills (excluding speciality paper)

Regarding short-term averages of COD, since data gathering does not allow enough representative data to be shown for this parameter, variations of daily COD loads for a German non-integrated tissue mill over the course of a year are shown in Figure 7.16.

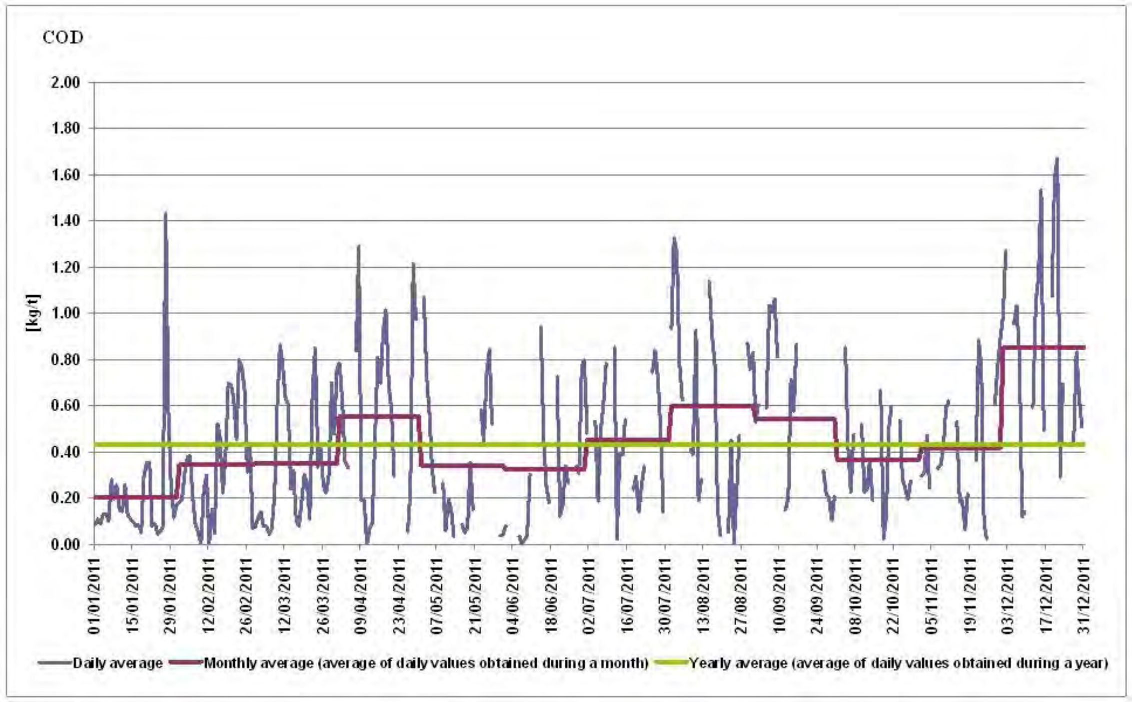
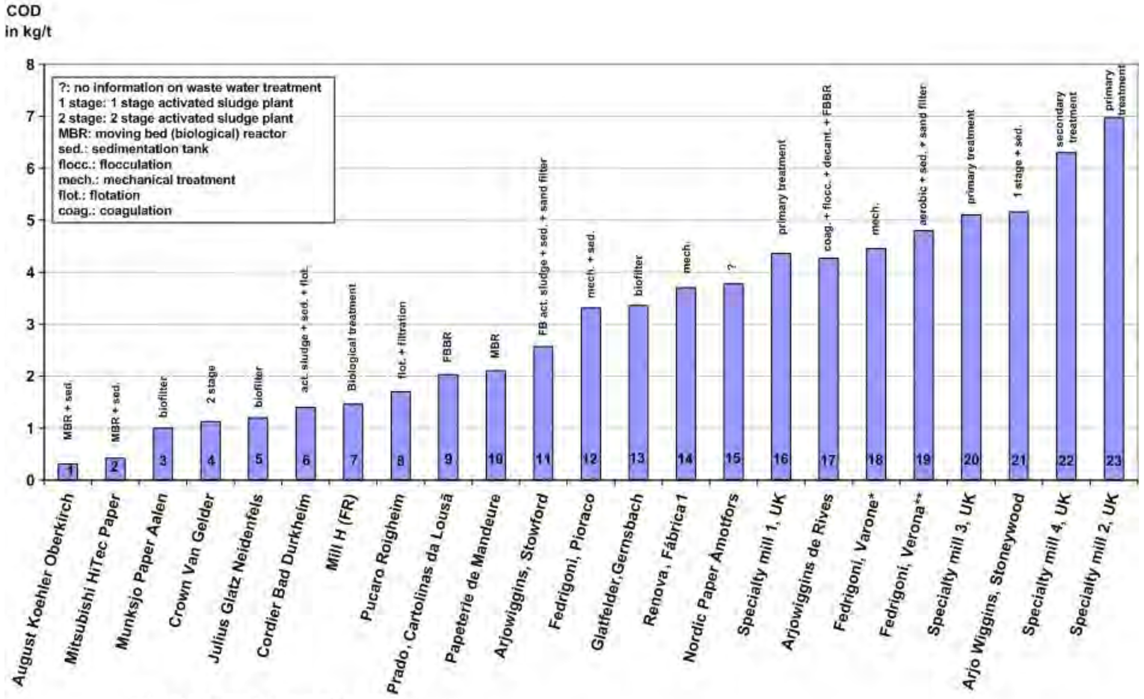


Figure 7.16: **Daily COD loads over one year from a German non-integrated tissue paper mill**

Speciality paper

For speciality paper mills, the concentration of the organic load discharged to waste water is often low, but together with the comparatively high waste water flow (see Section 7.2.2.2) it may result in higher specific emission loads per tonne of product than for standard wood-free fine paper. In Figure 7.17 the yearly average specific COD emission load is given for several non-integrated speciality paper mills (*Source*: EIPPCB survey, reference years 2006 and 2008). The major grades of speciality paper produced by the example mills are also given in the graph to indicate the variety of grades produced for graphical and industrial applications.



* 50% of the production is graphic paper
** 30% of the production is graphic paper

1. Carbonless paper, decor paper, finetech paper
2. Thermal paper, coated inkjet
3. Decorated paper
4. Specialties for graphical & industrial applications
5. Cigarette paper, fine paper
6. Specialty paper (Coloured, marbled, various surfaces and qualities)
7. Special creped paper
8. Electric insulation paper
9. White and mostly coloured Bristol boards
10. Mostly coloured and high white paper/board: tickets, filing, printing, specialities
11. Security papers
12. Technical drawing paper, creative paper for advertising and luxury, packaging (mostly coloured), security paper
13. Tea bag paper, food and beverage packing, composite laminate, metalised paper
14. Many coloured grades, greaseproof paper, others
15. Paper for stainless steel interleaving, high absorbent paper and electrotechnical paper
16. ?
17. Creative paper, luxury packaging mostly coloured
18. Specialty packaging, other specialty, graphic paper (50%)
19. Packaging paper and board , Special papers for commercial and specialised printing, publishing, covers, bookbinding, labeling and digital and impact-free printing. Graphic paper (30%)
20. ?
21. Casting paper, art paper
22. ?
23. ?

Source: Data collection/questionnaires, 2006 and 2008

Figure 7.17: Examples of specific COD emissions as a yearly average after waste water treatment from non-integrated European speciality paper mills

The reported COD emissions for speciality paper mills vary between 0.31 kg COD/t and 7 kg COD/t (*Source*: EIPPCB survey, reference years 2006 and 2008). The variation is greater than with non-integrated, mainly wood-free paper mills due to the variety of grades produced, but also due to the differences in terms of the management of the chemical additives used, water management and applied effluent treatment systems. Of the mills that responded to the EIPPCB questionnaires, almost half discharge less than 2 kg COD/t as a yearly average, and only two mills discharge more than 5 kg COD/t.

Yearly averages of COD concentration values for non-integrated speciality paper mills obtained by the EIPPCB data collection ranged from 17 mg/l to 118 mg/l.

Regarding short-term averages of COD, since data gathering does not allow enough representative data to be shown for this parameter, variations of daily COD loads for a single mill (Speciality DE 4) over the course of a year are shown in Figure 7.18.

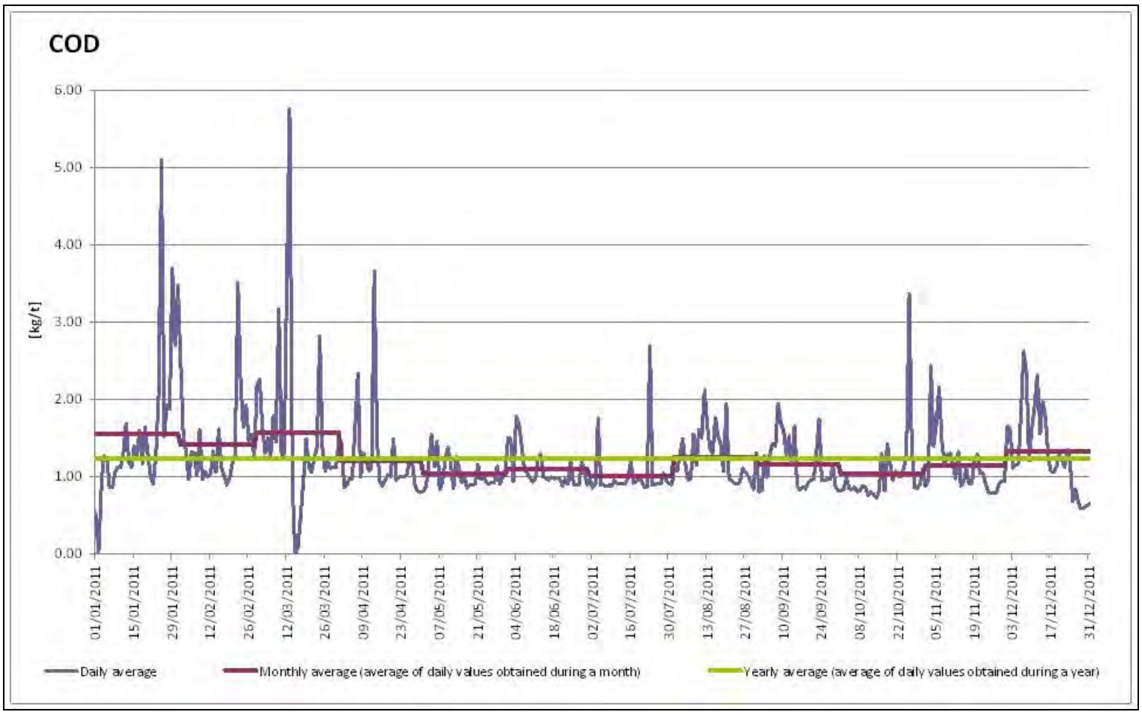


Figure 7.18: **Daily COD loads over one year from a non-integrated speciality paper mill (Speciality DE 4)**

Biological oxygen demand (BOD_5 or BOD_7)

Coated/uncoated graphic and tissue paper

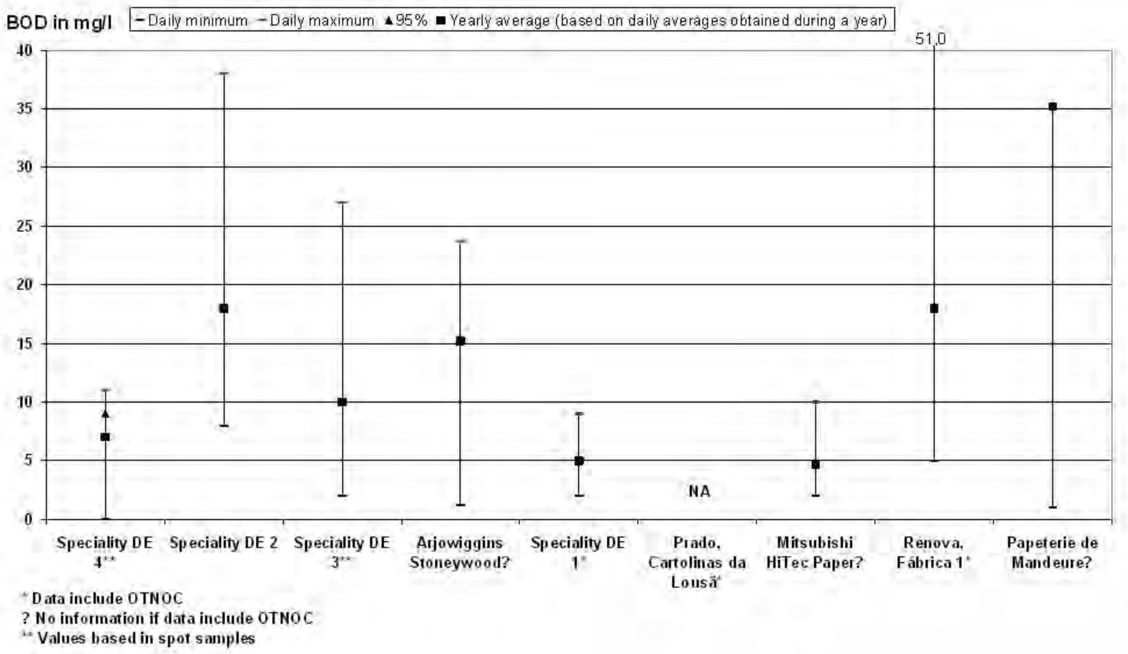
The BOD emission loads reported as a yearly average for non-integrated wood-free paper mills in the EIPPCB survey provided ranges of 0.03 – 0.27 kg BOD_5/t for coated and uncoated graphic paper and 0.01 – 0.19 kg BOD_5/t for tissue mills. Reported concentration values were in the range of 3 – 17 mg/l for graphic paper and 2 – 16 mg/l for tissue. Available ETS load data for non-integrated tissue mills (reference year 2008) range from 0.008 kg BOD/t up to 0.90 kg BOD/t, with the highest values (e.g. 0.77 kg BOD/t and 0.90 kg BOD/t) referring to mills without biological waste water treatment. The highest reported value for a plant with biological treatment was 0.51 kg BOD/t. Concentration values for tissue mills as given by ETS ranged from 0.7 mg/l up to 200 mg/l as a daily average.

Speciality paper

Reported yearly average BOD emission load values for non-integrated speciality paper mills range from 0.12 kg BOD_5/t to 0.3 kg BOD_5/t, while yearly average concentration values range between 4 mg/l and 23 mg/l.

In properly working biological treatment plants, the concentration of BOD_5 or BOD_7 after treatment is 10 – 20 mg/l as a yearly average. BOD levels of around 5 mg/l are hard to measure accurately and to reproduce. They should be interpreted as values close to the detection limit.

Short-term averages of BOD emissions reported from speciality mills are shown in Figure 7.19.



Source: EIPPCB questionnaires from 2007/2009

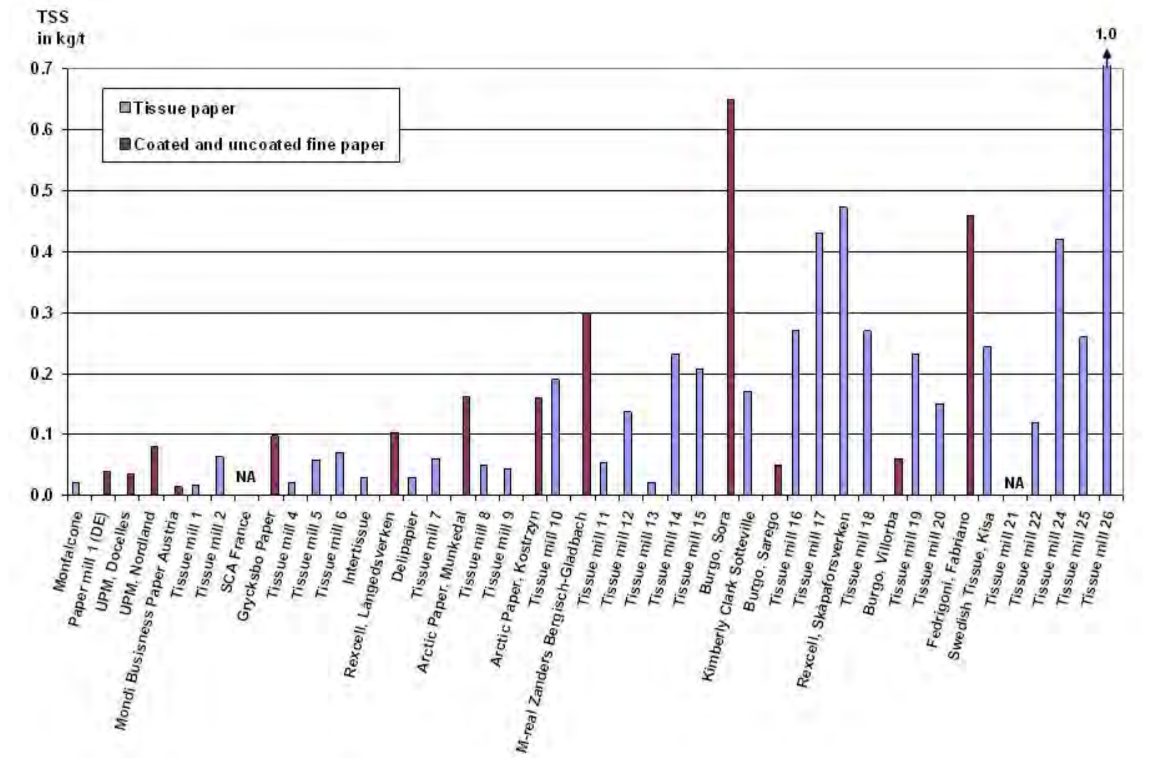
Figure 7.19: **Short-term averages of BOD emissions from non-integrated European speciality paper mills**

Total suspended solids

Coated/uncoated graphic and tissue paper

Figure 7.20 shows the data provided for the EIPPCB survey for TSS emission loads: 0.014 – 0.3 kg TSS/t for graphic paper mills (with the exception of two mills, which reported 0.46 kg TSS/t and 0.65 kg TSS/t, respectively) and 0.02 – 0.473 kg TSS/t for tissue paper mills. As can be seen in the figure, 11 of the 19 non-integrated graphic and tissue paper mills that reported TSS data for the EIPPCB survey discharge about 0.1 kg TSS/t or less. Of these, five mills reported even less than 0.05 kg TSS/t as a yearly average. Values for tissue mills reported in the ETS data range from 0.016 kg TSS/t to 1.0 kg TSS/t, with the upper range (mills >0.27 kg TSS/t, e.g. tissue mills No 24 and No 26) referring to mills without biological waste water treatment.

Non-integrated graphic paper mills (EIPPCB data collection) reported concentration values from 3.6 mg TSS/l to 26 mg TSS/l, and tissue mills from 6 mg/l to 12 mg/l as a yearly average value. Daily average values for tissue mills provided by ETS ranged from 1.8 mg/l to 20.8 mg/l after biological treatment.

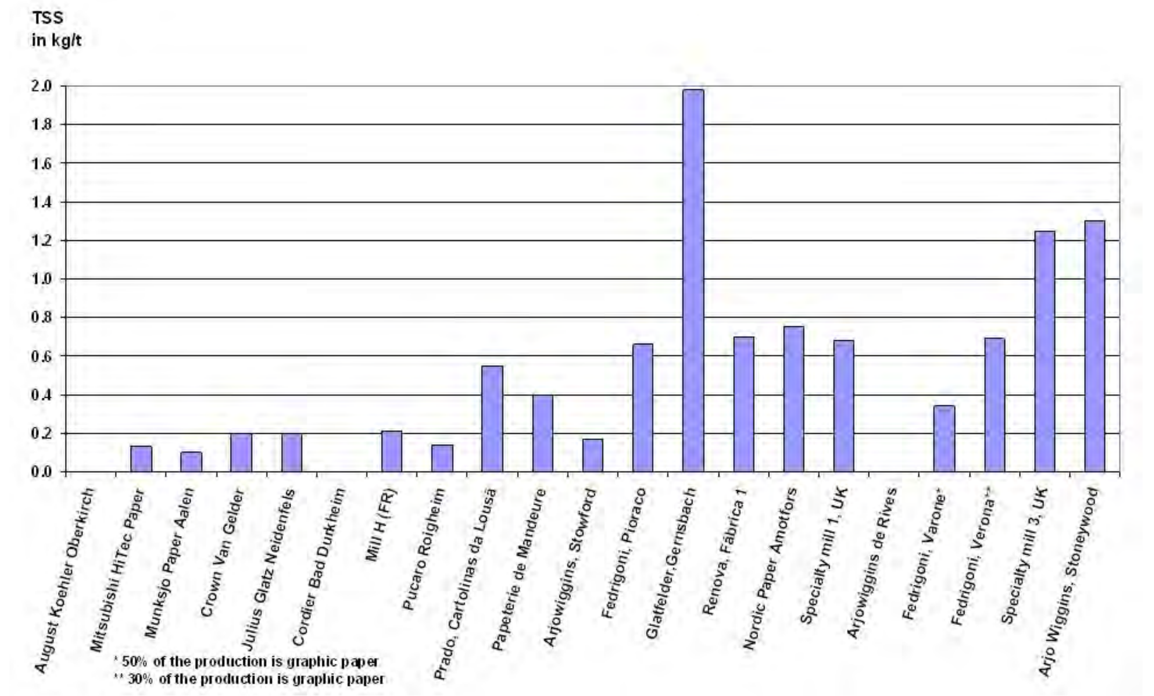


Source: Data collection/questionnaires [CEPI comment WD, 2012, ETS data]

Figure 7.20: Examples of specific TSS emissions as a yearly average after waste water treatment from non-integrated European paper mills (excluding speciality paper)

Speciality paper

In Figure 7.21 the yearly average for specific TSS emission loads as reported for the EIPPCB survey is given for non-integrated speciality paper mills. The data range from 0.1 kg TSS/t to 1.98 kg TSS/t, with the majority of reporting plants (15 of 18) emitting less than 0.8 kg TSS/t. The reported yearly average of TSS concentration values for speciality paper mills ranged from 2 mg/l to 31 mg/l (EIPPCB data collection).



Source: Data collection/questionnaires

Figure 7.21: Examples of specific TSS emissions as a yearly average after waste water treatment from non-integrated European speciality paper mills

AOX

AOX emissions from paper mills have decreased over the last years as chlorine bleaching is practically abandoned today. Sources of adsorbable organically bound halogens are mainly some chemical additives (e.g. wet strength agents and impurities, e.g. as epichlorohydrin), traces of organic halogens originating from the purchased ECF pulp, and, to a lesser extent, process water treated with chlorine-containing disinfectants (if applied).

AOX-reduced neutral wet strength agents are available on the market and are an option for further reduction of AOX emissions. Activated sludge treatment results in further AOX reductions of between 30 % and 50 %. However, this reduction is partly achieved by stripping these compounds during waste water treatment.

Coated/uncoated graphic and tissue paper

Reported yearly average specific AOX emission loads (EIPPCB data collection) for non-integrated graphic paper mills ranged from 0.0004 kg AOX/t to 0.01 kg AOX/t, while for tissue mills they ranged from 0.0005 kg AOX/t to 0.001 kg AOX/t. As a yearly average, AOX concentrations vary between 0.04 mg/l and 0.2 mg/l for graphic papers and between 0.08 mg/l and 0.3 mg/l for tissue.

Speciality paper

Speciality paper manufacturers reported AOX emission loads of 0.001 5 kg/t to 0.01 kg/t and concentration values of 0.02 – 0.36 mg/l as yearly averages.

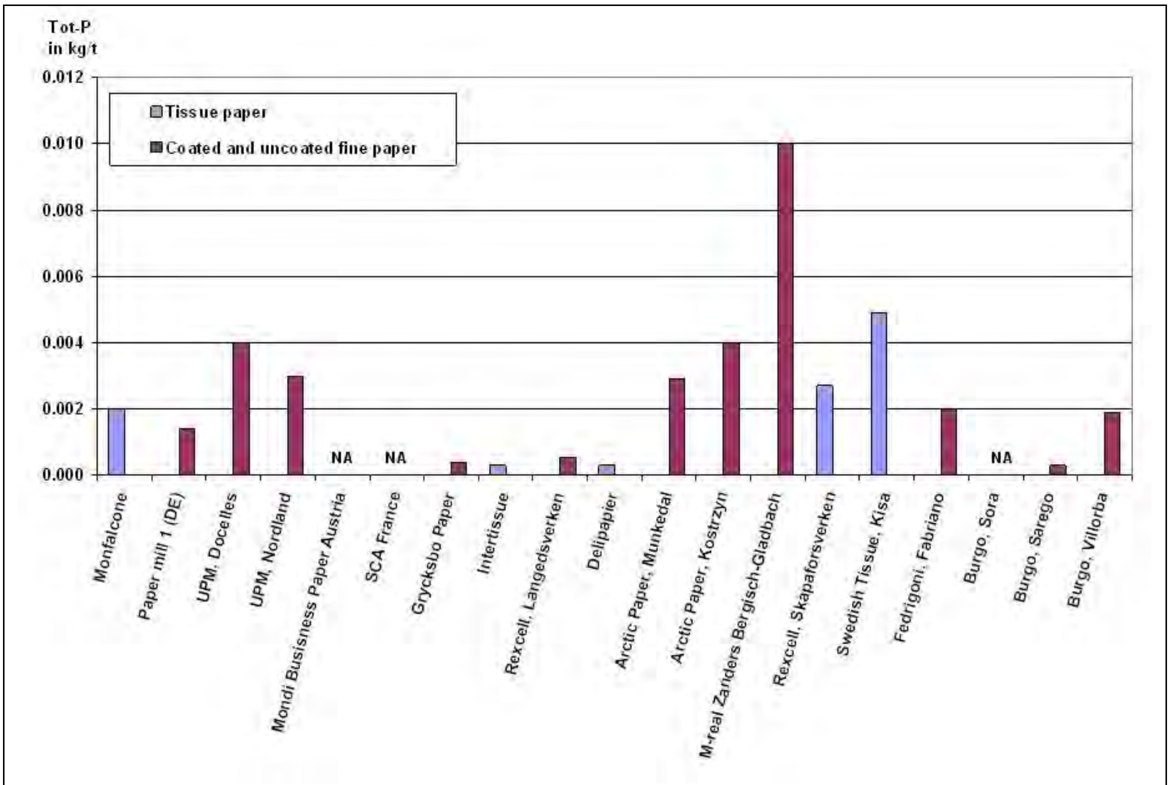
Nutrients

Effluents from pulp and paper mills normally contain only low concentrations of nitrogen and phosphate so nutrients need to be added for the effective operation of the biological waste water treatment plant. Nitrogen and phosphorus compounds in waste water originate mainly from the addition of these nutrients in the biological treatment plant (see Section 2.9.11.2.3). Some chemical additives may also contain organically bound nitrogen compounds. For example, optical brighteners may contain up to 30 % organically bound nitrogen (urea). During biological treatment, part of the organic nitrogen may be hydrolysed into ammonium and transformed to nitrate compounds in the aerated basins.

Assuming a controlled dosage to ensure optimal performance of the waste water treatment system, TN_b concentrations of 5 – 20 mg/l and tot-P concentrations of 1 – 2 mg/l are achievable (as a daily average).

Coated/uncoated graphic and tissue paper

In Figure 7.22 the yearly average of specific tot-P emission loads is given for non-integrated graphic paper and tissue mills (EIPPCB survey). Reported yearly average phosphorus emission loads (EIPPCB data collection) for non-integrated graphic paper mills ranged from 0.000 4 kg tot-P/t to 0.01 kg tot-P/t, while for tissue mills they ranged from 0.000 3 kg tot-P/t to 0.004 9 kg tot-P/t.



Source: Data collection/questionnaires

Figure 7.22: Examples of specific tot-P emission load as a yearly average after waste water treatment from non-integrated European paper mills (excluding speciality paper)

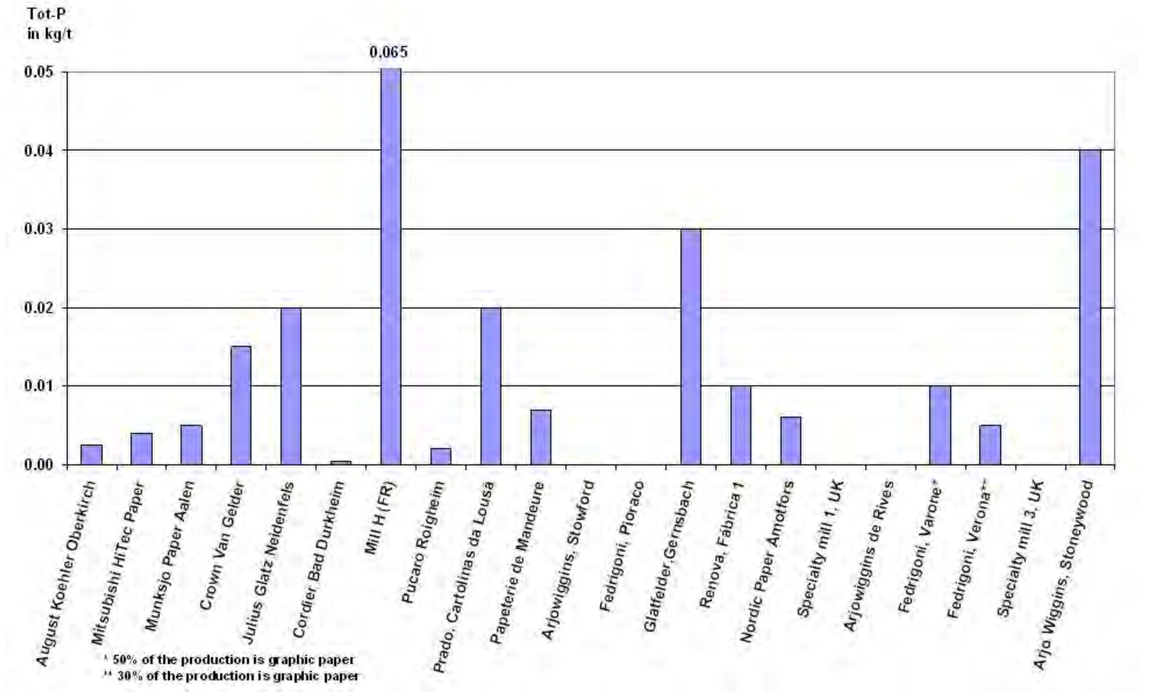
The figure shows that 14 of the 16 graphic and tissue paper mills that responded to the EIPPCB questionnaires discharge less than 0.004 kg tot-P/t, and that nine of these even reported yearly average values of below 0.002 kg tot-P/t. Only two mills reported higher values, with one as high as 0.01 kg tot-P/t.

Reported yearly average tot-P concentration values vary between 0.06 mg/l and 1 mg/l for graphic papers and between 0.08 kg tot-P/t and 1.3 kg tot-P/t for tissue, with only a few mills exceeding 1 mg tot-P /l.

Speciality paper

In Figure 7.23 the results for the data collection for speciality mills are given. Reported tot-P emission loads vary between 0.000 4 kg/t and 0.065 kg/t as yearly averages. Of 16 speciality paper mills that responded to the EIPPCB questionnaires, all but one discharge less – or significantly less – than 0.04 kg tot-P/t (14 mills). In fact, 13 mills discharge less than 0.02 kg tot-P/t and 10 of these even less than 0.01 kg tot-P/t.

Concentration values reported ranged from 0.02 mg/l to 1.25 mg/l. Of the 12 mills that reported concentration values, only two exceeded 1 mg tot-P/l as a yearly average value (1.2 mg/l and 1.25 mg/l); while nine mills reported tot-P values ≤ 0.3 mg/l. (EIPPCB survey)

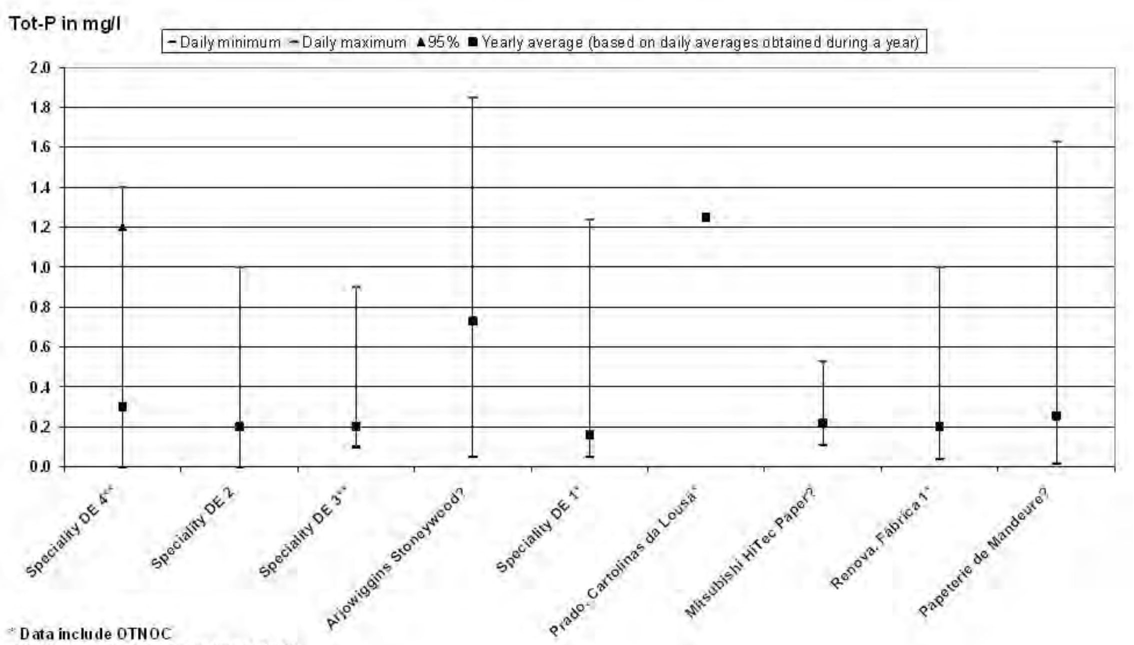


* 50% of the production is graphic paper
** 30% of the production is graphic paper

Source: Data collection/questionnaires

Figure 7.23: Examples of specific tot-P emission load as a yearly average after waste water treatment from non-integrated European speciality paper mills

Short-term averages of tot-P emissions reported from speciality mills are shown in Figure 7.24.



* Data include OTNOC
? No information if data include OTNOC
** Values based in spot samples

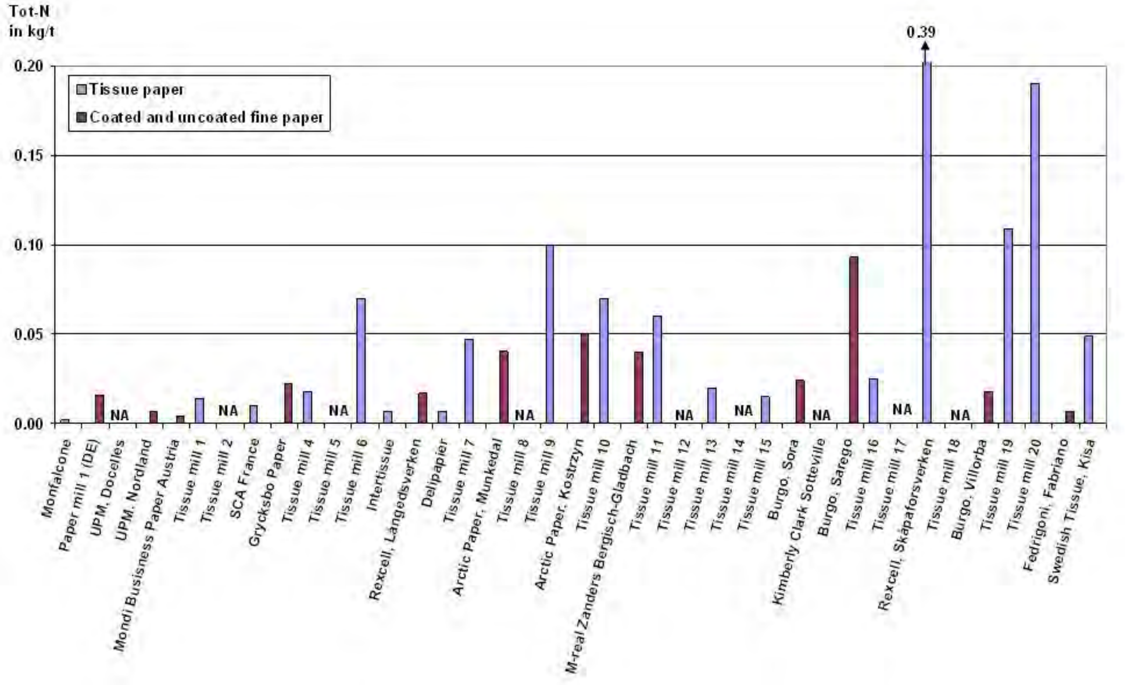
Source: EIPPCB questionnaires from 2007/2009

Figure 7.24: Short-term averages of tot-P emissions from non-integrated European speciality paper mills

Coated/uncoated graphic and tissue paper

Figure 7.25 shows the reported yearly averages for tot-N for non-integrated graphic and tissue paper mills that responded to the EIPPCB questionnaires and for tissue mills reported via the ETS. The values range from 0.004 kg tot-N/t to 0.093 kg tot-N/t for graphic paper and from 0.002 kg tot-N/t to 0.39 kg tot-N/t for tissue. Of the 18 mills providing data through the questionnaires, 14 discharge less than 0.05 kg tot-N/t and 9 mills reported N emission loads of less than 0.02 kg tot-N/t. Values for tissue mills reported in the ETS data (tissue mills No 1 to No 20) range from 0.014 kg tot-N/t to 0.19 kg tot-N/t, with most of the values below 0.01 k/ADt.

Concentration values reported ranged from 0.6 mg/l to 10.1 mg/l for graphic paper and from 0.9 mg/l to 16 mg/l for tissue. In general, reported N concentration values varied mostly between 1 mg tot-N/l and 7 mg tot-N/l; only two exceeded 10 mg tot-N/l as a yearly average value.



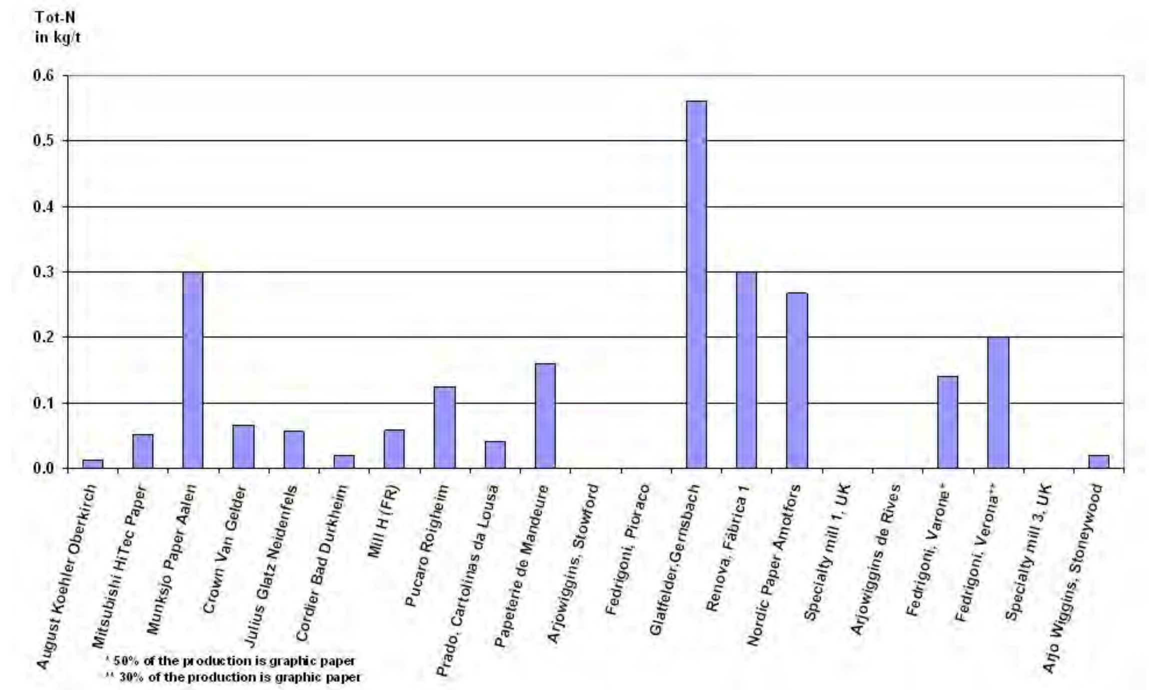
Source: Data collection/questionnaires

Figure 7.25: Examples of specific tot-N emission load as a yearly average after waste water treatment from non-integrated European paper mills (excluding speciality paper)

Speciality paper

Figure 7.26 shows the reported yearly averages for tot-N for non-integrated speciality paper mills that responded to the EIPPCB questionnaires. Values ranged in general from 0.013 kg tot-N/t to 0.55 kg tot-N/t.

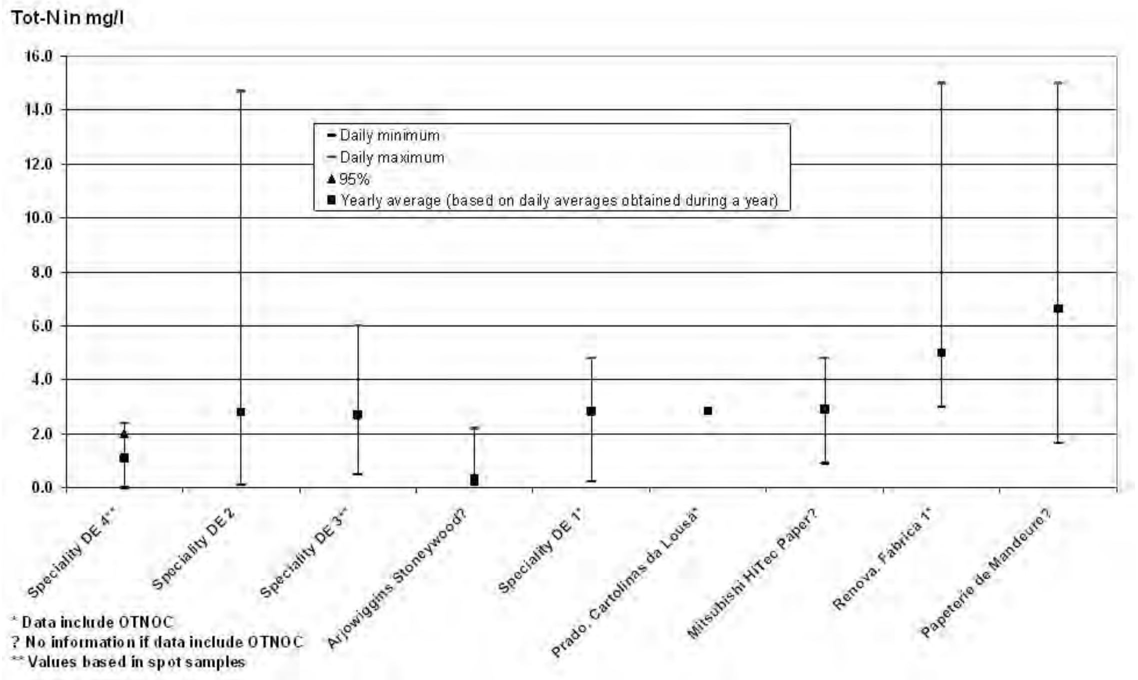
Speciality mills reported N concentrations between 0.32 mg/l and 6.64 mg/l.



Source: Data collection/questionnaires

Figure 7.26: Examples of specific tot-N emission load as a yearly average after waste water treatment from non-integrated European speciality paper mills

Short-term averages of tot-N emissions reported from speciality mills are shown in Figure 7.27.



Source: EIPPCB questionnaires from 2007/2009

Figure 7.27: Short-term averages of tot-N emissions from non-integrated European speciality paper mills

7.2.2.6 Solid waste generation

Various types of waste are generated at paper mills according to the following different sources:

- rejects from stock preparation,
- sludge from water treatment,
- other waste fractions.

Rejects from stock preparation

Rejects are generated by cleaning of the pulp furnish before the paper machine headbox. The rejects contain various impurities like shives, sand, etc. and also some fibres. The dry solids content is usually around 1 – 25 %. These rejects are normally led to the effluent treatment but may also be led directly to the sludge dewatering. Most of the solids will end up in the primary sludge from primary clarification. This is why the rejects are often not separately accounted for in the waste data.

Sludge from water treatment

Sludge from raw water and waste water treatment represents at many paper mills one of the main groups of potential waste. Different types of sludge can be distinguished.

1. Sludge from chemical pretreatment of surface water to generate process water by means of chemical precipitation/flocculation. It is only generated in mills using surface water that requires this special treatment. In these cases the amount of sludge can be significant.
2. Sludge from primary clarification. It is generated at most mills. It consists primarily of fibre and fines and of inorganic material at mills using fillers.
3. Excess sludge from biological treatment. It contains a high proportion of organic material. The generation of sludge in anaerobic treatment is moderate (about 1/7 compared to aerobic treatment).
4. Sludge from chemical flocculation is generated at mills carrying out tertiary effluent treatment (see Section 3.3.14). This treatment produces a considerable amount of sludge. The amount of organic/inorganic material in the sludge varies from mill to mill depending on the dosage and type of flocculants used. Many mills that manufacture coated papers operate a separate treatment of the waste water from coating operations. For these concentrated effluents, flocculation is a common practice resulting in sludge that has to be dewatered and further treated.

Table 7.19 gives some examples of the amount and types of rejects, sludge and other waste fractions generated per tonne of produced paper. The quantities of solid waste generated in paper mills depend on the type of paper manufactured, the raw materials used and the techniques applied. It is difficult to find representative figures for the typical amount of solid waste for different types of paper mills that are sufficiently qualified (clearly defined waste fractions, dry solids content, applied pretreatment, etc.), and that differentiate between different raw materials and paper grades. In different countries, different waste fractions are reported. The main valorisation options and major disposal routes are respectively described below.

Table 7.19: Examples of amount of solid waste (t/yr) for some paper grades

	Wood-free paper and board	Tissue from purchased chemical pulp	Speciality papers
Production per year (1994)	904 509	24 540	965 962
Number of mills	6	1	20
Solid waste, total	29 761	211	161 945
Bark	0	0	407
Rejects from screening/cleaning	0	0	639
Sludges, total	27 972	50	76 506
Chemimechanical sludge	8 852	0	46 259
Biological sludge	120	0	159
Mixed sludge from waste water treatment	19 000	50	30 088
Residues from incineration, total	1	0	26 842
Ashes/slags	1	0	26 671
Residues from abatement of air emissions	0	0	171
Other, total	1 788	161	57 551
Paper waste	1 709	90	46 817
Other	79	71	10 734
Specific waste (kg waste/t product)	**33**	**9**	**168**

NB: The figures refer to moist waste with a dry solids content needed for further utilisation ordisposal, they show the total waste regardless of whether they are utilised or not [Solid Waste Handbook, 1996].

Biological and chemical sludges have poor dewatering properties. The sludge is usually thickened before being dewatered in a belt press, filter press, screw press or on a vacuum filter. Normally they are mixed with primary sludge (or bark if available) before dewatering.

Inorganic and/or organic chemicals are used to improve the dewatering of sludge by forming larger flocks. Mixed sludge can be dewatered to a 25 – 35 % dryness with belt presses, 35 – 40 % with filter presses and to 40 – 60 % with a screw press using steam in the pretreatment stage. The achievable degree of water removal depends to a certain extent on the quantity of biological sludge mixed with primary sludge, the ash content and the fibre content. In some paper mills the sludge is also dried after dewatering.

In many Member States the dumping of waste with high organic content is discouraged by governments. The EU Directive on landfill of waste will support this tendency in setting targets to cut the amount of biodegradable (municipal) waste sent to landfills. Consequently alternative disposal routes and pretreatment options need to be developed for larger quantities of sludge (see Section 2.9.8). Many organic substances are burnt for energy recovery. Burning reduces the volume of waste and the inorganic content remains as ash, which is normally transported to a landfill site. Ash is also used as raw material for the cement industry.

Besides production-related rejects and sludge, ash slags and filter dust from power boilers form a group of waste which is generated in some mills (depending on the fuels used and the abatement techniques applied for emissions to air).

Other waste fractions

In addition, there are other types of waste generated in smaller amounts, but which may still create problems as regards disposal. The following types can be distinguished but they are difficult to quantify as a specific amount per tonne of product:

- scrap iron and other metals,
- plastics,
- chemicals including coating residues,

- spill oil,
- glass,
- packaging (e.g. container for chemicals, pallets),
- building waste as wood, concrete, bricks, etc.,
- waste from laboratories,
- domestic waste,
- paper waste that cannot be utilised in the mill,
- wires and felts.

Most of this material can be utilised when the single waste fractions are collected and stored separately.

7.2.2.7 Emissions to air

Emissions to air from energy generation
Emissions to air from paper and board mills are mainly related to energy generation, i.e. to various types of power plants and not to the papermaking process itself. Because atmospheric emission levels of paper mills are directly linked to energy consumption, saving energy will lead to a reduction in air emissions. For instance, the cogeneration of heat and power consumes less energy than the conventional separated generation of electricity and heat because the conversion efficiency of fuel use of CHP plants is significantly higher. For the amount of total primary energy used and the associated emissions, it is very significant whether the mill uses purchased electricity from the public grid or power generated on site in a CHP plant.

Furthermore, the emission levels depend on the type of fuels used (coal, oils, gas) and the implementation of emission control techniques for the reduction of SO_2 and NO_X, particulates and non-incinerated organic gaseous substances. Abatement techniques for emissions to air are generally applicable to combustion processes of fossil fuels for generating power and steam. Because air emission control techniques are not specifically related to the paper industry but the industry in general, this issue will not be comprehensively covered in this document. Only some generally acknowledged measures for improvement of the environmental performance of energy supply in paper mills are discussed in Section 2.9.7.

Emissions to air from the paper mill
Releases to air that are not related to energy generation are mainly volatile organic compounds (VOC). This emission is usually of minor importance and within generally acceptable limits (i.e. below national limit values for these substances).

Situations where emissions of volatile organic compounds need to be controlled are related to a limited number of paper mills of different types. In paper mills that utilise volatile organic chemical additives in the production process, these substances are measured in low concentrations in the exhaust air. Most volatile components of virgin pulps have been lost to the atmosphere by the time the pulp reaches the paper machine. However, in the dryer section of the paper machine or after coating the paper, the web is heated up to 100 °C to evaporate the residual water. Apart from the water vapour, volatile components from the fibre material and from chemical additives are also released. Usually no special abatement techniques for these emissions are applied in paper mills because the released loads are relatively small.

The results of an investigation into the exhaust air in seven paper mills in Germany are summarised in Table 7.20.

Table 7.20: Organic substances measured in the exhaust air of paper mills before heat exchange

Investigated installations	Total mass flow as $orgC_{total}$	Mass concentration as mg $orgC/Nm^3$	Remarks
PM, wood-free paper, unsized	0.7 kg/h	2 – 17 mg/Nm^3	98 % from the dryer section
PM+CM, wood-free paper, coated	No data	10 – 30 mg/Nm^3	Fluctuations; maybe partly caused by residual methane from the gas-fired IR dryer
PM+CM, wood-containing, coated	No data	48 mg/Nm^3 at pre-dryer 24 mg/Nm^3 at post-dryer	90 % from pre-dryer; 10 % post-dryer;
CM, wood-free paper, double-coated	4.9 kg/h	30 – 67 mg/Nm^3	Emissions partly caused by residual methane
PM, wood-free, size press	1.6 kg/h	2 – 77 mg/Nm^3	Main emissions (56 %) from suction of wire and press section
PM, RCF paper and board	0.8 kg/h	6 – 26 mg/Nm^3	70 % from pre-dryer
PM, RCF paper	2.4 kg/h	3 – 8 mg/Nm^3	

NB: PM = paper machine; CM = off-line coating machine; PM+CM = paper machine with in-line coating machine
Source: [114, PTS-FB 1997]

The measured concentrations of total organic carbon vary significantly. Values between 2 mg/Nm^3 and 135 mg/Nm^3 have been measured. A specific load between 0.05 – 0.5 kg $orgC_{total}$/t of paper was determined in the exhaust of the seven investigated mills [114, PTS-FB 1997]. The emission of some single substances of concern in the exhaust air of coating machines, e.g. as acrylonitrile (occurring only when acrylonitrile butadiene binder systems are used), can be avoided or reduced by careful choice of coating colour recipes. Coating colour recipes that contain carcinogenic compounds should be avoided. Formaldehyde (concentrations between 0.1 mg/Nm^3 and 4.8 mg/Nm^3 have been measured) is normally more difficult to prevent because it comes from different sources such as wet strength agents, preservatives, biocides, etc.

It can be concluded that the concentrations of organic substances in the exhaust air of paper mills can usually be considered low so that no abatement technique for emissions to air is applied. On the other hand, the amount of air vented out from the process is extremely high, which may justify considering the emissions of organic carbon compounds significant.

Examples of operations where higher concentrations of VOC are released are the following:

- coating of paper with coating colours that contain organic solvents, although the basis of coating colours is exclusively aqueous (lower concentrations of various volatile substances (e.g. as formaldehyde, alkyl-substituted aromatics, lower alcohols) can be measured in the exhaust of every coating machine);
- preparation of papers with resins and the production of speciality papers by using volatile additives.

Examples of volatile organic compounds (VOC) which are released to the atmosphere are the following:

- alcohols;
- formaldehyde contained in urea or melamine formaldehyde (UF/MF) resins used as wet strength agents;
- acetone and other ketones;
- phenols (only in special cases);
- solvents used for cleaning machine fabrics (usually a minor application);

- organic acids and residual monomers of polymers.

In a few special cases, particulates from some finishing operations may cause concern.

Emissions from sludge and residue incineration (optional) may also occur. However, the on-site incineration of sludge and other residues is usually only carried out in integrated mills. In integrated mills, sludge may be incinerated together with bark in bark boilers or in paper for recycling mills in dedicated incinerators together with other rejects.

Odours from vapours and from waste water treatment plants (local)
In paper mills, odours may be emitted (see Section 2.9.14). They may be caused by excessively long retention times of process water in the water system (pipes, chests, etc.) or deposits of sludge causing the build-up of volatile organic acids (volatile fatty acids, primarily acetic and propionic acids). These compounds may be formed by microbial action on organic substances (notably starches) under anaerobic conditions, which may be released at the wet end, during paper drying and during effluent treatment. To a small extent, hydrogen sulphide could also be generated under anaerobic conditions. If so, odours can be avoided by suitable process engineering measures. The waste water treatment plant may also emit significant quantities of odour. If the waste water treatment is well designed and controlled, annoying odours can be avoided.

7.2.2.8 Noise from paper machines (local)

Noise from paper mills has only a local impact but for the working environment and the neighbourhood it may be the most serious of all environmental problems caused by a paper mill.

Paper machines are known as noisy installations. The major noise sources of paper and board machines, in the wire section, press section, dryer section, coater, winder and ventilation, are compiled in Table 7.21.

Table 7.21: Major noise sources of paper and board machines

Wire section	Press section	Dryer section	Coater	Winder	Ventilation
Suction rolls	Built-in gears	Steam and condensate system	Air dryers	Dust control system	Process ventilation fans
Vacuum system	Suction rolls	Basement enclosure	IR dryers (cooling air)	Drives	Machine room ventilation fans
Showers	Hydraulic systems	Process ventilation	Structure-borne noise from machine frame	Trim handling	Air dryers
Drive system	Showers	Electric motors	Blade coating	The paper web	Nozzles
Ventilation	Steam boxes	Gears	Drives	Gears	Fan drives and motors
Electric motors	Structure-borne noise from machine frame (gears & guide rolls)	Broke conveyor	The paper web	Hydraulic system	Air intake opening
Centrifugal cleaners	Drives	The paper web	Fan room for air dryers	Knifes	
High pressure pumps	Vacuum system	Dry-end pulper		Nips	
Wet-end pulper	Press pulper			Winder pulper	

Besides the paper machine, there are other sources of noise that may contribute to the noise level. Examples are the refiners and vacuum pumps.

It is possible to decrease the noise level step by step by several measures at the main noise source. A possible measure for internal noise control is for example the installation of new closed hoods with higher sound insulation.

For external noise control, examples of measures are the installation of absorptive silencers and/or pipe resonators to reduce the noise levels from exhaust air fans and vacuum pumps, or silencers and sound insulation hoods for the fans on the building roof, etc. (see Section 7.3.16). The measures applied will depend to a large extent on the specific noise problem of a mill and the targets set. Usually they will be much stricter when the mill is located adjacent to a residential area.

To a certain extent, the suppliers of machinery have replied to this problem of noise and vibration in developing more silent equipment and efficient silencers. The activities are focused on the measures necessary to attenuate noise at the source. These measures already aim at the prevention of noise at the machine design stage and noise attenuation for existing equipment. The target noise levels applied depend on the country and the mill location and the objective of creating a better working environment for the papermakers themselves.

7.3 Techniques to consider in the determination of BAT

This section describes techniques (or combinations thereof), and associated monitoring, considered to have the potential for achieving a high level of environmental protection in the activities within the scope of this document. The techniques described will include both the technology used and the way in which the installations are designed, built, maintained, operated and decommissioned.

It covers environmental management systems, process-integrated techniques and end-of-pipe measures. Waste prevention and management, including waste minimisation and recycling procedures are also considered, as well as techniques that reduce the consumption of raw materials, water and energy by optimising use and reuse. The techniques described also cover measures used to prevent or to limit the environmental consequences of accidents and incidents, as well as site remediation measures. They also cover measures taken to prevent or reduce emissions under other than normal operating conditions (such as start-up and shutdown operations, leaks, malfunctions, momentary stoppages and the definitive cessation of operations).

Annex III to the Directive lists a number of criteria for determining BAT, and the information within this chapter will address these considerations. As far as possible, the standard structure in Table 7.22 is used to outline the information on each technique, to enable a comparison of techniques and the assessment against the definition of BAT in the Industrial Emissions Directive.

This section does not necessarily provide an exhaustive list of techniques which could be applied in the sector. Other techniques may exist, or may be developed, which could be considered in the determination of BAT for an individual installation.

Table 7.22: Information for each technique described in this chapter

Headings within the sections
Description
Technical description
Achieved environmental benefits
Environmental performance and operational data
Cross-media effects
Technical considerations relevant to applicability
Economics
Driving force for implementation
Example plants
Reference literature

A few measures described in this section are only valid for specific paper grades, whereas most are applicable independent of the paper grade produced. The former will be noted. Otherwise the measures are considered to refer to papermaking in general.

Because most paper mills in Europe are non-integrated paper mills, this section is dedicated to papermaking and related activities only. But many paper mills are integrated, i.e. pulp and paper is produced at the same plant. Others are partly integrated, i.e. part of the pulp used is purchased pulp and part is manufactured on site. In those cases, the reader should refer to the corresponding chapters on pulping as well (chemical pulping, mechanical pulping or processing of paper for recycling).

7.3.1 Water management and minimising water usage for different paper grades

This measure should be read together with Section 7.3.2 on the control of potential problems of closing up water circuits. See also Section 2.9.3.

Description
Although there are a lot of technical alternatives that might differ somewhat from mill to mill there are some basic water reduction solutions which are given below.

- Improvement of paper production planning.
- Efficient separation of cooling waters from process water and their recooling in cooling towers for reuse (see Section 2.4.2.1); 10 – 15 % fresh make-up water is required when reusing this stream. For protection, a micro-screen or other strainer is recommended to remove solids. Where cooling water fractions are sewered, they are not led to contaminated process water sewers.
- In integrated mills, the water circulation in the paper machine is kept separate from pulping sections and excess white water from the paper machine is fed in counter-current mode to the pulping department.
- The shower water system is usually the biggest consumer of fresh water in the paper machine system. Shower water consumption is usually in the range of 2 – 7 m^3/t, assuming a total water consumption of about 10 – 15 m^3/t of paper. To reduce the fresh water consumption to reasonable levels, most of the fresh water must be replaced by clarified white water. Efficient fibre recovery with associated clear or super clear white water production to replace fresh water in paper machine showers is applied for this purpose (see Section 7.3.3 and 7.3.4). Thus, a shower water system with significantly reduced fresh water demand can be achieved. However, normally it is not recommendable to use save-all filtrates for the press section showers (e.g. high-pressure felt showers) because otherwise precipitation of colloidal material from the clarified white water on the felt may occur. This may lead to clogging of the felt. Up to now, high-pressure felt showers require fresh water. If an operator still wants to use filtrate, the water treatment method has to be carefully investigated, that at least the colloidal material is eliminated (see Section 7.3.3 or 6.3.11).
- Recycling loop for part of the vacuum pump sealing water with cooling and solids removal (or sealing water-free vacuum systems, see Section 2.9.6.2.1).
- Management of all raw material flows through the paper mill in considering them a unit of fibres, chemicals and water that interfere with each other. All inputs of chemicals for instance are controlled and investigated with respect to how they influence water quality and wet-end chemistry (controlled system input, see Section 2.9.3).
- Design and maintenance of piping and storage chests in such a way that excess water volumes can be stored and the water quality is not deteriorated (see Section 7.3.7).
- Training and motivation of the staff, which is crucial to achieve and maintain low water consumption.

Depending on the starting point, the characteristics of the mill and the product quality, with these arrangements, the fresh water consumption of a standard quality uncoated paper or board machine could reach 3 – 12 m^3/t and a standard quality coated printing paper machine 5 – 15 m^3/t. For speciality papers, consumption levels can be significantly higher.

Reducing water consumption, aiming towards the further reduction of effluents, requires additional implementation of a physico-chemical (see Section 6.3.11), biological (see Section 6.3.4) or mechanical means (see Section 7.3.3) or their combination to treat the water for recycling.

The concentration of inorganic and organic substances in the water circuits have to be kept at acceptable levels to prevent problems in machine operation and fulfil paper or board quality requirements.

Achieved environmental benefits

Less use of fresh water. In paper mills with low water consumption, contaminants are more concentrated in the effluent which often contributes to higher removal efficiencies. To a certain extent, losses of raw material and energy might be reduced in paper mills with low water consumption. Lower water volumes usually also mean a lower heat load to the receiving water body.

Environmental performance and operational data

The achievements depend mainly on the previous situation of the mill. The degree of water circuit closure depends very much on the product manufactured. Depending on the initial state of the mill, achievable values for total fresh water use for some different paper grades are in the range of [244, Pulp and Paper TWG 2007], [138, PP TWG 2009]:

- newsprint: 8 – 13 m^3/t,
- coated and uncoated fine paper: 3 – 15 m^3/t,
- LWC paper: 10 – 15 m^3/t,
- SC paper: 10 – 15 m^3/t,
- multi-ply folding boxboard: 8 – 15 m^3/t (virgin fibres),
- fluting: 4 – 10 m^3/t (virgin fibres),
- tissue: 4 – 13 m^3/t (virgin fibres; heavy-weight products or lower quality grades), and 15 – 25 m^3/t (virgin fibres; light-weight products or high-quality grades),
- speciality papers: 13 – 65 m^3/t; consumption levels can be significantly higher in some cases.

The consumption of fresh water depends mainly on the paper grade, the number of showers and the amount of fibre-containing water used for the paper machine showers. Light-weight paper products generally require somewhat more water per tonne of end product than heavy-weight paper products.

Typical monitoring devices include flow meters for paper machine fresh water feed, shower water feed and major white water streams. Suspended solids or turbidity measurements for clear white water are important, especially if it is used for paper machine showers.

Clear or super clear white water from the save-all is increasingly used in paper machine showers. If the white water solids content or the particle size rises beyond the shower nozzle capacity, the nozzles would plug. The water distribution to such showers should therefore go through a protective in-line strainer equipped with an automatic purge, to protect against the effects of save-all upsets and in addition to avoid white water replacement with fresh water. Also, shower cleaning equipment, with an internal brush or other purging equipment, can help prevent problems.

Cross-media effects

No negative cross-media effects if the measures of Section 7.3.2 are implemented.

Technical considerations relevant to applicability

Water reduction measures can be carried out both in existing and new mills. However, the separation of pulp and paper water loops in integrated mills or a high degree of water system closure is more expensive in older mills because the major rebuild of piping and major modifications to the machine wet end are likely to be necessary when aiming for further closure. In existing machines, these modifications are beyond a point difficult to reach without a major rebuild or expansion of the process. With new machines, the reduced water consumption can be applied more easily. Another problem to be addressed in existing mills is the suitability of materials to withstand the accumulation of corrosive substances, such as chlorides, and elevated or increased water temperatures. In general, the more differentiated the products are and the more often the type of paper produced on a machine is changed, the more difficult it is to close the water loops. Smaller mills with only one paper machine usually face more production changes during the year (or day) than bigger mills manufacturing bulk grades. The individual configuration of plants has to be considered.

In existing mills, low water consumption as the result of a combination of different measures usually requires many years of development and improvements in the process.

Economics
No general information on cost structures for water loop closure is available because each single plant is an individual case in this respect. The costs of these measures depend on the number and nature of water circuit rearrangements necessary and the type of additional installation needed.

Driving force for implementation
A bundle of possible measures to reduce fresh water consumption is called for in mills where fresh water availability is restricted or where it is a paid commodity. The improvements often have a net positive effect because of possible savings achieved by lower costs for raw water, lower losses of fibres and fillers, sometimes lower energy consumption and lower volumes of waste water to be treated.

Both increases of production capacity and the limited hydraulic capacity of the existing effluent treatment plant are also reasons to apply these measures.

Example plants
The measures described are implemented in many paper mills in Europe.

Reference literature
[16, CEPI 1998], [244, Pulp and Paper TWG 2007], [138, PP TWG 2009].

7.3.2 Control of potential negative side effects from closing water circuits

Description
The enhanced recycling of process water in paper and board machines causes a rise in the concentration of colloidal and dissolved organic and inorganic constituents in these streams. Depending on the characteristics of the pulp in-feed and the used chemicals in papermaking, the closed-up water systems can have an adverse effect on the runnability of the machine, the quality of the end product and even the production costs due to increased use of chemicals. These potential negative effects need to be controlled. The possible advantages and disadvantages of reducing water consumption are given in Table 7.23. However, at water consumption levels as presented in Section 7.3.1, no adverse effects should occur if the water circuits are operated, maintained and controlled in a suitable manner.

Table 7.23: Possible advantages and drawbacks of increased closure of water circuits in paper mills

Possible advantages of closing up the water circuits	Possible drawbacks of closing up the water circuits
– Improved retention of soluble material in the paper web	– Higher concentrations of dissolved and colloidal materials in water circuits
– Reduced energy requirements for heating and pumping	– Risk of slime production leading to deposits and web breaks
– Better dewatering properties on the wire, which leads to energy savings in the dryer section	– Risk of lower product quality, e.g. concerning brightness, strength, softness, porosity
– Less investment costs for reduced equipment	– Increased consumption of process aids
– Saving raw materials due to lower losses	– Risk of corrosion (higher concentration of chlorides)
– Higher reduction efficiencies of waste water treatment	– Higher risk of blocking of pipes, shower nozzles, wire and felts
– Reduced total releases to water bodies	– Problems of hygiene control for tissue, food contact and medical applications

The pulp and the water carrying the fibres contain dissolved and colloidal organic compounds called 'anionic trash'. At higher concentrations, these organic substances affect the retention and formation of the paper web and increase the plugging of machine press felts and cause sticking of the paper web on machine rolls.

In the production of food packaging materials, the product must be free of harmful soluble matter. The temperature increase at the paper or board machine also needs to be controlled so that operating temperature limits, 45 – 55 °C, at the wet end are not exceeded. On the other hand, on the paper machine wire section, a hot pulp suspension is advantageous because the viscosity of water is decreased with increasing temperature, resulting in improved dewatering.

The measures for controlling the undesired effects of closed-up water circuits are given below.

- The paper or board machine white water system does not receive water from integrated pulping departments or from parallel machines. The separation of water loops is usually carried out with thickeners. The optimum design of water loops is crucial.
- The recycled cooling or sealing water and clean white water feed to machine showers are treated with an appropriate strainer to protect against the plugging or wear of machine equipment.
- Recycled sealing water is cooled sufficiently by heat exchangers or clean make-up water. The vacuum pump performance especially limits the allowable sealing water temperature.
- The composition (e.g. presence of colloidal substances), hardness, pH and temperature of recycled waters fed to a specific use must be compatible with the equipment or the process streams. It is beneficial to determine the water quality that is really needed.
- In integrated mills, the pulps should be efficiently washed prior to being fed to the paper mill to reduce the content of dissolved or colloidal substances. In those mills, it would also be beneficial to increase the consistency of the pulp fed to the paper mill to over 30 % instead of the typical 2 – 4 % in order to reduce the carry-over of dissolved matter. This can help to decrease the consumption of chemical additives such as alum, polymer or starch and machine aids like washing chemicals, slimicides and biocides.
- The selection of the chemical additives has to be reassessed when closed-loop principles are applied because some chemicals behave very differently in the changed chemical environment.
- The monitoring of recycled water streams by on-line meters and lab analysis is beneficial to prevent target quality limits from being exceeded.

Achieved environmental benefits

The measures are an integral part of the measure described in Section 7.3.1. They support these measures to achieve and maintain low fresh water consumption without significant adverse effects.

Environmental performance and operational data

The risk of scaling caused by calcium compounds, slime and pitch problems is pronounced and must be counteracted with an appropriate mixing of water fractions, pH control, increased dosage of machine aids or an appropriate purge of calcium out of the system (see Section 6.3.5). If the machine can be operated at over 50 °C, the growth of microorganisms and their activity in the water system is diminished. But anaerobic activity may still occur above 50 °C (thermophilic bacteria), generating odour in the sulphur- and carbohydrate-rich environment that needs to be controlled.

The optimisation required by the implementation of these control measures is usually carried out gradually over a longer period of time in existing mills. The success in applying this technology depends on the wet-end chemistry case by case. Some mills have controlled the possible adverse effects of closing up the water circuits just by using more chemical additives. The selection of proper chemical additives and their combination is a fairly sophisticated procedure and is often poorly understood, but is necessary to obtain maximum runnability and low costs and environmental impact.

Cross-media effects

In some cases the need for chemical additives and paper machine aid chemicals will increase. The type of chemicals used must be reassessed to maximise the suitability for a certain paper grade.

Technical considerations relevant to applicability

The measures can be applied both at new and existing mills. However, existing mills usually need many years to implement most of these improvements. The required level of measures varies for individual cases: the machine type, the product(s) and the degree of closure are the key parameters. The requirements are the least stringent for the production of unbleached packaging grades and get stricter for high-quality grades, such as fine papers.

Elevated dissolved or colloidal matter concentrations due to increased process water recycling tend to retain more of these substances in the end product. Limits to this are set by the product quality and the acceptable consumption of papermaking chemicals.

Also in sealing and cooling water applications, the stream temperature and dissolved and particulate solids concentrations are limiting factors. The latter must be dealt with using cleaning equipment and/or sufficient bleedout.

For sealing, mechanical seals that do not need any fresh water are also available.

Control of paper machine water and recycle quality calls for improved control and monitoring of the pulping process as well.

Economics

The costs of the measures depend on the number and nature of rearrangements necessary and the type of additional installations needed. No data on single costs are available.

Driving force for implementation

The enhanced recycling of process water in paper mills can have adverse effects on the runnability of the machine and the quality of the end product. These potential negative effects need to be controlled when paper mills are aiming at low water consumption.

Example plants

Numerous mills in Europe. Economical paper production has been successfully implemented in numerous partially closed-cycle mills, even for high-speed paper machines. Through the use of enhanced recycle water purification (see Sections 7.3.3, 6.3.4 and 6.3.11), certain problems can be solved and machine control with chemicals reduced.

Reference literature

[15, CEPI 1998].

7.3.3 Internal treatment of white water by use of membrane filtration and recycling of treated process water

Although the technique described in this section is the same as the one in Section 7.3.5, the application is very different.

Description

Conventional filtration cannot properly remove solids and colloidal material below 1 µm effective size. Thus small bacteria and colloids escape the filter media. However, this is only true for unflocculated solids and colloids. They can also be transformed into 100 – 1 000 µm flocs by flocculation and can be easily filtered off. But the addition of flocculants may have the drawback of undesirable salts being introduced into the water system (modern organic/synthetic flocculants do not introduce a significant salt burden).

Membrane technologies, depending on the applicable membrane cut-off size (corresponding to the approximate 'molecular weight' of the organic compounds removed) and filtering pressure, can theoretically remove almost 100 % of the organic material (see Figure 7.28) without introducing undesirable compounds into the water circuits.

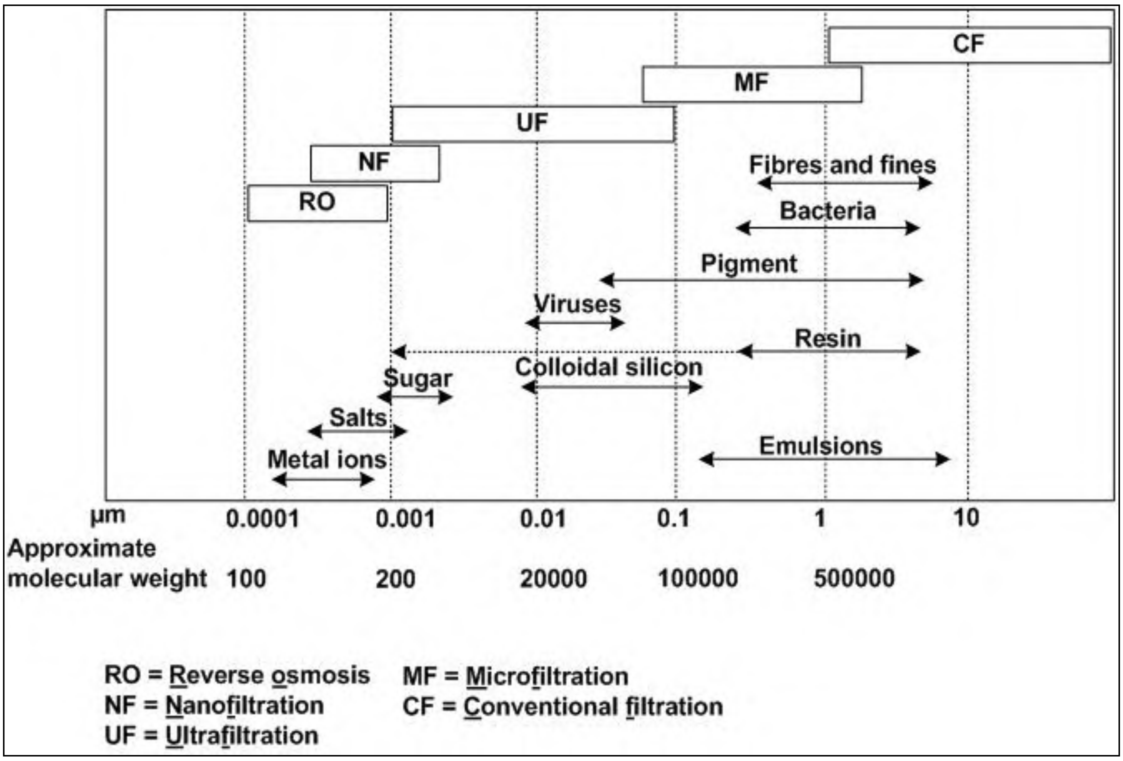


Figure 7.28: Filtration ranges of different filtration technologies

According to the differences in pore size, different membrane processes can be distinguished:

1. Micro-filtration (MF), which operates at below 1 bar pressure and uses membranes with 0.1 – 0.2 µm pore size, could be used where 1 – 5 mg/l of very fine solids is acceptable after treatment.
2. Ultrafiltration (UF) operates at 1 – 2 bar pressure difference and is regarded a possible solution for 100 % removal of residual solids and colloids and high molecular weight organics from pulp and paper mills' water or effluent streams. In Europe, a few full-scale applications for white water treatment with UF technology exist.
3. Nano-filtration (NF) or reverse osmosis (RO) use pressures reaching 15 – 25 bars, but so far these methods have not been seriously considered for full-scale use in the pulp and paper industry in Europe (there is one full-scale application in the High Desert of north-western New Mexico).

Any type of membrane filtration cannot handle sudden peaks of suspended solids. If the suspended solids are homogeneous, only a police filter is needed to avoid sudden peaks.

Key issues affecting the selection of a membrane technology are as follows:

1. Input stream, its composition and hydraulic load, including peak operating conditions.
2. Clean water quantity and quality required and the applicability of treatment output in varying operating conditions for intended end uses and the effect on pulp or paper quality.
3. High-pressure filtration methods produce cleaner water, but consume more electricity and must be sized larger or equipped with more efficient pretreatment or counter-measures to protect against plugging.
4. Maintenance requirements (symmetric or asymmetric membrane structure, washing with acids or alkaline solutions, spare capacity, automated or continuous cleaning). Symmetric membranes have a higher tendency to plug. Plugging can be avoided by maintaining highly turbulent conditions close to the membrane wall, but this requires somewhat more energy.
5. Final treatment and disposal of the concentrate or sludge, which in most cases is waste. Liquid waste may be concentrated enough to cause toxic effects at an effluent treatment or it may require further concentration or absorption into a solid fuel for disposal by incineration. Some inorganic salts in the concentrate are corrosive, which must be taken into account in the selection of equipment and piping materials.

When considering these aspects, UF can be used as a kidney to handle disturbing matter in the white water and close the water system further.

For in-line white water treatment, the kidneys consist of a common disc filter, a pre-filter (pressure screen or bow screen) for the removal of long fibres that could harm the membranes and the UF system. The rejects from the pre-filters are recycled back to the process. Optionally, the cloudy filtrate can also be sent to the UF feed together with clear filtrate. This is for cases where the clear filtrate is so clean (SS <20 mg/l) that some additional solids are beneficial to filtration by keeping the cross-flow membrane surface cleaner. Normally, the pre-filtered clear filtrate is piped to the UF system's feed tank and pumped into the UF unit. The number of filters in operation regulate the clean UF permeate capacity. The pressure difference is kept as low as possible at, for instance, 0.7 – 0.8 bars. The quality of the UF filtrate is sufficient for use as, for example, high-pressure (HP) shower water, sealing water and for the dilution of chemical additives. The concentrate from the filters can be piped to the main effluent treatment. A possible layout for an integrated paper mill using ultrafiltration for white water purification is shown in Figure 7.29.

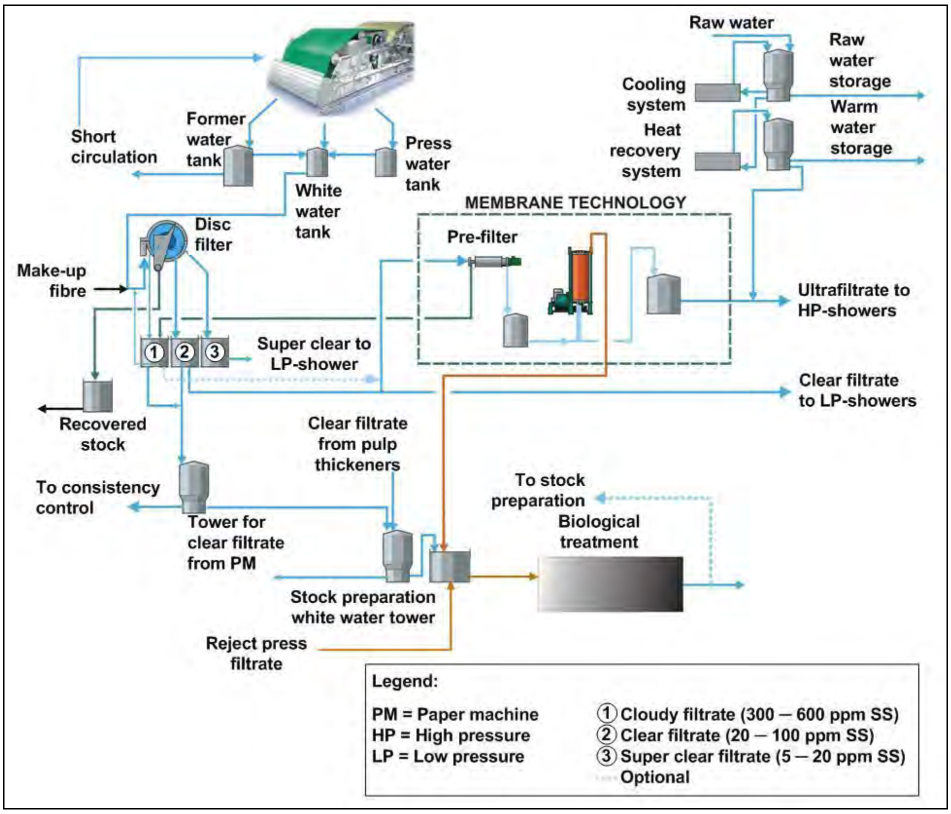


Figure 7.29: **Possible layout of an integrated paper mill using ultrafiltration for white water purification**

Achieved environmental benefits

UF technology is today commonly applied when fresh water consumption is to be decreased or when the hydraulic discharge load (not the organic load) needs to be reduced. By replacing warm fresh water with ultrafiltrated white water from the paper machine, a fresh water reduction of about 2 – 4 m^3/t of paper is normally achieved.

Ultrafiltration in white water applications usually means the treatment of clear filtrate and/or parts of the cloudy filtrate from the disc filter. The UF membranes in practice remove 100 % of TSS, 99 % of bacteria, 100 % of turbidity (all colloidal material is removed), and 45 – 70 % of anionicity. Dissolved COD is lowered by about 10 – 20 %. This means that UF still allows parts of the organic substances (e.g. all low molecular weight organics) and soluble inorganic matter to pass through. First of all, UF of white water gives better quality recirculated water which can be used for low- and high-pressure shower water in the wire section, dilution water for chemicals, press section lubrication water or other washing and cleaning purposes. There is not yet experience of using the permeate for felt cleaning.

Environmental performance and operational data

Membrane treatment processes used specifically for paper or board machines' white water have been tested basically at full scale for all common paper grades. The full-scale applications so far are:

- Sappi Kirkniemi mill (magazine paper), Finland; white water treatment, feed from save-all, the permeate is used at wire section showers (high- and low-pressure) and as sealing water;
- UPM-Kymmene Tervasaari mill (back paper for labels), Finland; applications: wire section high-pressure and low-pressure showers;
- Holmen Paper Madrid, (newsprint), Spain; applications: wire section high-pressure showers;

- Modern Karton mill (Testliner/fluting) based on old corrugated container (OCC), Turkey; applications: wire section high-pressure showers;
- Hokuetsu Mill (fine paper), Japan; applications: wire section high-pressure showers.

The practical limitations of membrane filters are usually set by the membrane material itself, which is sensitive to plugging unless the units are equipped with pretreatment for solids removal or in-built systems that provide cleaning or maintain strong turbulence close to the membrane surface. Regular washing of filters with acids or alkaline solutions (NaOH, detergents, and tensides) is required, generating small amounts of liquid waste. When the flux of permeate goes down, the membranes must also be changed from time to time (the lifetime of a membrane is about 15 months).

Cross-media effects

The electricity usage for UF technology depends on the paper grade and thus the process water quality to be treated (temperature, COD, etc.). White water from RCF-based Testliner/fluting processes is usually colder and more concentrated than white water from mechanical and wood-free printing paper manufacturing and therefore achieves a 30 – 50 % higher flux. So, one UF unit gives significantly different treated volumes (m^3/d). For printing paper, ultrafiltration requires electricity in the range of 2.6 kWh/m^3 of treated white water and approximately 4.7 kWh/m^3 for RCF-based Testliner/fluting mills.

A possible reduction of water consumption can indirectly lead to a decrease of the discharged nutrients load (N and P) because the total N and P releases are governed by the minimum concentration that is required for the growth of biomass in waste water treatment plants.

For membrane filtration, the solution as to how to treat the liquid or solid wastes is crucial. In full-scale UF applications, the concentrate from membrane filtration (3 – 5 % of the feed) is further treated in the biological treatment plant. In this case, no reduction of the total solid load to the receiving water body is achieved. However, investigations into whether to treat the concentrate separately are still being carried out.

Technical considerations relevant to applicability

UF could be applied on super clear filtrate or on biotreated water from the WWTP. The treatment of excess white water with UF membrane filtration for reuse at wire section showers has become a proven and accepted technique at paper and board mills when the fresh water consumption level has to be low. Ultrafiltrated water has also been used for press section showers, but this application is still only used in special cases due to the UF only partially removing the dissolved materials.

This technique is also applicable in RCF-based mills and has already been proved with full-scale applications (e.g. Modern Karton Sanayi Ticaret AS in Corlu, Turkey; Propapier Eisenhüttenstadt, Germany).

For process water with higher concentrations of organic substances, like that from the production of 'brown paper' from recycled fibre, biological treatment followed by sand filtration is another feasible option when the fresh water consumption level has to be low. It allows for the partial recycling of water from the long circulation. This technique is described in Section 6.3.4.

There are also combined systems under development, 'membrane bio-reactors' (MBR) as described in Section 2.9.11.2.1. In special applications, such as coating chemical recovery from paper machine coating effluents, UF membrane technology is already a tested technology and several applications exist (see Section 7.3.5).

In general terms, paper machine water loop closure with self-contained removal of dissolved organic or inorganic constituents is a technique that is still undergoing some development. It is not as well established as biological treatment for example.

Economics

The operating costs of ultrafiltration depend on the energy price and on the achieved flux (filtrated volume per membrane surface and hour). Assuming electricity costs of EUR 0.05/kWh, the following operational costs can be calculated:

- RCF Testliner/fluting based on old corrugated container (175 $l/m^2 \times h$): EUR 0.42 per m^3;
- printing paper (300 $l/m^2 \times h$): EUR 0.25 per m^3.

An example calculation for the operational costs of UF of white water of a printing paper mill that manufactures 350 000 tonnes/yr is given in Table 7.24 (data from a supplier, 2010). The membrane treatment capacity is 3.0 m^3/t, which corresponds to 126 m^3/h or 300 l/m^2h.

Table 7.24: Example calculation for operational costs of ultrafiltration of white water from printing paper production

Energy consumption	**8.3 kWh/t or 2.7 kWh/m^3**
Assumed energy price	EUR 0.05/kWh
Washing interval (alkaline)	7 days
Washing interval (acid)	30 days
Detergent consumption (alkaline and acid)	80 and 40 kg per washing
Detergent price (average)	EUR 2.2/kg
Membrane lifetime	15 months
Energy consumption	**EUR 0.14/m^3**
Washing of membranes	**EUR 0.03/m^3**
Services (change of membranes, maintenance)	**EUR 0.08/m^3**
Total operational costs	**EUR 232 000/year or EUR 0.25/m^3**

Although membrane filtration consumes energy, in some cases savings can be achieved with regard to the dryer section energy consumption. When fresh water consumption decreases, the process temperature increases. It is easier to remove water and to achieve better web dryness after the press section and thus less heating energy is needed at the dryer section.

Driving force for implementation

Membrane filtration may be applied in mills which face strict requirements for discharge either because they are situated near a sensitive recipient or because there are plans for a significant increase in capacity. Some authorities in Europe require that the effluent load does not increase with capacity. UF technology may also be applied in cases where availability of water is scarce.

UF of white water may also reduce the downtime of the paper machine caused by the required washing off of substances concentrated in the recycled clear filtrate.

Example plants

Membrane filtration of process waters is applied in about six European pulp and paper mills, however there is no reference from a 'totally closed' mill. These membrane applications are mostly on white water clear filtrates with the objective of reducing fresh water demand. Example plants are the Sappi Kirkniemi mill (magazine and fine paper production), Finland; UPM-Kymmene Tervasaari mill (released paper), Finland; Holmen Paper Madrid, (newsprint), Spain; Modern Karton Liner/Fluting mill, Turkey; Hokuetsu Mill (fine paper), Japan; Propapier Eisenhüttenstadt, Germany.

In the US, there are closed-cycle paper mills with membrane technology in combination with biological treatment (McKinley linerboard paper company, New Mexico, US).

Reference literature
[5, Bentley et al. 1999], [143, T.Sutela et al. 2006], [144, Sutela 2008].

7.3.4 Efficient fibre and filler recovery and broke system

For the recovery of coating colour, the reader is referred to Section 7.3.5

Description
Resource management in terms of efficient fibre recovery is standard practice in paper mills. In virgin fibre processing, typically over 98 % of the pulp fed through the paper or board machine stock preparation is acceptable for the end product. Paper and board mills achieve minimised losses of fibres and fillers by optimisation of the processes given below:

- Screening in stock preparation.
- Wet-end save-alls, the most common being disc filters or flotation cells. Also microfilters with low energy consumption are used. Depending on the application (treatment of the filtrate from screw presses, of vacuum sealing water, of white water for fibre and water recovery, for polishing the water from existing save-alls to a super clear filtrate quality), the filter medium of the microfilter can vary from a very fine 6 µm for special polishing applications up to a coarser quality of 1 000 µm used, for example, for thickening applications.
- Wet- and dry-end broke handling.

In integrated mills, rejects from the screening in stock preparation are normally returned to the pulping department where they are reprocessed. The good stock is sent back to the paper machine.

When the pulp is discharged from the paper machine headbox to the wire and starts forming the paper web, a fair amount of fibres and fillers are not retained the first time but are discharged to collection pits under the machine (see Figure 7.1). During the short circuit, the drained water is recycled untreated. The rest of these waters are passed through a save-all unit, typically a drum or disc filter or a dissolved air flotation unit (see Section 6.3.11), to separate solids from the water stream. These solids are then collected into a chest and are recycled back to the paper machine feed. The clarified water, called white water, is typically collected as clean and cloudy filtrates and is recycled to the appropriate uses in the paper machine: for pulp dilution in the machine stock preparation, for broke dilution or for paper machine showers. In integrated mills, the excess white water is best used in the pulping process or in the paper or board machines. In non-integrated paper mills, the excess white water forms the waste water.

For paper machine fibre and filler recovery with a save-all unit, the disc filter is for most cases an efficient solution to attain high recovery. A precoat-type unit in particular, which utilises a small amount of paper machine pulp feed on the filter surface to improve filtering efficiency and solids recovery, is often used at modern mills. The filter works in batch mode, but the solids removal and the regeneration by applying the precoat take only a short period of time. Other systems for the recovery of fibre and fillers are flotation cells, disc thickeners or membrane filters.

The disc filter allows efficient fractionation of white water to clear and cloudy filtrates and in many cases also produces a super-clean filtrate that can be reused in low-pressure showers. The super clear filtrate from a disc filter could have 10 – 20 mg/l suspended solids and clear filtrate 20 – 50 mg/l suspended solids (up to 100 mg/l in some cases). Clear filtrate can be used in low-pressure shower water at the paper machine and reduces fresh water usage. The cloudy filtrate and the rest of clear filtrate can be used for pulp dilution preceding the paper machine in the short circuit, for machine broke dilution and in integrated mills in the pulping process.

Other measures to reduce fibre and filler losses are given below.

- Tuning of the pulp refining and screening just ahead of the feed to the paper machine to maintain a proper balance of different types of fibres in pulp. Heavy refining increases the amount of short fibres that in turn may be removed as rejects in screening. In integrated mills, a certain fraction of rejects from the screening may be recycled to the pulping department.
- Efficient control of the paper machine headbox to produce an even paper web across the machine width.
- Efficient use of chemical additives together with a modern control system to reach improved fibre retention on the wire and good paper web formation.
- The broke and white water storage capacity also has an effect on solids management and water conservation. The chest sizes should allow at least two- to three-hour machine flow to be stored in broke chests to recover these fractions that are high in fibre content. This reduces the frequency and length of sudden peak fibre or hydraulic discharges to the mill sewer.
- In paper machines producing coated grades, the broke collected after the coater can be mixed with fresh pulp and wet-end broke.

For further polishing of the white water, micro-filtration or ultrafiltration are effective techniques (see Section 7.3.3). The ultrafiltrated water is free of suspended solids and colloidal substances; microbes, latex and other micro-stickies are also removed and the anionic trash is cut to approximately half of the original level.

Achieved environmental benefits
Efficient fibre and filler recovery in all possible stages of the paper mill allows for the return of raw materials to the machine feed instead of sewering them with the excess white water. The better recovery of solids means that this solid load is not passed to the primary effluent treatment and to effluent sludge disposal.

Efficient removal of suspended solids from white water is a prerequisite for further recirculation of treated water to production processes and a preliminary measure for closing up water loops.

Environmental performance and operational data
These measures are implemented in nearly all paper mills but to different extents. Generally, high performing unit processes, monitoring and process control of the unit operations by means of automation give the best results.

White water and broke chest level monitoring is important. Paper mill effluent sewers equipped with flow indication and turbidity meters help to register surges in solids discharge.

The total solids losses from a paper machine, from rejects from paper machine stock preparation, excess sewered white water, paper machine press sections and pulp tank overflows from better performing mills reach 10 – 20 kg/t (i.e. 1 – 2 % loss) for many paper grades. Some existing liner and fluting or speciality paper lines exceed 50 kg dry solids/ADt.

Cross-media effects
Due to lower suspended solids discharge, the effluent treatment operation receives less solid load and less sludge from primary treatment is produced. Fibres and fillers are used for the product and must not be handled as waste.

Improved runnability promoted by a lower solids content in white water circuits leads to fewer paper machine breaks.

Technical considerations relevant to applicability
The listed improvements can be applied in both new and existing mills. However, in older mills the paper machine areas are more limited for rebuilds due to space or layout problems.

Economics
No data available.

Driving force for implementation
Improved stock recovery is usually economically beneficial because of better raw material efficiency and because there is less waste to be disposed of. Lower solids content in white water circuits improves the runnability of the paper machine. Reduced solids load to the external treatment might also be motivation to implement the described measures for fibre recovery or spill prevention.

Example plants
Numerous mills in Europe.

Reference literature
[15, CEPI 1998].

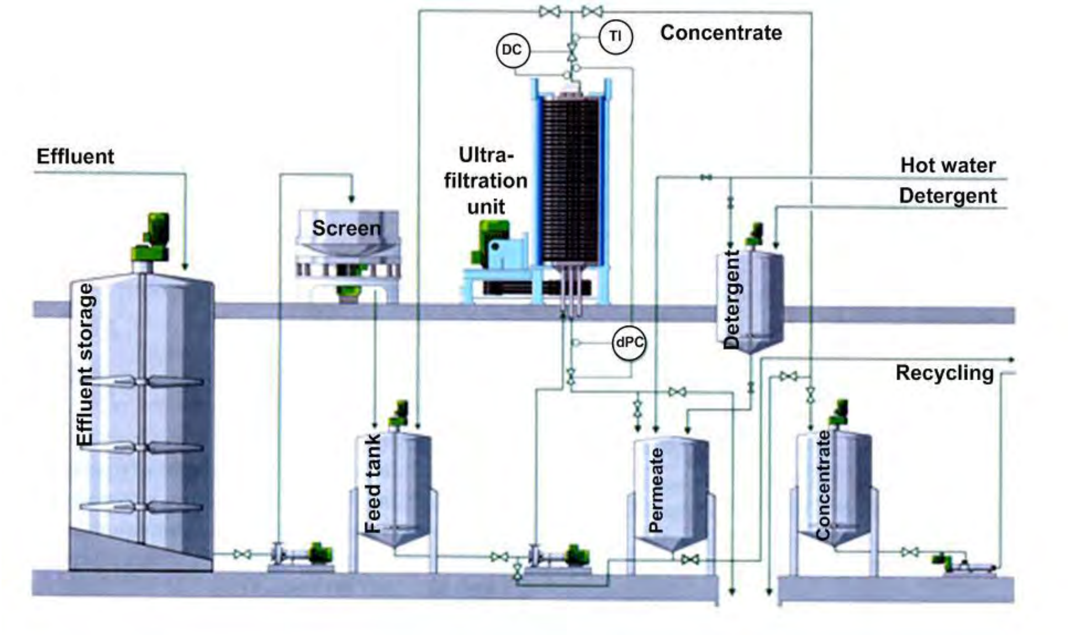
7.3.5 Recovery of coating colours/recycling of pigments

Description
Effluents which contain coating colour are created during the flushing of coating equipment, paper breaks and production changes in paper and board mills manufacturing coating grades. These mills generate a hydraulically low flow waste water (about 2 – 5 % of the total flow) which is rich in pigments and adhesives (see also Section 7.3.6). The heavy solids load and the compounds which are sticky by nature in these waste waters may cause operating problems in the effluent treatment, if sewered there without an appropriate pretreatment. On the other hand, the pigments are expensive, so the (partial) recovery of the coating colour for reuse is cost-effective in most cases.

Environmentally sound coating waste stream management comprises the items listed below.

- Minimum discharge of coating kitchen colours to sewer by efficient production and optimum inventory of prepared coating colours, especially when paper grade changes need a change in coating colour composition. Significant factors are efficient work routines and good housekeeping.
- Optimum design of coating colour kitchen and supply systems.
- Separate collection of effluents which contain coating colour.
- Coating chemical recovery by ultrafiltration or other recovery techniques from coating waste water.

I) Ultrafiltration
Ultrafiltration is a method in which water and chemicals are separated from each other using a semi-permeable membrane. The pores of the membrane are so small that they only let tiny molecules such as water, metallic ions, salts and starch monomers pass through, whereas the other components of the coating colour – pigments and binders – are too large to get through (see Figure 7.28). The effluent fed into the process is typically 2 – 4 % solids content and that of the concentrate 30 % in one-stage systems and 43 – 44 % with an additional second stage for high solids concentrate (e.g. Husum mill, SE). Added to fresh coating colour it will not dilute too much. As shown in Figure 7.30, a complete ultrafiltration system comprises the filter, necessary tanks, piping, field instruments and control system.



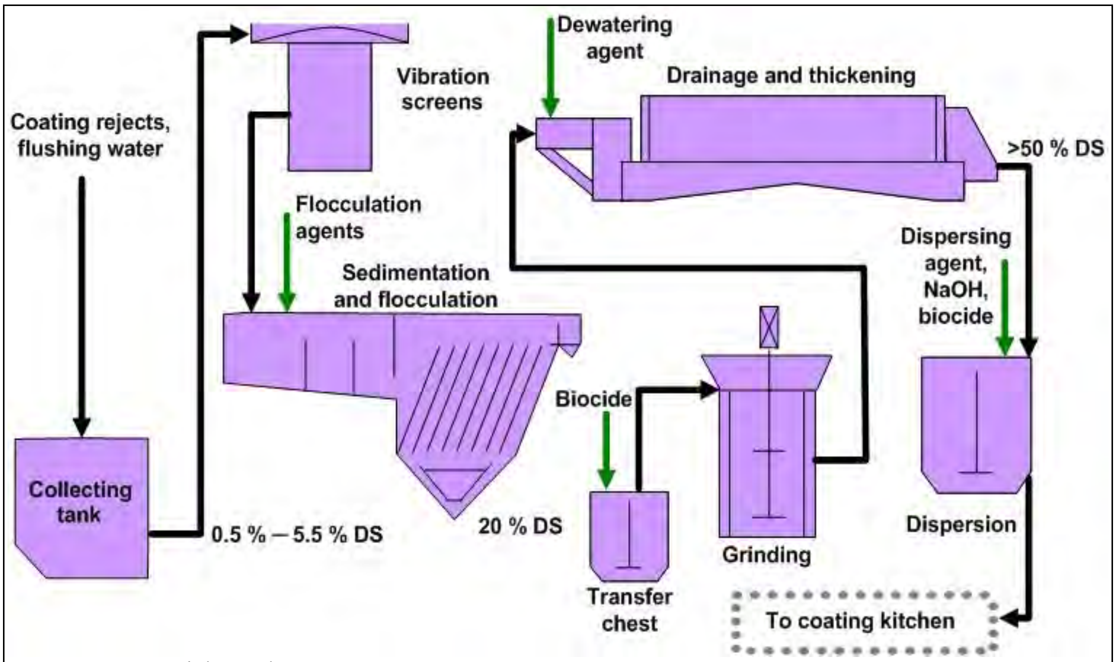
Source: [123, Roitto et al. 1997]

Figure 7.30: Example of an ultrafiltration recovery system for coating colours

II) Collection – screening – concentration – grinding – dewatering

This technique is an alternative to UF which started in 2008 in a German paper mill that manufactures around 300 000 t/yr of triple coated paper. Figure 7.31 shows the processing scheme for the recovery of coating colour rejects and rinsing water which contains coating colour. The coating colour recovery system consists of (i) the collection of effluents which contain coating colour in a central pit below the coating machine, (ii) a buffer tank and double-stage screening: 300 µm pressure screen and a 100 µm bow screen, (iii) a compact flocculation (cationic polymer and anionic polyacrylamide) and sedimentation unit for concentration of the pigments to 20 % DS, (iv) a grinder (ball mill), (v), a decanter (anionic polyacrylamide added) for dewatering the slurry to 50 % DS and (vi) a dispersing tank where the dispersion is finished by adding NaOH, a dispersing agent and biocides. From there, the recovered dispersion is pumped to the coating kitchen. A 150 µm control screening is installed in the pipe that leads to the dispersing units of the coating kitchen. The separated clear water is returned to the process (pulper) and leads to a reduction in the total water consumption of the mill of 0.43 m^3/t.

The advantage of this robust system compared to other options is that the impurities in the collected rinsing waters such as paper abrasion, agglomerates, fibres, dirt or sand are crushed in the ball mill to a particle fineness of 60 % of all particles below 2 microns and thus they no longer interfere with the subsequent reuse of the coating pigments.



Source: [142, C.Finke et al. 2009]

Figure 7.31: Processing scheme for the recovery of coating colour rejects and waste water

The collected effluents enter the system with approximately 0.5 – 5 % dry solids content and leave it at approximately 50 % DS. The coating colour recycling rate is almost 100 %. No negative impacts on the coating colour quality have been detected.

Achieved environmental benefits

After treating the colour effluents with ultrafiltration or other efficient recovery systems (see, e.g. Figure 7.31), the retentate can be reused as coating colour and the permeate can replace fresh water (water savings). At the same time, the organic (COD) and hydraulic load on the external treatment plant and the generated sludge are reduced. An example mill reduced the total solid waste of the entire mill by 60 % by putting into operation an effective coating effluent recovery system. Less transport of pigments and waste is another benefit.

The coating colour recovery option 'collection – screening – concentration – grinding – dewatering' achieves some energy savings when compared to the processing of the natural pigments which requires approximately 150 kWh/t; in contrast, the whole coating colour recovery system requires approximately 105 kWh/t of pigment recovered, which means that the recycling option requires 30 % less electrical energy compared to the grinding of fresh pigments.

Environmental performance and operational data

The application of ultrafiltration has proven successful in many mills. No negative effects on fine and art paper quality have been reported when using concentrate as a precoat. In magazine paper mills, small amounts of UF concentrate can be used without drawbacks in quality. In a board mill, the recovered coating colour is reused for back coating. The amount of concentrate must be constant. Also, bacteria and hygiene are important aspects to be considered. The lifetime of the membrane can exceed one year. The typical washing frequency is once a week, creating a liquid waste of about 2 – 5 m^3. Good results have been achieved for instance with polymer membranes using the cross-flow principle (or cross-rotation filtration).

The recovery option 'dewatering – grinding – thickening' (see Figure 7.31) produces pigments that have a defined grain size distribution. The quality of the recovered coating pigment is very similar to the originally used calcium carbonate. No problems with 'white pitch' (latex binder from recycled coated broke) have been observed. The process allows the reuse of almost 100 % of the coating pigments from the waste water (in the example case, 6 – 10 tonnes of pigments per day, oven dry), thus reducing the waste water load (COD), and the need to transport pigments and sludge. The treated flow is 400 m^3/day.

Cross-media effects

The technique achieves significant savings in terms of transport, raw material needed (pigments) and quantity of solid waste to be disposed of. Ultrafiltration and the alternative coating colour recovery systems require electrical energy and some chemicals for operation; however, the required power is overcompensated by having recovered the pigments. Reduction of coating waste water discharge improves the performance of the effluent treatment and the organic load to be treated. Depending on the coating/paper produced ratio, the amount of solid waste can be lowered by 60 %.

Technical considerations relevant to applicability

Management of remaining coating colours after application and separate collection of coating effluents for their subsequent treatment can be applied at both new and existing mills. Ultrafiltration is applicable for most mills manufacturing coated grades such as magazine paper, fine paper or board. This coating colour recovery system can be unsuitable for some speciality grades, e.g. if effluent volumes are very small or are generated in various places of the mill, when many changes in coating occur in a short time or if the different coating colour recipes are unsuitable for mixing. In these cases, the coating effluents are sent directly to the waste water treatment plant or are treated separately by precipitation before entering the biological treatment (see Section 7.3.6). With ultrafiltration, the achievable concentration of the recovered solids is limited to about 35 – 45 %. If there is no excess water in the formulation of the coating colour, it can be difficult to reuse all the concentrate.

The alternative coating colour recovery system (see Figure 7.31) that uses a ball mill followed by a thickener as the core process is suitable for all mills that have a significant amount of coating colours that are sewered (e.g. multiple coatings, larger mills). Because of the very effective grinder, the system is very robust, not sensitive to disturbances and delivers a pigment quality that can be used in most coating applications. Solids concentrations of > 50 % DS can be achieved.

Economics

I) Economic calculation of the ultrafiltration coating colour recovery process

The example calculation refers to a paper mill that produces 800 tonnes of coated paper/day and has 330 working days/year. The coating colour production is 30 % of the paper production or 240 t/day DS. The economic calculation is approximated in Table 7.25.

Table 7.25: Economic calculation of the ultrafiltration coating colour recovery process

Coating colour loss data		
Coating colour loss	2 % of production or 4.8 t DS/day	
Coating colour effluent data		
Coating effluent dry solids content	2 %	
Coating effluent amount	240 m^3/day or 10 m^3/h	
Cost data		
Coating colour value	EUR 350/t DS (× 4.8 t/d × 330 days)	EUR 554 400/year
Water cost (fresh + waste water)	EUR 0.50/m^3	EUR 39 600/year
Waste tip cost (landfill)	EUR 100/t wet	EUR 528 000/year
Final DS content of coating effluent	30 % DS	
Total annual savings with coating colour recovery		**EUR 1 122 million/yr**
Ultrafiltration data	80 m^2 membrane surface, needed flux: 125 l/m^2 × h or 2.8 l/s =10 m^3/h	
Annual operational cost		
Electric power	EUR 0.05/kWh/t	EUR 31 680/yr
Detergent		EUR 9 476/yr
Membrane + spare parts		EUR 21 700/yr
Biocides		EUR 5 000/yr
Total annual operational costs		**EUR 67 856/yr**
Annual net savings		**EUR 1 054 million/yr**
Payback time (investment costs of EUR 1.1 – 1.3 million)		**Approximately 1 yr**
Source: Data from a supplier, 2010		

II) Economic calculation of the recovery option 'collection – screening – concentration – grinding – dewatering'

This recovery option enables nearly 100 % recovery of the coating colours. Savings of approximately EUR 840 000/year were achieved (data base: 2009) consisting of reduced costs for coating pigments (approximately EUR 265 000/year), sludge disposal (approximately EUR 500 000/year), waste water (EUR 65 000/year) and fresh water (approximately EUR 10 000/year). Operating costs amounted to EUR 350 000 per year including costs for chemicals (EUR 300 000/year), energy (EUR 20 000/year) and maintenance and repairs (EUR 20 000/year). In the example case, the recovery system generates payment surpluses of EUR 510 000/year. The investment cost of the coating colour recovery system was EUR 1 million for a mill that manufactures 300 000 t/yr of triple coated paper; treated flow 400 m^3/day; 10 t pigments recovered/day. The payback time of the investment is 1.65 years (without subsidies).

Driving force for implementation

Improvement of raw material economy in production (minimisation of coating losses). The key factor for implementation of UF is reducing the costs for the raw materials (costly coating colours) and for waste disposal. Furthermore, the technique reduces the load of suspended solids and COD discharged and improves the operability of the effluent treatment. It is the preferred option compared to the pretreatment of coating waste water.

Example plants

Example plants for ultrafiltration of coating-containing effluent recovery and reuse of the original pigments follow: Blendecques board mill, FR; Assi Frövifors board mill, SE; Cascades Djupafors board mill, SE; Hansol Taejon board mill, South Korea; Yuen Foong Yu Fine Paper mill, Taiwan; Metsä-Serla Kirkniemi, FI; Metsä-Serla Äänekoski, FI; APP Pindo Deli, Fine paper mill, Indonesia; MD Papier Plattling, DE; SCA Fine Paper Stockstadt, DE; Papierfabrik Albbruck, DE; M-real Husum, SE; Zhuhai S.E.Z Hongta Renheng board mill, China; Sun Cartonboard, China; Henan Pyuang, China; Hokuetsu Paper Mills, Niigata, Japan; Klabin S.A. Telemaco Borba, Brazil; Stora Enso Suzhou Paper, China; Sun Paper, Yanzhou, Tianzhang, China; UPM-Kymmene Changshu, China; Jiangxi Chenming Paper, Nanchin, China; UPM-

Kymmene, Rauma, FI; Tullis Russell, Glenrothes, Scotland; Shandong Bohui Paper Group, China; Jilin Paper Co Ltd, China; Cartiere Burgo Verzuolo, IT; Metsä-Serla, Kangas, FI; UPM-Kymmene, Kuusankoski, FI; Komline-Sanderson, Peapack, US.

The recovery option '*collection – screening – concentration – grinding – dewatering*' is running in one paper mill only (Sappi Ehingen, DE).

Reference literature
[99, Nygard et al. 1997], [123, Roitto et al. 1997], [141, Kuula et al. 2008], [142, C.Finke et al. 2009].

7.3.6 Pretreatment of effluents which contain coating colours

Description
Coating chemicals include several groups and types, where the pigments and binders are the two main elements.

Coating colour discharges can be divided into two main types of waste water.

- Undiluted surplus coating colour (about 50 – 70 % dry solids) from the coating kitchen and coater station. In case of product changes and during breaks, the supply system has to be washed (disperger, chests, pumps, piping, and coater station). Furthermore, sometimes not all of the coating colours can be completely used and the rest are washed as well. The concentrated discharge can be collected in tanks or mobile containers for solid waste disposal.
- Diluted coating components from washing water from tanks, pipes, etc.

The dry solids content of diluted coating colour effluents is typically 2 – 4 %. If these effluents are directly discharged to the waste water treatment plant, sudden high organic peak loads would have to be handled in the treatment plant (COD values of >10 000 mg/l up to 100 000 mg/l). Therefore, the diluted spills are better collected in tanks and pretreated before discharge to the external waste water treatment plant.

If waste waters are not treated before biological treatment they can have adverse effects on the waste water treatment plant, causing difficulties in primary clarification and in the subsequent biological steps.

A typical pretreatment consists of collection, precipitation and dewatering. The coating colour waste waters are separated from other process water, collected and sent to an equalisation basin. From there, the waste water is screened and pumped to chemical precipitation. The flocculation chemicals are added in a rapid mixing zone. Aluminium sulphate and polyaluminium chlorides are used as precipitation chemicals. Polyelectrolyte is used as a flocculation aid and is dosed into the flocculation tanks. The flocculated waste water flows into a lamella clarifier where the suspended solids settle on the bottom of the clarifier and the clear overflow is discharged to the waste water channel for further treatment. Sludge from the bottom of the clarifier is collected to a sludge tank and from there it is pumped to a centrifuge for dewatering. The dewatered sludge at a concentration of about 30 – 40 % is transported to waste recovery or landfilling.

There is at least one mill however where the precipitated coating colours are dewatered by centrifugation and reused as coating colour for the precoat. This option is still being developed.

Achieved environmental benefits
The main achievements are operational benefits in the waste water treatment plant (WWTP). Total suspended solids (TSS) and organic loads to the WWTP are reduced and also accidental spills (sudden loads of suspended solids) to the treatment plant can be minimised. The upsets of the primary clarifier can be reduced because there are fewer sudden disturbances in the settling

of TSS or increases in the torque of the clarifier drive mechanism. The risk of clarifier overloading is reduced. The upsets of the biological system are reduced because the inert matter (pigment particles) in coating effluent is not carried over and accumulated in the active biomass of the biological treatment process. Thus, the environmental load is reduced. The clear filtrate from the coating colour effluent treatment can be reused elsewhere in the paper mill, for instance for dilution of coated or uncoated broke. However, waste water streams are only controlled and concentrated but waste remains. Therefore the recovery and recycling of effluents which contain coating colours (Section 7.3.5) is considered the preferred option.

Environmental performance and operational data
The process has been used for many years in paper mills across Europe. However, some difficulties have been detected from the dewatering of the sludge produced during precipitation.

Cross-media effects
The separation of coating colour effluents from the biological waste water treatment normally has a positive effect on the further treatment of the biological sludge. It is easier to incinerate the dewatered excess sludge of the main waste water treatment plant of the mill because a separate pretreatment for coating waste water reduces the ash content of the main sludge streams.

For the flocculation unit, flocculation chemicals and chemicals for pH adjustment are required, resulting in a certain increase of salts in the effluent.

Technical considerations relevant to applicability
The pretreatment of coating waste water can be applied at both new and existing mills. However, in existing mills the arrangements for waste water collection and rerouting may be more complicated and more expensive. For new installations, recovery of coating colour (see Section 7.3.5) is the preferred option.

Economics
The investment for the separate coating waste water treatment by means of flocculation is about EUR 1.2 – 1.4 million for a production of about 1 000 ADt/d. The annual operating costs are EUR 75 000 – 150 000 per year, excluding landfill costs.

Driving force for implementation
The driving force to adopt this measure is the difficulties in the external waste water treatment plant if this pretreatment is not applied. The high TSS load and chemical composition of coating waste water can upset the operation of the primary clarifier and the biological process and result in sludge incineration problems.

Example plants
Numerous plants in western Europe (DE, AT, FR, SE, FI).

Reference literature
[15, CEPI 1998].

7.3.7 Optimum design and construction of tanks and chests

Description
Accidental discharges typically occur due to:

- paper machine operational upsets and paper breaks;
- scheduled maintenance shutdowns and start-ups and stops required to change from one paper grade to another;
- poor management of white water tanks or machine broke chests in the wet-end or dry-end broke chests or off-machine coating.

For measures to avoid accidental discharges from the storage and handling of chemicals, the reader is referred to Section 2.9.2.3. For measures to ensure the smooth running of the processes and to reduce peak loads, see Section 2.9.10.

The most important measure for keeping accidental discharges to a minimum is the proper layout design and management of the white water towers and broke chests. Otherwise, there is an increased probability that significant water and solids discharge to the sewer will occur. The white water storage capacity must match the broke storage so that no fresh water is required during sheet breaks or when the broke is returned to the machine. In paper machines producing coated grades, the return of the broke collected from on- or off-machine coaters must be carefully controlled. This is because the proportion of coated broke must be below a certain limit to make a proper mix of fresh pulp and different brokes and thus to avoid problems in the paper machine wet end. The coated broke storage volume must meet this demand.

The control of white water tank levels according to the broke inventory, pulp inventory and production plans must be exercised carefully to prevent spillages. The mill personnel should be aware of the incidents that lead to accidental releases.

In mills that change paper grades frequently, the tank control is more difficult because the inventories are often kept low in order to minimise losses from clean-ups at grade changes. For this reason, the machine feed characteristics must also be controlled more carefully so that the amount of broke stays low. In mills with many paper machines, such losses may be reduced if another machine can use the paper broke.

Advanced on-line monitoring of paper sheet and machine parameters and process automation enables more accurate process control and helps reduce the number of web breaks and operational upsets (see Section 7.3.8). Advanced stock tower controls and in-line mixing can eliminate the need for some storage chests or missing chests.

In case of accidental spills, an equalisation basin (retention basin) prevents a sudden overload of the water treatment plant (WTP). From there, the spillage can be discharged gradually to the WWTP in a controlled manner (see Section 7.3.10). The waste water treatment is the most crucial point for accidental discharges. For a continuously well performing waste water treatment plant, good communication between the employees of the production units and the operators of the waste water treatment plant is a prerequisite for prompt action in case of an accidental spillage.

Achieved environmental benefits

The measures reduce the frequency of hydraulic or solids peak discharges to the waste water treatment plant.

Environmental performance and operational data

Within the operational practice of many paper mills, sufficiently large storage towers for white water and broke are often available. Volumes can be reduced through model-based control methods of tank levels and flows. Dynamic modelling has brought improved understanding at many mills for advanced control of machine operations.

Cross-media effects

The development of efficient white water and pulp chest management results in improvements to production economy (runnability, machine capacity). Large storage capacities of white water broke and coated broke may increase the biological activity in tanks and chests, which may lead to unstable operation of the paper machine and finally production losses. With advanced process control methods, the storage volumes could be significantly reduced.

Technical considerations relevant to applicability
Control of accidental discharges is of primary importance in the paper machine and can be applied in existing and new mills. However, problems may arise in older mills if they do not have enough space to expand water or pulp storage.

Economics
Investment costs for one additional white water tower of 3 000 m^3 and one uncoated broke tower of 2 000 m^3 would be about EUR 1.0 – 1.2 million. If a second broke tower for coated broke were required, it would cost – with necessary auxiliary equipment, piping and electrification – about EUR 0.4 – 0.5 million. These investments correspond to a paper production of 1 000 ADt/d.

Driving force for implementation
First, these measures are to prevent disruptive discharges from the paper machine entering the mill sewer and to keep the load to the effluent treatment more stable. Second, the process automation coupled with a sophisticated white water, pulp and broke inventory improves the machine runnability and production.

Example plants
Numerous mills in Europe.

7.3.8 Measurement and automation

Description
For highly effective papermaking, it is important that the process be stable and the quality uniform. These characteristics are essential for environmentally sound production. Instability in stock preparation and the wet-end area causes web breaks and thus disturbances in water systems. On-line measurements and accurate process control are therefore essential for effective papermaking. The major areas where measurement and automation increase both quality and productivity and environmental performance are mentioned below.

- Save-all operation: suspended solids or turbidity measurements are important peak indicators when the target is to use clear filtrate from the save-all as much as possible for paper machine shower water. Unnecessary fibre losses are thus avoided and the load on waste water treatment is diminished. Feed consistency measurement and control facilitate the optimisation of disc filter operation.
- Blending: in thick stock proportioning and blending, variations in consistency and pulp quality (e.g. freeness, fibre length, ash content) are stabilised in order to avoid quality variations at the paper machine.
- Refining: the refining control strategy requires accurate flow and consistency measurements as a minimum. For optimum refining control results, pulp quality measurements such as freeness/drainage and fibre length measurements are needed.
- Wet-end management: the information on headbox and white water total solids and filler consistency levels provides an early indication of potential problems in wet-end chemistry. Automatic retention aid control where the target is to retain uniform amounts of fines and fillers in the paper web is based on on-line fibre and filler consistency measurement in short circulation. The use of white water consistency control has drastically increased the stability of wet-end operations and reduced the number of wet-end breaks.
- In addition to the consistency variation in short circulation, variations in the incoming dissolved and colloidal material are a major source of problems in paper machine runnability and optimisation. Cationic demand together with pH, temperature and conductivity is measured from the white water and is used to control the detrimental substances. While retention control acts by controlling flocculation, charge control stabilises by controlling coagulation.

Achieved environmental benefits
The increase of productivity and decrease of breaks or losses by use of appropriate measurements and automisation have positive effects on the environment (lower emission load per product manufactured). Less disturbances in water systems, less energy consumption and less waste are the results of better process control. It is difficult to quantify the environmental benefits achieved because they depend on the characteristics of the installation, the degree of productivity before improvement, the paper grade(s) manufactured, etc. Measurement and automation facilitate water management and reduce the pollution load to the waste water treatment and the losses of raw material.

Environmental performance and operational data
Measurement and automation have been applied in many existing mills to increase efficiency without problems and is normally implemented and further developed at new mills.

Cross-media effects
No negative cross-media effects reported.

Technical considerations relevant to applicability
The aforementioned measurements and controls can be applied at both small and large, new and existing mills. The greatest benefits are obtained when high-quality end products are produced.

Economics
Eliminating paper breaks results in more machine uptime and thus gives higher production yields per day. Energy which is wasted during the breaks, e.g. for heating, drying cylinders and running pumps, is saved.

High and uniform retention also means savings in the waste water treatment plant. The waste water treatment plant need not be over-dimensioned for peaks when a more uniform waste water load is reached with a more uniform retention control.

Against these savings, the investment and operating costs of the equipment have to be taken into account. The payback time for measurements and control when implemented is typically less than one year. After appropriate training, the mill operators can operate the unit. The mill's electrical and instrumentation staff can do the necessary maintenance work when needed.

Driving force for implementation
Measurement and automisation are primarily applied for economic reasons and to achieve higher paper quality. They result in time savings in paper production (e.g. they allow for faster grade changes, faster start-ups, faster recovery after sheet breaks), lower production costs (e.g. by furnish component optimisation, effective usage of additives, decreased energy consumption) and maximised paper quality (e.g. through less cross direction (CD)/machine direction (MD) variation, optimised dewatering, formation). Optimised dewatering for a given machine is obtained by a proper stock preparation and wet-end management (e.g. refiner control and control of chemicals). It is furthermore easier to manufacture a wider range of paper grades.

Example plants
Numerous mills in Europe.

Reference literature
[96, Nokelainen et al. 1995], [97, Nokelainen et al. 1997].

7.3.9 Use of chemicals

Description
Chemical additives contribute to the effluent load and, therefore, the use of chemicals minimising emissions to water is a technique to consider. Two examples of these techniques are the minimisation of the release of chemical additives (e.g. greaseproof/waterproof agents) containing per- or polyfluorinated compounds (PFC) or contributing to their formation, and the switch to low AOX-containing product aids.

Achieved environmental benefits
The reduction of emissions to water.

Technical considerations relevant to applicability
The minimisation of the release of chemical additives (e.g. greaseproof/waterproof agents) containing per- or polyfluorinated compounds (PFC) is applicable only for plants producing paper with grease- or water-repellent properties.

The switch to low AOX-containing product aids is applicable to plants producing paper grades with high wet strength.

Driving force for implementation
To reduce emissions to water.

7.3.10 Installation of an equalisation basin and primary treatment of waste water

Description
For most paper mills, this measure is not considered as a stand-alone technique but as a pretreatment. Pretreatment is usually carried out ahead of biological treatment in order to facilitate and improve the treatment process. In some special cases where the organic load is too low for efficient biological treatment, primary treatment may be the only waste water treatment.

The methods that follow are the most important ones.

- Coarse screening is carried out in order to remove larger objects and sand, which may cause damage to the subsequent equipment.
- Equalisation and spill collection may be required for effluents with large variations as regards flow and content of pollutants. Such variations may disturb the function of the subsequent treatment processes, particularly biological processes. A retention time of four hours in the equalisation basin can be taken as an indication for appropriate design. However, the appropriate retention time of the equalisation tank depends on fluctuations in water quality.
- Primary or mechanical treatment. Sedimentation is carried out for the removal of suspended solids (SS), such as fibres, bark particles and inorganic particles (fillers, lime particles, etc.). A certain minimum size of the particles is required. The finer particles will settle too slowly for practical use or not settle at all. Also, microfilters are used as a first stage before the clarifier, which allow for recovering of some fibres. Micro-flotation can also be used for primary clarification. Some smaller mills use primary treatment by means of filtration as the only waste water treatment.

The particles, settling to the bottom of the primary clarifier form a sludge, which has to be removed. This is achieved by pumping in circular clarifiers in combination with bottom scraping. The sludge is normally low in DS content, approximately 1 – 2 %, and has to be thickened and dewatered before final disposal.

Achieved environmental benefits
Reduction of the discharge of total suspended solids that consist of inorganic and organic substances.

Environmental performance and operational data
The result of the primary treatment depends on the effluent properties, but also on the degree of internal fibre recovery in the pulp or paper mill. For suspended solids (TSS), the removal rate may be within 60 – 90 %. For settleable solids, the removal rate will normally be higher, approximately 90 – 95 %. TSS values after the primary sedimentation may be in the range of 30 – 200 mg/m^3. The higher levels are normally observed when a secondary treatment follows.

Cross-media effects
The effluent treatment plant produces sludge which, after dewatering, has to be further treated. There are many different options for further treatment of this sludge which are to a certain extent site-specific (see Sections 7.3.13 and 2.9.8). One option is incineration.

Technical considerations relevant to applicability
The process can be applied at both existing and new paper mills. Some kind of water consumption reduction measures should preferably be carried out prior to installing the primary treatment in order to reduce the hydraulic load and thus the investment costs for the clarifiers.

Economics
The investment cost of primary treatment for a new 1 000 ADt/d integrated paper mill comprised of pumping, a primary clarifier, sludge dewatering and chemical dosing systems is EUR 3.5 – 4.5 million. The operating costs very much depend on the required chemical consumption (if applicable) and are EUR 0.4 – 0.6 million/year.

Driving force for implementation
Primary treatment is used to reduce the TSS load to the receiving water body or biological treatment.

Example plants
Numerous paper mills in Europe.

7.3.11 Aerobic biological waste water treatment

Description
See Section 2.9.11.2.1

Achieved environmental benefits
Reduction of emissions of organic matter (COD, BOD), AOX, phosphorus, nitrogen and chelating agents to water.

Environmental performance and operational data
Emission loads presented here are the result of a combination of process-integrated measures (see Sections 7.3.1 – 7.3.10 plus primary treatment) and biological treatment.

For biological treatment of paper mill effluents, the following pollution load reduction efficiencies can usually be achieved: activated sludge: 85 – 96 % for BOD_5; 75 – 90 % for COD. Combined systems such as activated sludge combined for example with moving bed reactors or trickling filters often achieve the highest removal efficiencies.

These removal efficiencies are achieved by low load activated sludge systems with a food/mass ratio between 0.1 and 0.2 kg BOD_5/kg TSS × d. In a few applications also for high load plants, good removal efficiencies are reported:

- trickling filter: up to 90 % for BOD_5 and 80 % for COD (*Source:* experience, e.g. from Crown Van Gelder paper mill, 2011);
- moving bed biofilm reactors (MBBR)/suspended carrier reactors: 85 – 95+ % BOD_5; 80 – 90 % COD;
- submerged biofilter: 60 – 80 % for BOD_5; 50 – 60 % for COD.

Removal efficiencies also depend to a certain extent on the incoming concentration and characteristics of pollutants. Inflow concentrations of organic substances to the waste water treatment plant are influenced by the raw materials used, the paper grades produced, the specific water consumption, the chemical additives used (e.g. higher presence of polyvinyl alcohol reduces the abatement efficiency) and the process-integrated measures applied.

Waste water from paper mills after treatment reach values of <50 – 140 mg COD/l depending on the degree of closing up of the water circuits. BOD_5 levels below 25 mg BOD_5/l are normally achievable and values as low as 5 mg/l can be achieved (close to the detection limit). The COD/BOD ratio of filtered samples of paper mill waste water after biological treatment is usually between 4 and 7 or 8 (up to 10). Proper design and maintenance of the treatment plant are a prerequisite for well performing biological systems.

Achieved emissions to water from non-integrated paper mills after aerobic treatment are shown in Table 7.26, differentiating between paper grades, kinds of fibre furnish used and the type of waste water treatment applied [244, Pulp and Paper TWG 2007], [248, Hamm 2007], [138, PP TWG 2009].

Table 7.26: Annual average emissions of non-integrated paper mills after biological treatment

Examples of non-integrated paper mills and fibre supply	Reported achieved emission levels after aerobic treatment							Production (t) 2006 or 2008 and type of effluent treatment
	COD	BOD_5	Tot-P	Tot-N	AOX	TSS	Flow (m^3/t)	
Uncoated paper mills or mills manufacturing coated and uncoated paper (DE (3), FR (1), PO (1))								
Paper mill 1 (100 % chemical pulp)	70 mg/l	14 mg/l	1.0 mg/l	2.0 mg/l	0.17 mg/l	24 mg/l	3.2	1.19 million, coated/uncoated fine paper
	0.23 kg/t	0.04 kg/t	0.003 kg/t	0.007 kg/t	0.6 g/t	0.08 kg/t		Trickling filter + single-stage AS
Paper mill 2 (100 % chemical pulp)	50 mg/l	17 mg/l	0.8 mg/l	2.4 mg/l	0.04 mg/l	19 mg/l	15.6	347 000, coated & uncoated paper
	0.78 kg/t	0.27 kg/t	0.010 kg/t	0.040 kg/t	0.5 g/t	0.3 kg/t		Single-stage activated sludge
Paper mill 3 (95 % chemical pulp, 5 % DIP)	17 mg/l	3 mg/l	0.13 mg/l	1.5 mg/l	0.04 mg/l	3.6 mg/l	10.8	287 000, coated/uncoated
	0.18 kg/t	0.03 kg/t	0.0014 kg/t	0.016 kg/t	0.4 g/t	0.04 kg/t		Single-stage activated sludge
Paper mill 4 (100 % chemical pulp)	50 mg/l	12 mg/l	0.9 mg/l	6.5 mg/l	0.19 mg/l	mg/l	4.6	123 635, uncoated
	0.23 kg/t	0.056 kg/t	0.004 kg/t	0.03 kg/t	0.9 g/t	0.036 kg/t		Single-stage activated sludge
Paper mill 5 (93 % chemical pulp, 7 % CTMP)	83 mg/l	13 mg/l	0.45 mg/l	6 mg/l	ND	20 mg/l	8.7	262 758, uncoated offset paper
	0.72 kg/t	0.11 kg/t	0.004 kg/t	0.05 kg/t	ND	0.16 kg/t		Moving bed reactor + single-stage AS
Coated paper mills (FR (1), SE (1))								
Paper mill 1 (100 % chemical pulp)	119 mg/l	9 mg/l	1.0 mg/l	10.1 mg/l	0.2 mg/l	26	6.9	108 913, coated paper
	0.82 kg/t	0.063 kg/t	0.007 kg/t	0.07 mg/l	1.4 g/t	0.18 kg/t		Single-stage activated sludge
Arctic Paper Grycksbo, SE	71 mg/l	ND	0.06 mg/l	0.6 mg/l	0.1 mg/l	16 mg/l	7	265 000, coated paper
	0.5 kg/t		0.4 g/t	0.004 kg/t	1.0 g/t	0.11 kg/t		MBBR + chemical treatment (flotation)
Tissue paper mills (FR (1), UK (2), PO (1), DE (1), IT (1))								
Paper mill 1 (100 % chemical pulp)	65 mg/l	16 mg/l	0 (1)	16 mg/l	ND	0 (1)	6.2	64 496, tissue
	0.4 kg/t	0.1 kg/t	0 kg/t (1)	0.1	ND	0 (1)		Fixed bed biofilm reactor + biofilter
Paper mill 2 (100 % chemical pulp)	138 mg/l	13 mg/l	0.08 mg/l	1.8 mg/l	0.3 mg/l	8 mg/l	4	60 000, tissue
	0.55 kg/t	0.05 kg/t	0.0003 kg/t	0.007 kg/t	1 g/t	0.03 kg/t		Moving bed biological reactor
Paper mill 3 (77 % chemical pulp; 23 % deinked stock)	27 mg/l	7 mg/l	1.3 mg/l	0.9 mg/l	ND	11 mg/l	24	120 000, tissue
	0.71 kg/t	0.19 kg/t	0.01 kg/t	0.045 kg/t	ND	0.28 kg/t		Single-stage activated sludge
Paper mill 5 (100 % chemical pulp)	114 mg/l	10 mg/l	0.6 mg/l	1.4 mg/l	0.2 mg/l	6 mg/l	5	60 000, tissue
	0.57 kg/t	0.05 kg/t	0.003 kg/t	0.007 kg/t	1 g/t	0.03 kg/t		Moving bed biological reactor
Paper mill 6 (100 % chemical pulp)	95 mg/l	2 mg/l	0.35 mg/l	5.2 mg/l	0.08 mg/l	12 mg/l	5.8	60 000, tissue
	0.55 kg/t	0.01 kg/t	0.002 kg/t	0.03 kg/t	0.5 g/t	0.07 kg/t		ND (biological treatment)

(1) Although it does not seem correct, the paper mill reported '0' (data refer to 2008).

NB: ND = No data provided.

Sources: EIPPCB Questionnaires 2007 and 2009, [248, Hamm 2007], Swedish Statistics 2007

In cases where smaller paper mills manufacture standard grades, these mills may achieve emissions that are quite similar to those of large mills (e.g. RCF-processing mills producing graphic recycling paper with deinking and folding boxboard). Many smaller mills, however, produce customised speciality papers or paper for niche markets (e.g. cigarette papers, filter papers, decorative paper). For these mills, it is mainly the specific waste water flow that distinguishes them from other paper mills manufacturing standard grades (the specific waste water flow of speciality paper mills may vary between 13 m^3/t and 200 m^3/t). The corresponding loads for the different parameters after treatment are in many cases in the same range as standard grades, in some cases just slightly higher than for standard wood-free paper grades. The annual average emission loads of some example speciality paper mills after biological waste water treatment are shown in Table 7.27 [138, PP TWG 2009], [248, Hamm 2007]. More data for speciality paper mills can be found in Section 7.2.2.5.

Table 7.27: Annual average water-based emissions of non-integrated speciality paper mills after biological treatment

Examples of non-integrated speciality paper mills	Reported achieved emission levels after aerobic treatment								Production (t) 2006 or 2008 and type of effluent treatment
	Unit	COD	BOD_5	Tot-P	Tot-N	AOX	TSS	Flow (m^3/t)	
Speciality paper mills									
Crown Van Gelder, NL; 100 % CP	mg/l	87	23	1.2	5.1	0.2	16	13.0	212 500, specialties for graphical & industrial. applications
	kg/t	1.13	0.30	0.015	0.066	0.002	0.20		Trickling filters, two-stage plant
Paper mill 1	mg/l	24	ND	0.22	2.91	0	8	17.4	36 700, coated thermo-graphic paper, inkjet paper
	kg/t	0.42	ND	0.004	0.051	0	0.131		Aerobic moving bed biological reactor
Paper mill 5	mg/l	17	ND	0.16	2.83	0.04	10	198.0	13 000, coated tea bag, food/beverage packing, etc.
	kg/t	3.36	ND	0.030	0.560	0.008	1.980		Biofilter
Paper mill 8	mg/l	118	ND	0.73	0.32	ND	25	52.4	Casting paper, art paper
	kg/t	5.16	ND	0.040	0.020	ND	1.300		Single-stage activated sludge plant
Paper mill 15	mg/l	34	ND	0.26	1.28	0.14	ND	13.2	130 000, coated carbonless, decor paper, finetech paper
	kg/t	0.31	ND	0.003	0.013	0.002	ND		Moving bed reactor
Prado-Cartolinas da Lousã, PT, 100 % CP	mg/l	113	ND	1.25	2.8	0.05	31	16.5	24 310, white & coloured Bristol board
	kg/t	2.03	ND	0.020	0.040	ND	0.55		Fixed bed biofilm reactor + O_3
Pucara Roigheim, DE, 100 % CP	mg/l	48	7	0.06	3.6	ND	4	35	14 500, insulation paper
	kg/t	1.7	0.2	0.002	0.124	ND	0.14		Flotation/ filtration
Julius Glatz Neidenfels, DE, 100 % CP	mg/l	17	4	0.26	0.77	0.02	3	74	48 000, cigarette paper, fine paper
	kg/t	1.2	0.3	0.02	0.056	0.002	0.2		Biofilter
Munksjö Paper Aalen, DE, 100 % CP	mg/l	21	4	0.10	6.0	0.20	2	47	75 000, decorated paper
	kg/t	1.0	0.2	0.005	0.3	0.01	0.1		Biofilter
Cordier Bad Dürkheim, DE, 35 % CO, 65 % cotton linters	mg/l	68	6	0.02	1	0.36	ND	20	13 440, customised graphic and technical paper
	kg/t	1.4	0.12	0.0004	0.019	0.007	ND		Activated sludge, sedimentation/ flotation

NB: CP = purchased chemical pulp; ND = no data provided.

Source: EIPPCB Questionnaires, [248, Hamm 2007], data for the Crown Van Gelder mill received via TWG comments on the 1st draft of the PP BREF, 2011.

Part of the added nutrients will normally be released together with the treated effluent. When the system is well optimised, a nutrients discharge of 1 mg tot-P/l and below 10 mg $N_{inorganic}$/l is achievable (as a daily average value).

During aerobic waste water treatment, excess sludge is produced which has to be thickened, dewatered and further treated. A typical value for low-loaded activated sludge plants is in the range of 0.3 – 0.4 kg excess sludge/kg BOD_5 eliminated (as dry solids). Sometimes slightly higher values are also observed. The treatment of low BOD_5 concentrations in submerged biofilters generates less excess sludge: about 0.2 kg excess sludge/kg BOD_5 eliminated (as dry solids). High-loaded plants have a higher specific excess sludge generation.

For aeration of the active biomass and for pumps, electrical energy is needed. The specific energy consumption for degradation/elimination of 1 kg BOD_5 amounts to 0.3 – 3 kWh. It depends mainly on the type and design of the aeration system applied, the correct dimensioning of the plant and the designed organic load of the activated sludge system:

- high load activated sludge systems require about 0.3 – 0.5 kg O_2/kg BOD_5 eliminated;
- low load systems require 1.5 – 2 kg O_2/kg BOD_5 eliminated.

Consequently, high load activated sludge treatment consumes about 0.5 kWh/kg BOD_5 eliminated and low load activated sludge treatment consumes about 1.5 – 2 kWh/kg BOD_5 eliminated. However, if the low-loaded system is well-designed, a value of <1 kWh/kg BOD_5 eliminated can be achieved [91, Möbius 1997]. This value can also be used to compare expected operating costs of different waste water systems.

Cross-media effects
Aerobic biological waste water treatment consumes energy (e.g. for aerators and pumps) and generates sludge that normally requires treatment before utilisation or disposal.

Especially during the summer period, the waste water treatment plant of paper mills may emit annoying odours. If the waste water treatment is well designed and controlled, annoying odours can be avoided (see Section 2.9.14).

Technical considerations relevant to applicability
Not applicable to plants where the biological load of waste water after the primary treatment is very low, making biological treatment not technically or economically viable.

Economics
The following figures on investment costs for biological treatment can only give a rough indication of the magnitude of the costs involved. When comparing investment costs based on the pollutant load treated (e.g. kg COD), one has to bear in mind that treatment plants are often oversized to take into account a possible future increase in production.

However, some examples of treatment systems in French paper mills are compiled here:

- activated sludge for a printing paper mill (200 t/d paper production): EUR 2 million;
- activated sludge for a printing paper mill (300 t/d paper production): EUR 3 million;
- biofiltration for a speciality paper mill (130 t/d paper production): EUR 1.5 million;
- activated sludge for a printing paper mill (260 t/d paper production corresponding to 2.5 t COD/day): EUR 2 million;
- activated sludge for a corrugated paper mill (100 t/d paper production): EUR 1.5 million (all data from [CTP, Grenoble]).

The investment costs can be summarised as follows:

- activated sludge treatment: EUR 300 – 600 per kg COD=day;
- biofiltration: EUR 500 per kg COD=day.

The investment costs depend above all on the quantity of pollutant load to be treated per day.

Driving force for implementation

Many Member States have set requirements for paper mill effluents which generally consider biological treatment to be BAT on a sector level. As a consequence, many paper mills in Europe have built biological waste water treatment plants or other treatment systems with comparable efficiencies.

Example plants

Numerous aerobic waste water treatment plants are operated in European paper mills.

Reference literature

[91, Möbius 1997], [Cost data from CTP, Grenoble, 1999], [113, PTS 1998], [138, PP TWG 2009], [244, Pulp and Paper TWG 2007], [248, Hamm 2007].

7.3.12 Tertiary waste water treatment - chemical precipitation

Description

See Section 2.9.11.3.1.

Achieved environmental benefits

Reduction of emissions of phosphorus and TSS and part of the organic matter (particulate and colloidal compounds).

Environmental performance and operational data

Results of annual average values from Swedish plants where chemical precipitation is used in combination with biological treatment are given in Table 7.28. Swedish pulp and paper mills of different types apply chemical precipitation: non-integrated paper mills (coated paper, tissue), integrated RCF-processing mills, newsprint mills, CTMP mills or integrated chemical pulp mills (see Section 3.3.14). Table 7.28 does not necessarily show mills that have applied all water-related BATs, but shows rather the achieved emission levels by the use of chemical precipitation of the targeted parameters, i.e. TSS, N, P. The COD load is less affected by this treatment.

Table 7.28: **Performance of chemical precipitation/flocculation as a stand-alone or tertiary treatment for paper mill waste water**

Mill, type of paper, pulping process	Waste water flow	COD after treatment (1)		TSS (1)		Tot-P (1)		Tot-N (1)	
	m^3/t	kg/t	mg/l (2)	kg/t	mg/l (2)	kg/t	mg/l (2)	kg/t	mg/l (2)
Munkedal, purchased chemical pulp,	3	0.5	166	0.2	66	2.1	0.7	35	12
Nyboholm, tissue, purchased chemical pulp	13	2.2	170	0.3	23	4	0.3	33	2.5
Grycksbo, coated paper, purchased chemical pulp	7	0.5	71	0.11	16	0.4	0.06	4	0.6
Hallsta, newsprint, TMP/GW/RCF deinked	12	5.3	441	0.4	33	3	0.25	48	4
Ortviken, newsprint, TMP	20	3.8	190	0.2	10	4	0.2	79	4
Braviken, newsprint, TMP/RCF deinked	15	2.4	160	0.4	27	5	0.33	75	5
Inlands, RCF non-deinked	24	4.9	204	0.7	30	13	0.5	82	3.4
Katrinefors, tissue, RCF deinked	51	3.4	66	0.5	10	6	0.12	175	3.4
Edet, tissue, RCF deinked	37	4.7	127	0.78	21	10	0.3	141	3.8
Fors, CTMP, packaging paper	27	6	222	0.4	15	3	0.1	57	2.1

(1) The emission levels refer to the amount of paper produced (and not to the pulp produced).
(2) Concentration values calculated from reported yearly waste water flow and load.
Source: Swedish Forest Industry Federation and Swedish Statistics 2007

Reduction rates of about 97 – 99 % for TSS and 70 % for COD in relation to the raw effluent (before any treatment, i.e. before the primary clarifier) are achieved. The COD reduction is mainly achieved due to the reduction of TSS. The soluble part of COD (and BOD) is only slightly reduced (about 10 %). The reduction of the soluble compounds of COD and BOD is achieved by biological treatment (see Section 7.3.11).

The COD/BOD ratio in the range of 3 after chemical precipitation and shows that a substantial part of the removed COD consists of less biodegradable, and therefore potentially more harmful, matter. It also shows that these effluents are appropriate for further biological treatment.

The amount of generated sludge is in the range of 3 – 6 kg/m^3, including 60 – 80 % water (after presses or centrifuges, the dry substance is about 20 – 40 %).

The chemical cost is substantial and the purification is selective; neutral substances cannot be captured as efficiently as dissociated ions or colloidal and particulate matter.

Cross-media effects

The precipitation of TSS, nutrients and, to a lesser extent, organic material with inorganic chemicals results in a great quantity of sludge that is difficult to dewater and is often dumped to landfill. The use of precipitants results in an increase of salts (chlorides or sulphates) in the effluent. The amount of metal-salts used is normally between 200 g/m^3 and 400 g/m^3.

The treatment consumes some energy for pumps and drives.

Technical considerations relevant to applicability
Applicable to both new and existing mills. It is especially applied at smaller mills.

Economics
The investment costs for physico-chemical treatment amount to EUR 1 million for a printing paper mill with a capacity of 100 t/d. The investment costs for chemical precipitation include an equalisation tank, chemical dissolving equipment, chemical dosing equipment, a precipitation and flocculation unit and a clarifier. No data were available on operating costs.

Driving force for implementation
Usually the chemical precipitation of waste water from non-integrated paper mills is applied when the nutrients, TSS and non-soluble parts of the organic matter in the effluent have to be removed.

Example plants
See Table 7.28.

Reference literature
[Swedish Forest Industry Federation and Swedish Statistics 2007]

7.3.13 Dewatering and thickening of sludge before final disposal or incineration

Description
During pulp and paper manufacturing and in their on-site effluent treatment plants, large amounts of sludge are generated in the primary treatment, biological waste water treatment and chemical flocculation plants, including coating colour treatment. Aerated lagoons, as well as anaerobic plants, typically generate less sludge.

Sludge handling in paper mills includes the following main stages:

- reuse of fibre sludge from primary treatment, which is practised in many cases;
- thickening and dewatering of fibre/biological/(chemical) sludge;
- final disposal of dewatered sludge.

Reuse of fibre sludge is practised in cases where this is suitable with regard to product requirements. In the presence of biological/chemical sludges, at least a part of the fibre sludge should be dewatered, rather than reused. This is because biological and chemical sludge have very poor dewatering properties, and normally they are mixed with some fibre sludge to achieve acceptable dewatering properties.

The dewatering aims at removing water from the sludge as far as possible, in order to reduce transport costs and facilitate final disposal. Different types of mechanical equipment are available for this operation.

Biological and chemical sludge is normally pre-dewatered prior to the dewatering and thickening. This means an increase of DS content from about 1 – 2 % to 3 – 4 % or higher. The pre-dewatering of sludge is usually performed in gravity tables, gravity disc thickeners, hydrostatic disc thickeners and, for biosludge, also by thickener centrifuges.

Prior to dewatering, the sludge normally must be conditioned with flocculants. Usually a polyelectrolyte is added. This refers particularly to sludge mixtures with biological and/or chemical sludge, but fibre-containing sludges are often also conditioned by adding flocculants.

Dewatering equipment includes the following types:

- belt presses (double wire presses),
- screw presses,
- decanter centrifuges,
- chamber filter presses.

Installations built during the 1980s and 1990s were fitted with belt presses. They have a reliable function and produce fairly high DS values: 40 – 50 % with fibre sludge and 25 – 40 % with mixed fibre/biological(chemical) sludge. However, a more recent trend is to use screw presses.

Screw presses can be used in two ways:

- to increase the DS content after belt press dewatering; an approximate DS increase of 10 % can be obtained;
- direct dewatering; a higher DS content can be obtained compared to belt press dewatering.

An increasing application of screw presses has been observed for some years, due to an increasing interest in sludge incineration, requiring high DS values. When the sludge is incinerated, the drying of sludge should also be considered in order to improve the heating value (see Section 2.9.6.1.4).

Decanter centrifuges are mostly used for sludge with very poor dewatering properties, such as pure chemical sludge or biological sludge (if it is dewatered separately). They produce lower DS contents than the belt and screw presses.

Achieved environmental benefits
The sludge dewatering can reduce the sludge volume and weight resulting in less transport and less volume for disposal.

Environmental performance and operational data
For fibre sludge pre-dewatering, continuous rotary drum filters or gravity disc thickeners are also operated in the paper industry resulting in approximately 8 % DS together with a clear filtrate that has a low content of suspended solids.

Many types of dewatering equipment, ranging from low-efficiency drum filters (in terms of DS content) to high efficiency screw presses, have been used in all types of paper and board mills. Belt presses (double wire presses) and screw presses used to achieve high sludge dryness have proven to be efficient in most cases.

Cross-media effects
No significant effects reported.

Technical considerations relevant to applicability
The measure can be adopted in new and existing mills.

Economics
The reported costs refer to the amount and type of sludge to be thickened and dewatered. According to data from a supplier [108, Krieger, Bellmer 2010], the total investment costs for a sludge thickening/dewatering system for sludge from the paper industry including a pre-thickener and screw presses (only machinery without instrumentation, electrical and control technology, pipes, valves or construction works) are:

- for 5 – 10 BDt/d, i.e. bone dry tonnes of sludge per day: approximately EUR 16 000 – 31 000 per tonne of sludge (bone dry) per day
- for 50 – 100 BDt/d: approximately EUR 8 000 – 16 000 BDt/d.

The lower values refer to sludge with better dewatering properties such as fibre sludge or deinking sludge; the higher values refer to sludge with higher proportions of biological and chemical sludge that are more difficult to dewater. The dry solids content of the sludge is increased from 1.5 – 3 % to up to 40 – 60 %.

Operating costs for screw presses are:

- energy costs: EUR 1.5 – 3/tonne of sludge (bone dry) per day;
- cost for flocculants: EUR 4 – 16/tonne of sludge (bone dry) per day;
- maintenance costs per year are approximately 5 – 10 % of the machinery investment costs (mainly for processing the screw shaft and new screen baskets).

The costs depend to a certain extent on the sludge composition and demand for flocculation chemicals.

Driving force for implementation
A high dry solids content for transportation and final disposal is the driving force to implement this technique. This technique produces the highest possible dry solids content and thus higher upper heating value if incineration is the final treatment option.

Example plants
Numerous plants all over the world for all types of effluents.

Reference literature
[1, Finnish BAT Report 1997], [75, Pöyry 1997], [108, Krieger, Bellmer 2010].

7.3.14 Prevention, reuse, recycling and treatment of process residues

See Section 2.9.8.

7.3.15 Energy saving in papermaking

Description
Benchmarking is often the starting point for energy efficiency improvements. 'Best practice benchmarking' is the process of comparing the steam and electricity consumption of the mill's own processes to performance levels of best practice mills that use similar processes and manufacture similar products. The comparison allows for assessing the potential for energy improvements and the development of plans on how to make improvements in energy efficiency. The steam and electricity consumption of processes are preferably determined on a totally site-integrated basis that takes into account all necessary process departments such as water preparation, power plants, effluent treatment, debarking (if applied), pulping and papermaking.

The use of simulation models is the most appropriate method for determining the mass and energy balance of the processes and the entire mill. Rough models exist for various paper grades. The models may be validated quite easily through a reasonable amount of measurements and by refining the underlying process models. To feed the model with data, the amount of purchased electricity and fuels must be known and also the consumption of electricity in detail. Knowledge is also required on average consumption and variations in energy consumption over time.

Energy consumption figures together with the technologies used in the process form the reference level that can then be compared with the best practice mills. This reference level is however complicated by the fact that there are no two completely identical paper mills and mills are operated differently. There are many variations in specific energy consumption figures within the production of certain paper grades.

After determining the reference level, the operators of the paper mill may evaluate how the energy efficiency can be improved through process changes and by changing the operation of the process. Some of these measures are linked with investments to replace, rebuild or upgrade process equipment and are mostly not only applied for saving energy. They simultaneously increase production efficiency, improve product quality and reduce overall costs. The horizontal measures for the reduction of energy consumption in pulp and paper mills applicable to most paper grades are discussed in Section 2.9.5 and 2.9.6.

The available techniques listed in Table 7.29 may be used in analysing the improvement potential of a mill. The achievable savings with a certain technique are only indicative because, for more precise and reliable figures, the current levels of energy consumed in a given mill (before these measures are implemented) should be known as well as the effects of integrating energy-saving techniques. Also, the composition of the furnish has a strong effect on the consumption figures. In some cases, the paper quality process demands may restrict the use of certain techniques and sometimes it is not possible or economically feasible to introduce new techniques into old paper mills. Most of the measures listed in Table 7.15 are discussed in this document (for cross references, see the first column on the left), others are taken from [249, Blum et al. 2007].

Table 7.29: Available energy-saving measures and indicative improvement potential

Number, BREF Section (^{1})	Technique/measure	Relevant process	Achievable savings (kWh/t)		Paper grade where applicable
			Electrical	Heat	
#1, 6.3.10.1	HC pulping (up to 20 %)	Pulping	3 – 8	-	RCF-based paper
#2, 6.3.10.2	High efficiency screening	Screening	2 – 10	-	RCF-based paper
#3, 6.3.10.3	Shutdown of disperser (trials are required)	Dispersing	15 – 30	10 – 20	RCF-based paper
#4, 2.9.6.2.3	More precise dimensioning of pumping, variable speed drive control of pumps, gearless drives	Pulping, screening, cleaning, approach flow	20 – 30	-	All grades
#5, 7.3.15.2	Optimisation of existing refining plants	Pulp refining	5 – 15	-	Wood-free fine papers, tissue, speciality paper
#6, none	Cutting edge refining technologies	Pulp refining	up to 100	-	Wood-free fine papers, tissue, speciality paper
#7, none	Steam box	Pressing	-	Approx. 50	Mechanical pulp, RCF-based mills
#8, 2.9.6.2.1	Vacuum system optimisation (e.g. turbo fans instead of water ring pumps)	Forming, dewatering, pressing	10 – 60	-	All grades
#9, 7.3.15.1	Shoe press or extended nip press (increase solid content before drying)	Pressing	-	Up to 200	Printing and writing, RCF-based paper
# 10, 2.9.6.1.2	Use of thermo-compressors (reducing condenser losses)	Drying	-	5 – 120	All grades
#11, none	Generation optimisation & distribution network maintenance	Compressed air	5 – 10	-	All grades
#12, 7.3.15.3/ 2.9.6.1.3	Optimisation of heat recovery, air system, insulation	Drying	-	40 – 100	All grades
#13, 2.9.6.2.2	Use of high efficiency motors (EFF1)	All subsystems	0 – 15	-	All grades
#14, 5.3.9	Heat recovery from TMP refiners	TMP refiners	-	1 000 (1 500kWh/t pulp)	TMP mills
#15, 7.3.15.3	Heat recovery from hot bleaching waste water	Bleaching	-	5 – 10	Mechanical, TMP, RCF-based
#16, 2.9.6.1.1	Heat recovery from axial blowers (if used) for supply air of drying hood	Drying	-	20 – 30	All except tissue
#17, 7.3.15.3	Heat recovery of exhaust air from the Yankee hood with a trickling tower	Drying	-	Up to 50	Tissue paper
#18, 7.3.15.3	Preheating of shower water with heat exchanger	Forming and dewatering, pressing	-	Up to 30	All grades
#19, 2.9.6.1.4	Use of waste heat for sludge drying or upgrading of dewatered biomass	Waste water treatment	-	30 to 50	All grades
# 20, none	Recovering heat from infrared exhaust hot air	Drying of coating colours	-	ND	Coated grades

(^{1}) The numbers given to each technique are referred to in Table 7.31: Energy consumption associated with the use of BAT. Where no cross reference is given, the measure is taken from [249, Blum et al. 2007] and further described there.

Further measures that are also linked to energy efficiency include supported web handling to reduce the incidence of web breaks, or good housekeeping with regards to water use (reuse and recycling of water). Saving water means saving energy in most cases because it is associated with higher process temperature and less water to be heated up. Closed cooling water systems may reduce the total water consumption by almost 20 m^3/t paper in many cases.

When applying the energy-saving measures mentioned above, the indicative energy consumption levels can be found in Table 7.30.

Table 7.30: Indicative energy consumption levels for heat and power for different types of non-integrated graphic paper and tissue mills with conventional drying system

Type of paper mill	Indicative energy consumption level for process heat (kWh/t)	Indicative energy consumption level for electricity (kWh/t)
Non-integrated graphic paper (coated or uncoated)	1 300 – 1 700 (upper end of the range refers to mostly coated grades)	550 – 800 (upper end of the range includes coating and refining)
Non-integrated tissue	1 800 – 2 100	900 – 1 100
Speciality paper	Not applicable(**)	
(**) Due to the high diversity of products, varying raw material compositions and manufacturing processes, the energy consumption values vary widely between mills.		

The following system boundaries were considered for the indicative energy consumption levels given in Table 7.30 above.

(1) The energy consumption levels refer to entire mills' net production and include pumps, agitators and compressed air. Peripheral subsystems for raw and waste water, sludge and rejects such as dissolved air flotation, reject screw presses or sludge presses, and waste water treatment are also covered.
(2) The ranges include all process units related to stock preparation and papermaking, starting with the feed conveyor or slushing of pulp and ending after the last slitter winder, i.e. before converting.
(3) The figures for power consumption do not consider the primary energy input of fuels for the generation of power but represent process heat and power used. Electric infrared (IR) dryers are part of the power consumption.
(4) For heat, the consumption values refer to the thermal capacity of the steam used and the lower calorific value for gas in the case of IR or air dryers. Gas infrared dryers are included in the heat consumption.

Besides the selection of techniques, the manner of operation (energy-efficient practice) and the energy management in the mill are an important issue (see Section 2.9.5). Equipment is often not used at its optimum energy efficiency and, with better management, further savings can be achieved.

The pinch method for the optimisation of thermal integration of paper mills can be a beneficial tool to move towards energetically optimised processes.

Table 7.31 shows examples of specific energy consumption (SEC) values for different types of paper mills using a combination of energy-efficient techniques. Some characteristics of the mills, e.g. raw material used, applied techniques and mill size are also compiled. The applied energy-saving techniques have the numbering as Table 7.29 above.

The energy demand also depends on the product quality (especially in tissue mills). Therefore, the reported ranges of energy consumption of paper mills shown in Table 7.31 should be taken only as an indication of the need for process heat and power at energy-efficient paper mills. The improvement potential through the use of all available techniques together with optimised process integration might still be significant compared with these papermaking lines.

Table 7.31: Examples of energy consumption associated with the use of some techniques to consider for different types of paper production

Grade of paper	Heat and power consumption (kWh/t)		Raw material mix used	Remarks	Reference	Type of paper mill	Applied techniques (refer to Table 7.28)
Integrated coated mechanical	Power	1 200	40 % mechanical pulp, 30 % virgin fibres, 30 % coating pigments	Groundwood pulp line	[249, Blum et al. 2007]	600 000 t/yr magazine paper on three paper machines	#7; #9; #10; #13; #15; #16; #18
	Heat	1 700					
Non-integrated uncoated wood-free	Power	600	100 % virgin fibres (+ fillers)		[249, Blum et al. 2007]	400 000 t/yr printing paper on two paper machines	#4; #6; #10; #13; #18
	Heat	1 300					
Non-integrated coated wood-free	Power	600	60 % virgin fibres 40 % fillers & coating pigments		[249, Blum et al. 2007]	300 000 t/yr coated fine papers on two paper machines	#4; #13; #10
	Heat	1 200					
RCF without deinking (packaging)	Power	300	100 % paper recycling (ordinary grades)	Grades: fluting and medium	[249, Blum et al. 2007]	300 000 t/yr corrugated base paper on one paper machine	#1; #9; #10; #13
	Heat	1 100					
RCF with deinking (graphic)	Power	900	100 % paper for recycling (ordinary and medium grades)		[249, Blum et al. 2007]	70 000 t/yr recycling papers on one paper machine	#2; #9; #13; #18; #19
	Heat	1 200					
RCF-based board (with deinking)	Power	450	100 % paper for recycling (ordinary and medium grades)	Uncoated	[249, Blum et al. 2007]	100 000 t/yr folding boxboard on one board machine	#4; #7; #9; #10
	Heat	1 000					
Non-integrated tissue mill	Power	900	100 % virgin fibres	No TAD use	[249, Blum et al. 2007]	50 000 t/yr handkerchief on one tissue machine	#4; #10; #13; #17
	Heat	2 000					

NB: Conversion of heat consumption: 1 kWh = 3.6 MJ; example: 1 700 kWh/t heat × 3.6 = 6 120 MJ/t heat.
Source: [249, Blum et al. 2009]

The techniques described in Sections 7.3.15.1 to 7.3.15.3 should be taken as examples of possible energy savings through energy-efficient techniques. Integration of processes, efficient heat recovery from the exhaust air from the dryer section of the paper machine and from other losses – together with energy-efficient refining and achieving the highest dry solids contents in the press section – are the most important aspects for reducing energy consumption in papermaking. The interrelationship between energy consumption and energy supply also has a strong influence on energy-efficient solutions.

7.3.15.1 Optimisation of dewatering in the press section of the paper machine (wide nip press)

Description

A paper machine constitutes a huge dewatering process. It comprises in principle three major parts:

- the wire section for sheet formation and the first dewatering by gravity and vacuum/suction;
- the press section for further dewatering of the wet web by mechanical forces;
- the dryer section for drying the web to the final dryness by evaporation on steam-heated cylinders.

After the press section (see also Figure 7.1), normally the web dryness is 45 – 50 %, i.e. about 1 kg water/1 kg furnish is left. To evaporate these last 'water drops', a lot of evaporation energy and a long dryer section is needed.

In a paper machine, most of the energy is needed for paper drying (steam 572 kWh/t). Electrical energy is needed for roll and cylinder drives (electrical 100 kWh/t) and to create a vacuum (electrical 67 kWh/t). The higher the dryness of the paper web after the press section, the lower the thermal energy required for the final paper drying. By increasing the dryness of the paper web entering the dryer section by 1 %, approximately 4 % heat (in terms of low-pressure steam of approximately 2 bar) can be saved. Therefore, measures have to be taken in the paper machine to maximise the dry content by wet pressing.

In a conventional roll press nip, the nip pressure has reached its high limit and cannot be further increased to improve dewatering in the press section. By substituting conventional short nip presses with wide nip press(es), also known as shoe press(es), a higher pressure impulse than in a conventional roll press is achieved resulting in an intensified dewatering of the wet web and higher dryness of the paper web after the press section. The shoe is loaded against a counter roll with hydraulics. The press concept leads to a significant extension of the pressing zone and contact time in the nip compared to conventional roll presses. High after-press dryness gives drying energy savings and a good runnability in the dryer section because of the good wet strength of the web.

Achieved environmental benefits

The effects on the environment are related to savings of thermal energy for paper drying. Dryness increases of between 5 % and 15 % are reported after the installation of a shoe press in existing paper machines for packaging paper and board [69, IFP 1998]. This increase depends significantly on the previous performance of the rebuilt press section and the selected new shoe press concept.

In one case, the rebuild of the press section resulted in a dryness increase of 6 % after the installation of one shoe press. The specific steam demand for paper drying was reduced from 2.13 to 1.76 tonnes of steam per tonne of paper, which is equivalent to an 18 % thermal energy saving. The reduction in emissions to air due to energy production depends strongly on the type of fossil fuel used. In the paper mill concerned, 46 000 tonnes of steam (equivalent to

5.1 million m^3 natural gas and an avoided CO_2 emission of 8 900 tonnes) have been saved annually.

On paper machines with limited drying capacity, every 1 % reduction in sheet moisture can be translated into a 4 – 5 % productivity increase. If the drying capacity of the paper machine is not limited, an equivalent steam consumption decrease in the dryer section can be achieved. Dryer section steam savings of up to 170 kWh/t can be reached.

However, for a given paper density, the dryness improvement is furnish-dependent. With wood-free paper grades, the after-press dryness is about 3 to 5 percentage points higher when applying the shoe press. With wood-containing paper grades, the corresponding figure is about 4 to 7 percentage points. The difference is even greater, up to 12 percentage points, at high machine speeds, because with a long nip dwell time of the shoe nip, the dryness will stay at a high level when increasing the machine speed. With grades containing wood, the whole shoe press load capacity can be utilised, because the best paper properties can be achieved with a high-pressure level in the nip.

When replacing a roll press with a shoe press in a paper machine, the typical total savings in dryer energy are 20 – 30 %.

Environmental performance and operational data

One example of a press rebuild is Nordland Papier in Germany. In the compact three nip press section of this copy paper machine, the last roll press nip was replaced with a shoe press nip. After the rebuild, the dryness after the press section was about 3 – 4 percentage points higher. At the same time the production speed was increased from 850 m/min to 1 200 m/min, the increase in production being 30 %. To reach this dryness improvement, a linear load of 500 – 600 kN/m was applied on the shoe press. Later production broke all records and this rebuilt machine became the most efficient fine paper line in the world. Savings in the specific steam demand for paper drying are 30 %.

Similar results have been achieved in several equivalent rebuilds around the world.

Cross-media effects

Replacement of the conventional roll nips with shoe nips will not significantly increase the electricity requirements. The shoe press has a higher specific electricity consumption but fewer nips producing a dryer sheet, which compensate for each other. Reduced thermal energy consumption can be transformed into avoided air emissions.

The shoe press is a tool for increasing the machine speed while maintaining good runnability. High efficiency saves raw materials and energy and ensures higher machine uptime with less waste. High after-press dryness means lower energy requirements and thereby fewer emissions in energy production.

The increased dryness after shoe pressing results in an increase of the apparent density and internal bond strength of the finally dried sheet. The relationship is almost linear. Higher strength of the paper web generally improves the runnability of the paper machine due to fewer web breaks. The result is a higher paper machine efficiency. For example, after a shoe press rebuild, if the number of unplanned web breaks is reduced by two per day (with a duration of 20 minutes each), the daily paper machine production capacity will increase by almost 3 %.

If the production capacity of a paper machine is limited because of its drying capacity, the reduced steam demand for drying after installation of a shoe press will make it possible to increase the speed of the paper machine. In those cases, production can be increased by up to 20 % for the same amount of steam as was used before the application of a shoe press.

Technical considerations relevant to applicability
The shoe press can be applied in both new and existing paper machines with most paper grades (apart from tissue) provided that sufficient space is available in the press section and that the building construction permits the higher weights of a shoe press. The maximum load of the hall crane has in some cases to be increased due to the heavier shoe press rolls. Because of the large additional investment costs, the economic advantage is doubtful in the case of smaller paper machines, say with a trimmed width of less than 2.5 m.

With bulk sensitive grades, basically wood-free grades, a low load (600 kN/m) long shoe (250 mm) is advantageous. With grades containing wood, a higher load (800 kN/m) and shorter shoe (180 mm) can be used.

The shoe press has even been developed for high-speed machines (up to 2 000 m/min).

Economics
The investment costs of a shoe press in a paper machine of 5 m untrimmed width total about EUR 10 million (including the whole installation). The operational costs including felts, roll covers, roll grinding, drive energy for a shoe press are roughly identical to the costs of a conventional press. The savings of steam for paper drying are in a range between EUR 10 and EUR 15 per tonne of steam, resulting in a specific steam consumption of 2 tonnes of steam per tonne of paper and savings between EUR 20 and EUR 30 per tonne of paper.

In press rebuilds, the typical repayment period of the investment is about 2.5 years, if there are no other limits in speed increase.

Driving force for implementation
The driving forces for implementing a shoe press are manifold. Besides improved strength characteristics, cost savings can be obtained due to a reduced steam demand for paper drying at constant paper production or, alternatively, the production capacity can be increased at identical operational costs. Better dryness gives energy savings. The press section concept can be simplified. The shoe press has been a key component for further machine speed increase. In a modern high-speed paper machine, the required dryer section length is 35 % less due to one shoe press nip in the press section. Better dewatering effects enhance product quality (higher uniformity of the paper).

Example mills
Due to its superior dewatering capacity, the shoe press was first introduced for linerboard grades at the beginning of the 1980s and on paper machines about ten years later.

There have been several rebuilds and new high-speed machines around the world using the shoe press component. Since 1997 all new high-speed paper machines (LWC, SC, etc.) include shoe presses.

In the area of Testliner and Wellenstoff, in Germany the following installations are known (in alphabetical order): Papierfabrik Adolf Jass/Fulda, Papierfabrik Klingele/Weener, Papierfabrik Schoellershammer/Düren, SCA Packaging Industriepapier/Aschaffenburg, Stone Europa Carton Aktiengesellschaft, RCF DE 4, RCF DE 6.

Reference literature
[69, IFP 1998].

7.3.15.2 Use of high efficiency refiners or optimisation of existing refiners

Description

For many paper grades, pulp refining is an essential process step to achieve the required paper properties. Refining is an energy-intensive process. High efficiency refiners have a reduced 'no-load power' which is caused by motor losses, pumping and friction. The reduction of the no-load power significantly increases the electrical efficiency of the refining process: depending on the application, under unfavourable conditions, the no-load power can amount to 30 – 50 % of the refiner's energy consumption. Either by use of new high efficiency refiners or by optimising the operating mode of existing refiners, significant electrical energy savings can be achieved.

Achieved environmental benefits

Savings of power for refining due to a lower no-load power.

Environmental performance and operational data

Results in energy savings of refiners strongly depend on the raw material used, the required refining results and whether or not the refiners are completely replaced. Different applications of more efficient refiner concepts have been used in paper mills:

- In a graphic paper mill, a power saving of 110 kWh/t refined pulp compared to the formerly used cone refiners was achieved by use of optimised refiners (e.g. multi-disc or double cylinder refiners).
- For the manufacturing of speciality paper (e.g. for capacitor, decor, security papers), a high share of power consumption is spent on the refining of pulp in order to meet the product quality requirements. Substantial changes in the refining plant are often not possible or require a large investment. However, in many mills there are potential savings in improving the existing refining plants by optimisation of the feed pumps, the work load or the mode of operation. In an example mill (speciality base paper, 50 000 t/year), two refiners were operating in serial mode. The work load of both units was approximately 50 % of the installed capacity; the no-load power was approximately 40 % of the total power consumption. When increasing the refining power and the work load, the share of no-load decreases. The mode of operation was changed to a batch operation system. The savings potential amounted to 18 % of the power consumption required for the refiners. The discontinuous mode of the refiner operation led to a more frequent switching of operation.

Cross-media effects

No negative cross-media effects.

Technical considerations relevant to applicability

The applicability of high efficiency refiners depends on the raw material used and the paper or pulp properties required. They can be applied in both new and existing plants using virgin pulp.

The adjustment of the refining operation can be applied to mills in which either the refining plant is oversized or is operated in an inefficient mode. The capacity of the feed pump, refining and storage chests may need to be adapted to ensure a reliable operation.

Economics

Changing the refiner equipment means a substantial change of the process, which is associated with high investment costs. The example in Table 7.32 gives a simplified economic assessment of the use of high efficiency refiners (300 bone dry tonnes/day) for short-fibre (hardwood) refining.

Table 7.32: Cost calculation for a refiner (300 bone dry tonnes/day) for hardwood refining

Cost-relevant aspects	Energy use	Cost/savings
Mill consumption without high efficiency refiners	2 145 kWh/t	
Mill consumption with high efficiency refiners	2 100 kWh/t	
Power savings (12 %)	45 kWh/t or 9 770 MWh/year	
		EUR 488 500/year
Carbon dioxide	6 077 t/year	EUR 91 155/year
Total savings (power, prevented CO_2 emissions)		EUR 580 000/year
Investment for the high efficiency refiner		EUR 600 000
		Payback time: 1 year

NB: Assumptions for the economic assessment: cost of electricity: EUR 50/MWh (2007); CO_2 emissions (German energy mix): 622 g/kWh; carbon dioxide costs: EUR 15/t.
Source: [249, Blum et al. 2009]

Changes in the operational mode of the refiners can be carried out without investments in many cases. Depending on the individual case, it might be of economic interest to enlarge the chest capacity.

Driving force for implementation
Cost reduction by electrical energy savings. Improvements in product quality are possible.

Example plants
A few plants in Europe have installed new refiners or refiner fillings. Numerous plants in Europe (at least four in Germany) have optimised their refiner operating mode.

Reference literature
[249, Blum et al. 2007]

7.3.15.3 Steam condensate recovery and use of efficient exhaust air heat recovery systems

Description
The purpose of the heat recovery system is to utilise waste energy from the process in an economically profitable way. Nearly all the heat energy consumed in a paper mill is used for paper drying, making the dryer section easily the largest thermal energy consumer in a paper machine. Figure 7.32, originally prepared by Metso Paper Air Systems, represents heat recovery under Scandinavian winter conditions. In Central Europe, the need for heat recovery would be less because of higher air and water temperatures (see Figure 7.33). Figure 7.32 shows the main energy flows in the dryer section of a newsprint machine equipped with air-to-air and air-to-water heat recovery units. Figure 7.33 shows a Sankey diagram, where no heat is recovered for machine room heating. The values in Figure 7.32 can be converted from kW to kWh/t or to MJ/t by first dividing the kW value by the production capacity expressed in tonnes/hour, e.g. for exhaust air:

$$\frac{15530kW \times 24t/h}{980t/d} = 380\text{ kWh/t.}$$

The value in kWh/t can be converted into MJ/t: 380 kWh/t × 3.6 MJ/kWh = 1 368 MJ/t.

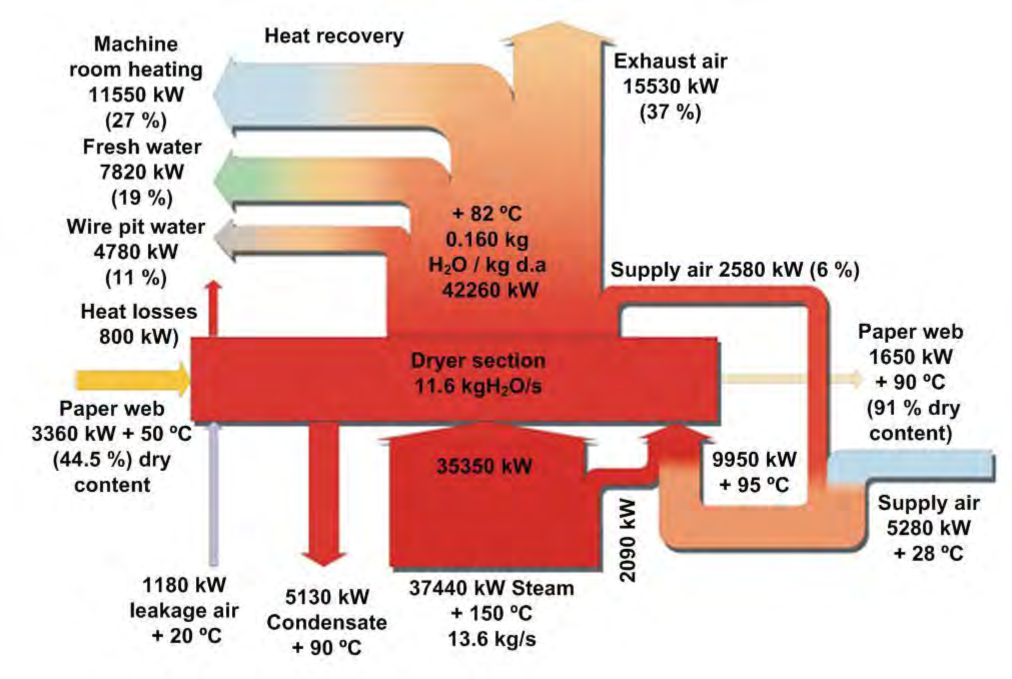
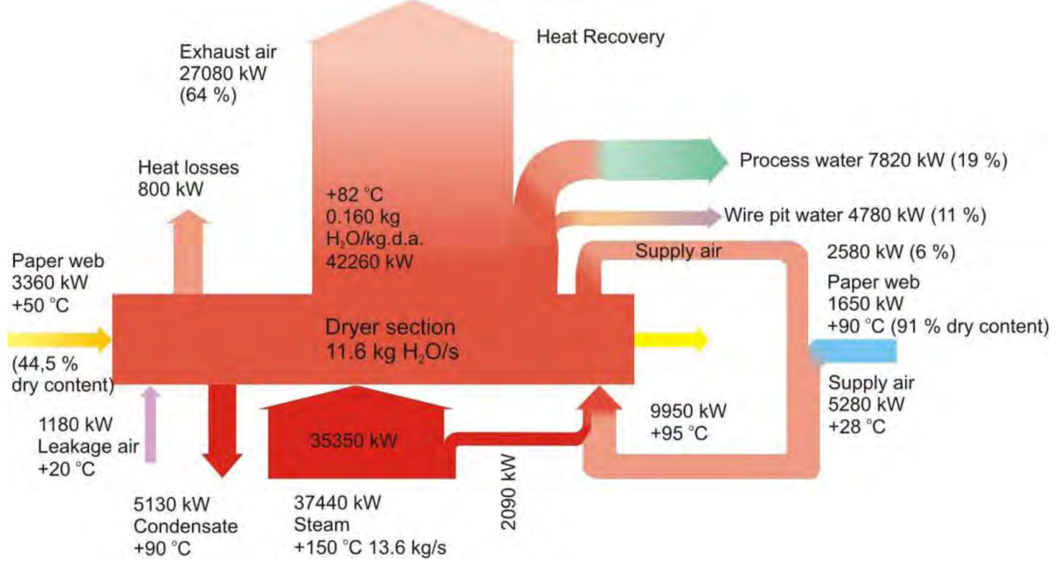


Figure 7.32: Sankey diagram for a newsprint machine (980 t/d)



Source: [CEPI Comments WD Chap 7]

Figure 7.33: Typical Sankey diagram for a paper machine in warmer regions

Roughly 80 % of the energy needed in the dryer section is brought as primary steam to the dryer cylinders, the rest coming as drying and leakage air and with the paper web. Nearly all energy leaving the dryer section is initially exhausted with the exhaust air. The normal arrangement in heat recovery is first to recover heat to the supply air of the dryer section, and then to the circulation water or fresh water (e.g. for showers). The recovered heat in the circulation water, is mainly used to heat the building ventilation air. Another major heat recovery use is for the heating of process water (e.g. for showers) and wire pit water. The heating of wire pit water does not apply to TMP mills but for instance to recycled fibre-processing mills. Supply air to the dryer section is always heated by the heat recovery system.

For heat recovery, air-to-air heat exchangers or air-to-water heat exchangers, plate heat exchangers and in some cases scrubbers for warming process water with recovered heat (see Figure 7.34) are used. The plate heat exchangers are mainly used for heating hood supply air and machine room ventilation air. The most common application for air-to-water heat exchangers is the heating of circulation water and process water. These heat exchangers are part of heat recovery towers. In Figure 7.34 an example is given for combined heat recovery where first the hood air supply and secondly the circulation water is heated.

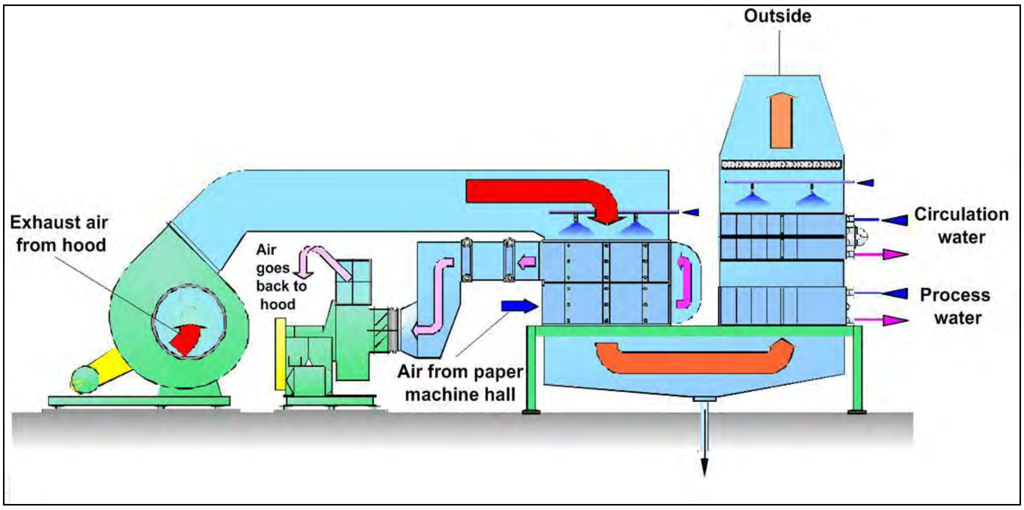


Figure 7.34: Example of a heat recovery tower

Achieved environmental benefits

Considerable amounts of primary steam are saved, which correspondingly means a lower environmental impact from steam generation. The achievements depend, among other things, on the climatic conditions.

Environmental performance and operational data

Different types of heat recovery systems are available depending on the machinery supplier. The optimum heat recovery system for the specific requirements of each paper mill has to be designed individually for each application. Usually the heat exchangers are equipped with washing devices to maintain clear surfaces and to avoid clogging.

Further possibilities for heat recovery in paper mills are listed below. Their applicability depends mainly on the fibre source, the processes used and the available heat sources that are not yet exploited.

- TMP mills: heat recovery from the TMP refiners (see Section 5.3.9).
- Integrated mechanical and thermomechanical paper mills: heat recovery from the bleaching process (exchange between the waste water from bleaching and the clear filtrate of the paper machine). The filtrate from the bleaching stage has an elevated temperature of approximately 55 – 60 °C. The heat can be recovered to heat up the clarified white water from the paper machine. This may replace direct steam for the heating of white water. This can in principle also be applied at RCF mills with deinking and bleaching [249, Blum et al. 2007]
- Most grades: preheating of shower water with an appropriate waste heat source. For example, heat from the steam condenser, non-used waste heat from the dryer of the paper machine or (for coated paper grades) the exhaust air from the coater hood can be recovered with heat exchangers and used for this purpose.
- Tissue mills: the exhaust air of the Yankee hood can be cooled down when coming into direct contact with clear filtrate for the papermaking process that needs to be heated up. For instance in a trickling tower, the hot exhaust air from the Yankee hood can be directed into the counter-current flow with clear filtrate to be heated up. Savings of steam for the heating of white water can be achieved [249, Blum et al. 2007].

Energy integration studies quite often identify a number of additional heat sources that can be utilised, but do not provide information on suitable heat consumers. In principle, upgrading the value of heat flow (with heat pumps or thermo-compressors, see Section 2.9.6.1.2) may improve the heat recovery so that the heat may be used, e.g. to dry wet fuels or sludge and increase the energy output of combustion (see Section 2.9.6.1.4).

Cross-media effects
No cross-media effects. Energy-saving measures are preferably based on accurate energy balances of the whole mill including energy flow diagrams and alternative process options. There is a strong link between water and energy systems.

Technical considerations relevant to applicability
Heat recovery can be applied at both new and existing plants. Heat exchangers for heating hood supply air are always applicable. Whether heat recovery for heating of circulation water (for heating of the machine hall) or process water can be applied depends on the specific characteristics of production and climatic conditions. Because of the interaction between system units, optimised heat recovery can only be achieved by analysing the entire heat system of the mill.

Economics
Heat recovery systems usually have short payback times. It is not always economical to recover as much heat as possible and depends also on the energy price. The specific situation of the paper mill always needs to be analysed.

Driving force for implementation
Energy savings, reduced droplet and mist formation.

Example plants
Numerous plants in Europe.

Reference literature
[249, Blum et al. 2007].

7.3.16 Measures for noise reduction

See also Section 2.9.13.

Description
In a papermaking line, there are many noise sources (see Section 7.2.2.8). Therefore, many mills carry out noise emission monitoring and some also apply noise modelling in order to predict annoyances due to noise in the vicinity of the mill. The main noise sources, such as pressurised exhausts, exhaust fans and vacuum pump exhausts, can be equipped with absorptive or reactive silencers. Sound insulation enclosures (hoods) for the exhaust fans on the building roof are another effective noise attenuation measure.

In the planning and operation of installations, measures necessary for noise prevention must already be taken into account during the planning phase. When implementing noise reduction measures, the following technical aspects should be considered:

- obtaining information at an early stage about noise emissions of machinery, installations and parts thereof;
- use of low noise machines and processes (noise reduction at the source);
- reducing noise generation and transmission;
- reducing sound emission, e.g. by use of sound absorbers, pipe resonators or a combination of both;
- sound insulation enclosures for noisy equipment;

- maintenance of machinery and soundproofing equipment.

The starting point for noise abatement is the authorities' requirements depending on the mill location (distance to the neighbourhood, recreational or industrial area, etc.). The immission (reference) points can be located at the mill border and/or in several locations in the residential area.

Achieved environmental benefits
Reduction of noise emission and annoyance.

Cross-media-effects
Silencers may increase the pressure loss of exhaust air which leads to a slight increase of power consumption (kWh/t) from fans, but the additional power consumption is not significant.

Environmental performance and operational data
Silencers for external sound level attenuation have been successfully used in many mills in Europe. Maintenance consisting of regularly cleaning and changing absorption material (when needed) is required when the exhaust air contains moisture and particles.

Example 1: Installation of absorptive silencers (French paper mill)

In this case, the equivalent A-weighted sound pressure level targets in the parts of the village bordering the paper mill are 65 dB(A) during the day and 55 dB(A) at night. Measurements of the noise sources showed that the contribution of the closed hood exhaust air fans was among the biggest. Calculations showed that attenuation of these by 15 dB(A) would be enough to reach the target level at night of 55 dB(A) at the reference points.

Fan noise can be characterised as broad band noise and thus absorptive silencers are suitable in this case. Absorptive silencers are efficient at middle and higher frequencies. The fans are located outside and therefore they also need sound insulation. Figure 7.35 shows the noise levels measured before and after the silencer installation at one immission point (sound insulation included).

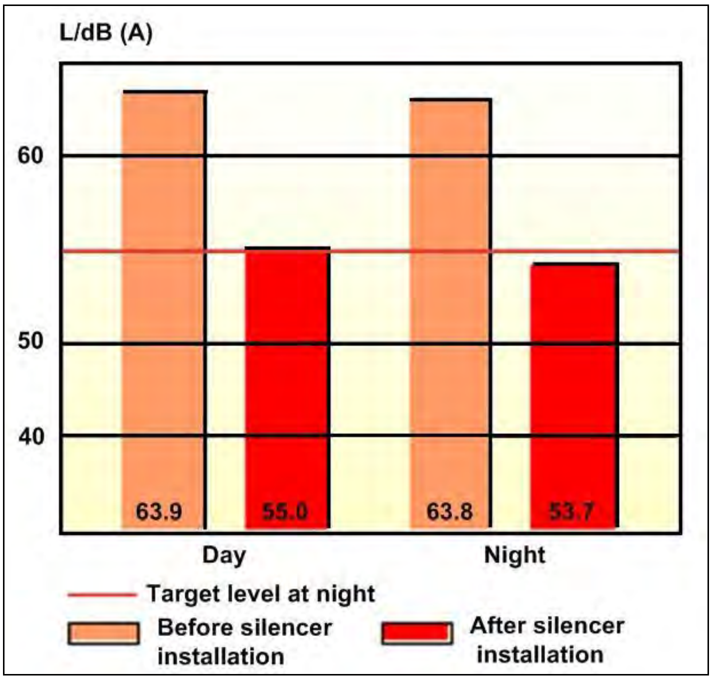


Figure 7.35: **Sound levels (LAeq) at one reference point 'before and after silencer installation**

Example 2: Installation of reactive silencers (German paper mill)

In this case, the noise emission from vacuum pumps of a paper machine caused too much noise at the reference point outside the mill area. Measurements of sound pressure levels at a distance of one metre from the vacuum pump outlet revealed a noise peak at a frequency of 160 Hz, as shown in Figure 7.36. This peak was over 10 dB(A) higher than any other frequency. Reactive silencers (e.g. pipe resonators) are efficient for lower frequencies (below 500 Hz) and were installed in this case. Measurements after installation of the silencers showed that the peak noise level was effectively reduced by about 28 dB(A) and the target value at the immission point, 26.9 dB(A), was reached.

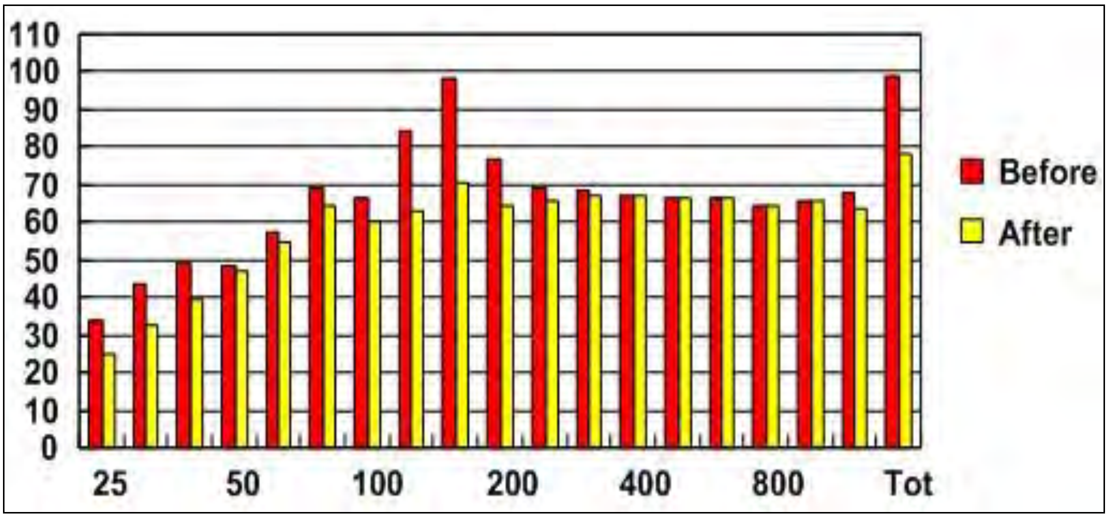


Figure 7.36: **Pipe resonator attenuation: noise levels before and after silencer installation**

When the target level one metre from the outlet of fans or vacuum pumps is lower, a combination of reactive and absorptive silencers is required. Also, special sound insulation enclosures are needed for fans located outside.

Example 3: Overall noise control of paper machine lines (German & Swedish paper mills)

The immission (reference) point targets in the mill surroundings resulted in guaranteed values for the sound pressure level at a distance of one metre from each external noise source of L_{pA} (1 m) = 70 dB(A). All paper machine supplied in Europe today include a large number of silencers. A modern SC magazine paper mill in Sweden and an uncoated publication paper mill in Germany have the same sound pressure level requirements as those mentioned above.

The number of pieces of sound attenuation equipment dedicated to external noise control in these cases is 60 – 70 pieces per line, similar to those shown in Figure 7.37.

Figure 7.37: Silencers on the paper mill roof

For wet-end process ventilation, absorptive labyrinth baffle-type silencers are installed to obtain efficient broad band attenuation. For other process ventilation, efficient baffle-type silencers are installed. It is very important that the silencers have doors to allow access for cleaning and baffle change on site. For turbo blower exhausts, with a sound pressure level of L_{pA}(1 m) = 135 dB(A), a lot of attenuation is needed in order to reach the level L_{pA}(1 m) = 70 dB(A). For this, a combination of absorptive baffle silencers and reactive multi-port pipe resonators are needed.

Example 4: Vacuum pump sound attenuation (Swedish paper mill)

For vacuum pumps that have low frequency noise peaks, a combination of absorptive and reactive silencers is required. In the case of a newsprint paper mill in Sweden, the guarantee value was a sound pressure level of $L_{pA}(1\,m)$ = 75 dB(A) at one metre from the discharge. Additionally there was a guarantee for the noise peak at 100 Hz of $L_p(1\,m)$ = 103 dB(A). The guarantee was $L_p(1m)$ = 79 dB(A), without A-weighting. Based on field measurements, a reactive silencer for the 100 Hz frequency and a baffle-type silencer for the whole frequency range were dimensioned. Figure 7.38 shows the measured sound pressure levels before and after the installation. A significant reduction at 100 Hz was achieved.

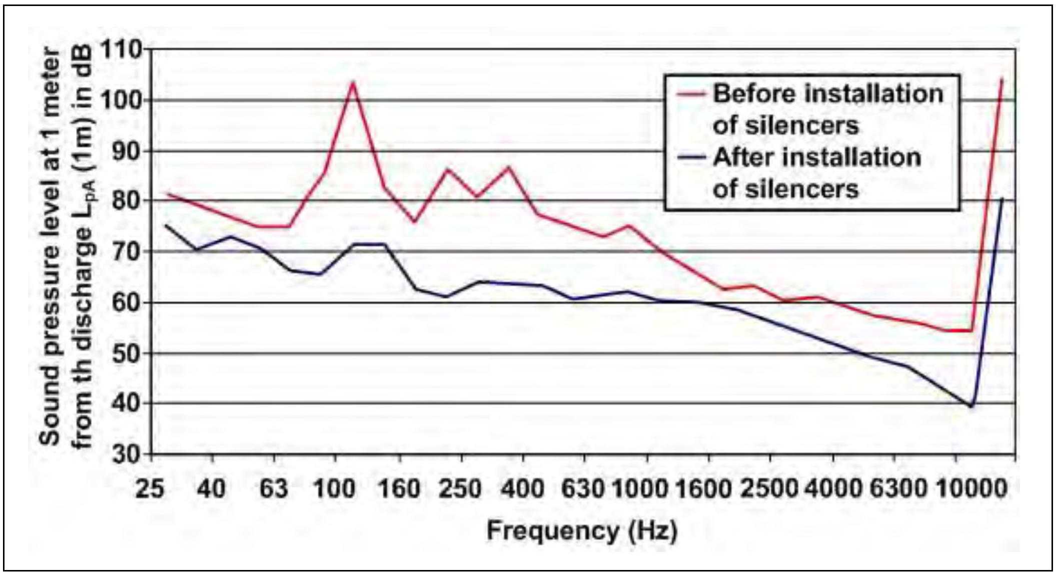


Figure 7.38: Attenuation of vacuum pump noise by installation of silencers

Technical considerations relevant to applicability

External noise attenuation measures can be applied in both new and existing mills. It is mainly the procedure to determine the current and targeted noise levels that makes the difference.

In cases of existing machines, the attenuation procedure starts with noise measurements at the immission (reference) points in the residential area. Measurements will continue in the mill in order to find the most critical noise sources. Silencer dimensioning is an interaction of measurements and calculations.

In new installations the sound power levels are based on the machine supplier's sound power level data (ISO 3740 to ISO 3747 for machines or ISO 8297 for industrial installations). Calculations of predicted noise levels at immission points at a defined distance are carried out using computer programs for noise propagation, e.g. according to DIN ISO 9613-2:1999, evaluating the contribution of all relevant noise sources. Limitations of space and existing layout might limit the applicability or lead to somewhat different solutions.

Economics

It is very difficult to give accurate figures on the cost of sound attenuation because the costs depend on the size of the mill, the paper grade produced, the speed of the paper machine, etc. Total sound attenuation costs (external and internal) of a papermaking line are estimated to be in the range of 0.5 % of the investment costs of the machinery, or even higher depending on the target noise levels.

External sound attenuation costs of a paper machine are in the order of EUR 0.2 – 0.4 million depending on the target level and the delivery scope.

Figure 7.39 shows the relative costs of external sound attenuation. When the sound pressure level target is decreased from 85 dB(A) to 75 dB(A), the costs are doubled.

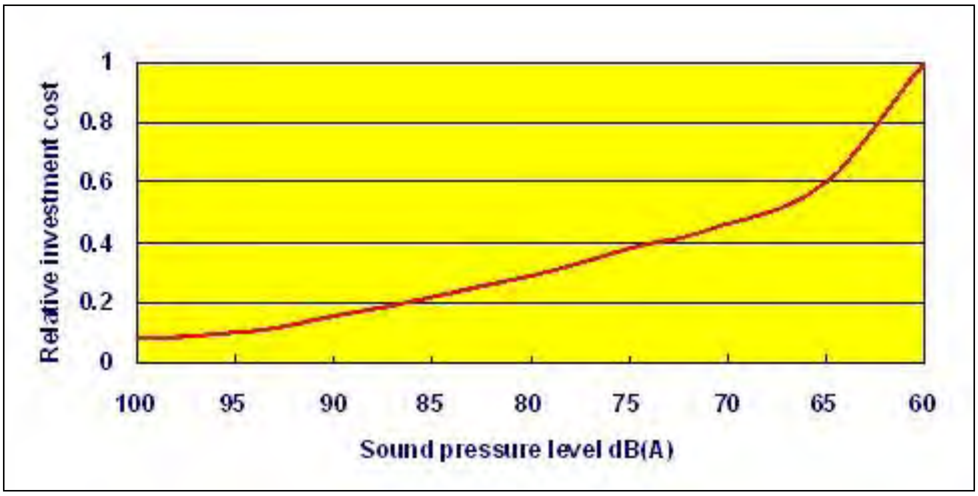


Figure 7.39: **Relative costs of external sound attenuation**

Driving force for implementation

The noise control requirements mostly originate from authority requirements at the immission (reference) points in the communities or at the mill borders. For the machinery suppliers, the guarantees are sound levels at the immission (reference) points, or sound power or sound pressure levels at the noise sources.

Official requirements in different countries together with EU directives have led to increased demands for noise prevention at the machine design stage. But they have also set noise standards for existing equipment and external noise control. Depending on the type of area affected by noise from paper mills, defined noise levels have to be achieved to avoid a harmful noise impact in the neighbourhood.

Example plants

General measures for noise attenuation are implemented in numerous plants in Europe. Different types, design and amounts of silencers are used in most European mills.

7.4 Emerging techniques

In this section, some promising techniques are addressed that cannot (yet) be considered BAT due to the stage of development of these techniques. Nevertheless, in due time, they may qualify as BAT and therefore they are described briefly here. It should be noted that the description of promising techniques in this chapter is not intended to give a complete overview of all relevant developments. The development of papermaking technologies is guided by reduced profitability. Higher input costs and reducing selling prices call for next-generation approaches that respond to the increasing competition from electronic media and plastics, and societal concerns over climate change, water and energy availability and sustainability.

Introduction

Recent developments and anticipated technology show that the paper mill of the future can probably be described by the following characteristics:

- improved energy efficiency;
- reduced environmental impacts (emissions to air, water and soil, odour and noise);
- novel fibre properties;
- high-consistency processing;
- advanced control methods;
- new added value product concepts.

Novel more efficient technologies may be developed throughout the whole papermaking line. Examples of topics under research and development are outlined in Table 7.33.

Table 7.33: Emerging techniques of papermaking production lines

Process	Energy efficiency improvement	Reduced water consumption	Added value
Pulping processes			
🟨 New mechanical pulping	+++	0	+
🟨 Processing paper for recycling for quality improvement	+	0	++
🟩 Efficient pulp washing technology	+	+++	++
🟩 Enzymes (e.g. use of sterease to reduce the size and tackiness of stickies)/biochemicals	++	+	++
Stock preparation			
🟨 Fractionation methods to add value	+	0	++
🟨 Internal water treatment	-	+++	++
🟩 Fibre modification methods	+	0	+++
🟩 Higher consistency processing	+	++	0
Papermaking			
🟨 New web-forming techniques	++	++	+
🟨 Simplified shoe press concept	+	+	++
🟨 Impingement drying	-	0	++
🟨 Use of cooling water as process water	++	+++	0
▨ Increased water recycling/control methods	-	++	+
▨ Simplified runnability systems	+	0	0
▨ Multilayer forming technologies	++	-	++
🟩 HC forming technologies	++	++	++
Finishing			
🟨 Curtain coating	+	0	++
🟨 Spray coating	+	0	++
🟨 Metal belt calender	+	0	++
▨ High solid sizer	+	+	++
🟩 Powder coating	++	+	++
Miscellaneous			
🟨 Direct drive systems	++	0	0
🟨 More precise dimensioning	++	+	0
▨ Heat recovery with heat pumps	++	0	0
▨ Forward-looking control methods	++	++	++
🟩 Low friction materials	++	+	0
🟩 New vacuum system	+++	+	0

Source: M.Karlsson, UPM, 2010

Legend:
+++ = large positive effect; ++ = medium positive effect; + = positive effect;
0 = no effect; - = negative effect

🟨 **Short term**	▨ **Medium term**	🟩 **Long term**

Special emphasis will be placed on delivering improved energy efficiency, reduced environmental impacts and new product features. However, these technologies will not be considered alone, but they will be affected by the development of various biorefinery concepts. There will be increased interest in various processes aiming at the production of transportation fuels and chemicals from biomass. In the future, mills will become multiproduct mills (see Section 2.1).

Dynamic simulation and total site integration tools will provide new help in complex optimising tasks to manage the entire paper mill process. Automation and 'intelligence' in paper machines will increase rapidly and become embedded in the paper machine. Sensors for instance will predict paper properties with the help of a few appropriate measurements and this will enable fast and efficient control of the process, e.g. in grade change situations. New measuring methods are needed to manage fast processes. Besides consistency and flow measurements, on-line chemistry monitoring systems will also become tools for process optimisation.

The cost of investing in new, more complex techniques is a significant factor in paper mills' profitability and favours larger units. Increasing effectiveness and decreasing emissions go hand in hand. The complexity of water treatment techniques will tend to increase. To implement these techniques and maintain them properly is a challenge for smaller mills.

In the following sections, some of the emerging techniques for the reduction of raw material use and emissions are discussed. These techniques are still under development. Some are currently researched with a promising perspective for future applications, others already run in a few full-scale applications.

The information given includes a short description of the technique, an assessment of the status of development, the environmental benefits and cross-media effects, economic considerations, if data are already available, and a reference.

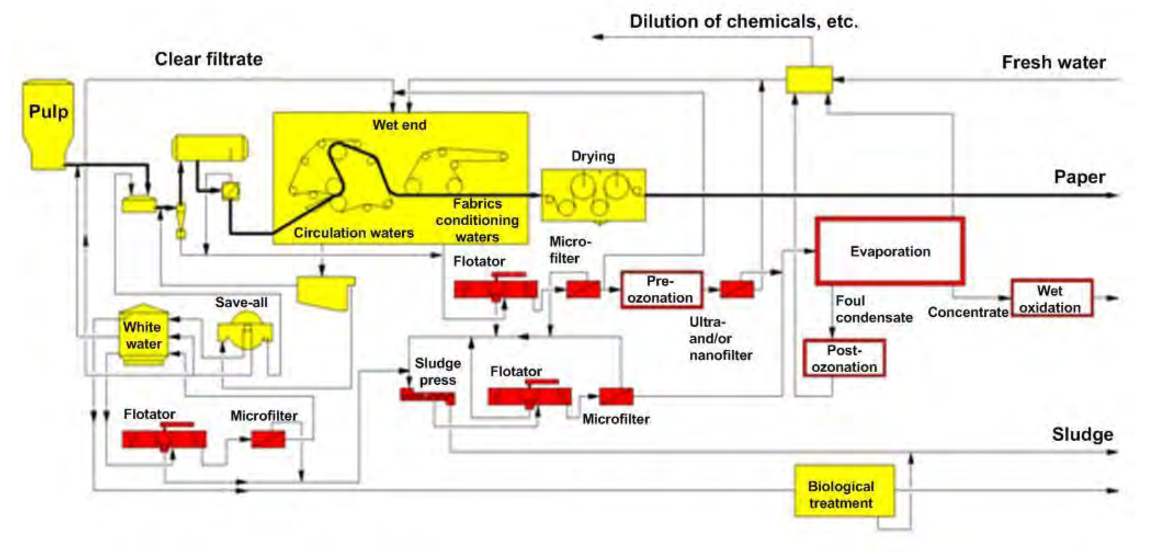
7.4.1 Minimum effluent paper mills - optimised design of water loops and advanced waste water treatment techniques

Description

Advanced waste water treatment in the pulp and paper industry is mainly focused on additional biological membrane reactors, membrane filtration techniques such as micro-, ultra- or nano-filtration, ozone treatment and evaporation. Due to the relative lack of full-scale experience, the sometimes relatively high costs and the increased complexity of the water treatment, there are only currently a few full-scale applications of tertiary treatment of waste water mill effluent.

However, these techniques have the potential to be applied especially as in-line treatment, as 'kidneys' to eliminate those substances that negatively interfere with the efficiency of paper production or paper quality.

An example of possible internal treatment and reuse of paper machine water including membrane filtration, ozonation and evaporation is shown in Figure 7.40.



Source: [26, Edelmann et al. 1997]

Figure 7.40: Example of possible internal treatment and reuse of paper machine waters

Status of development

Full-scale experiences with these techniques in paper mills are limited to a few examples in the world. Depending on the technique applied, there are still operational problems and relatively high costs. Lately, more mill-scale experiences have been gathered from ultrafiltration techniques. UF of clean filtrates effectively eliminates suspended solids, bacteria and lipophilic extractives, so that the resulting permeate can be used to replace fresh water in the dosing of chemicals and in paper machine showers. In a mechanical pulping mill application, ultrafiltration has been reported to result in lower bleaching and wet-end chemical consumption and better machine runnability and paper quality [143, T.Sutela et al. 2006].

However, when building new mills or upgrading and increasing the capacity of existing mills, these techniques can be seriously considered. These techniques for water reclamation can also be used to reduce the fresh water consumption in existing mills without completely closing the water system. It is expected that these techniques will have further applications in the paper industry in the near future. There is a trend to shift from end-of-pipe treatment to the in-line treatment of partial streams of the process water. It can be expected that the pioneers using these techniques are located at recipients which face very strict requirements or where the water body does not allow any increase in the pollutant load. If mills wish to increase capacity, they have to apply one or several of the aforementioned techniques.

The status of water treatment techniques in the paper industry can be summarised as follows.

- Save-all filters (common technique). The output of super clear filtrate for reuse can be increased, e.g. by use of microfilters.
- Flotation (industrially proven).
- Washing presses (industrially proven).
- Reject and sludge dewatering technique (industrially proven).
- Biological in-line treatment (first industrial applications realised) with the (partial) recirculation of treated process water; in some cases combined with a decarbonisation unit.
- Pre-filtration + membrane filtration (UF, NF) (first industrial applications realised).
- Pre-filtration + evaporation (first industrial applications realised). If fresh water is replaced with evaporated water, there are probably no effects on chemistry or on papermaking.
- Ozonation (at least three industrial applications implemented in Europe). If fresh water is replaced with partially purified water, there is the potential for build-ups of disturbing

substances. For example, the inorganic salts are not affected and they can interact with process chemicals and equipment. These potential effects have to be controlled and the knowledge of the water quality needed has to be increased.

- Enzymatic treatment of process water (in research phase).

Environmental implications
The objective of advanced waste/process water treatment techniques is usually to further remove pollutants that are not removed by common biological treatment such as use of activated sludge plants. These pollutants are residual COD, colour, nutrients or suspended solids. Advanced water treatment processes produce a high water quality. As a consequence, there is a better chance of reusing the 'effluent' in the process as fresh water. Thus, advanced waste water treatment can contribute to further water system closure. However, it can also be applied to achieve lower discharge loads to the receiving water body.

Very often it is a significant increase in the capacity of mills that gives the incentive to look for new technical solutions with less pollution. Some authorities in Europe require that the amount of effluent and waste of mills seeking to increase capacity will not exceed the level before the investment. This means that new ways have to be found to decrease the fresh water usage and to minimise the amount of solid waste.

Economic considerations
No data available.

Literature
[26, Edelmann et al. 1997], [143, T.Sutela et al. 2006].

7.4.2 High-consistency papermaking (lean water processing)

Description
In the state-of-the-art papermaking process, paper products are formed from a low consistent water suspension (approximately 0.6 – 1.0 %) made up of fibres, fillers and chemicals. This suspension is pumped through a headbox that spreads it on a plastic wire. With the complex design of the headbox, sufficient turbulent flow conditions are created to control the homogeneity of the papermaking suspension through the subsequent drainage process. Due to the low consistency, chemicals have to be used to increase the retention of furnish components on paper. The recovery of unretained material and water consumes a lot of energy and requires numerous unit operations and pieces of process equipment.

Thus increasing consistency would be a technological step forward for papermaking. It is expected that the HC short circulation process will consume 50 % less energy and 30 % less vacuum energy, and that the capital intensity of the process will be reduced by 30 %. Due to improved retention, the consumption of chemicals and the environmental load of the process will also be reduced.

Status of development
Increasing the consistency in forming was initially studied in the 1980s, e.g. in Finland, but with little success. The early studies resulted in an unacceptable sheet quality due to the difficulties in maintaining sufficient turbulence during web drainage. However, during recent years, substantial progress has been achieved through the integration of the headbox and drainage (see Figure 7.41). The operation window of current machines can most likely be widened by optimising the whole process, e.g. raw materials, machinery, clothing and chemicals. This can however lead to difficulties in the dewatering or runnability of the paper machine. In recent studies, the control of fluidisation and the screening of high-consistency stock, together with product quality, have been found to be the major difficulties to overcome.

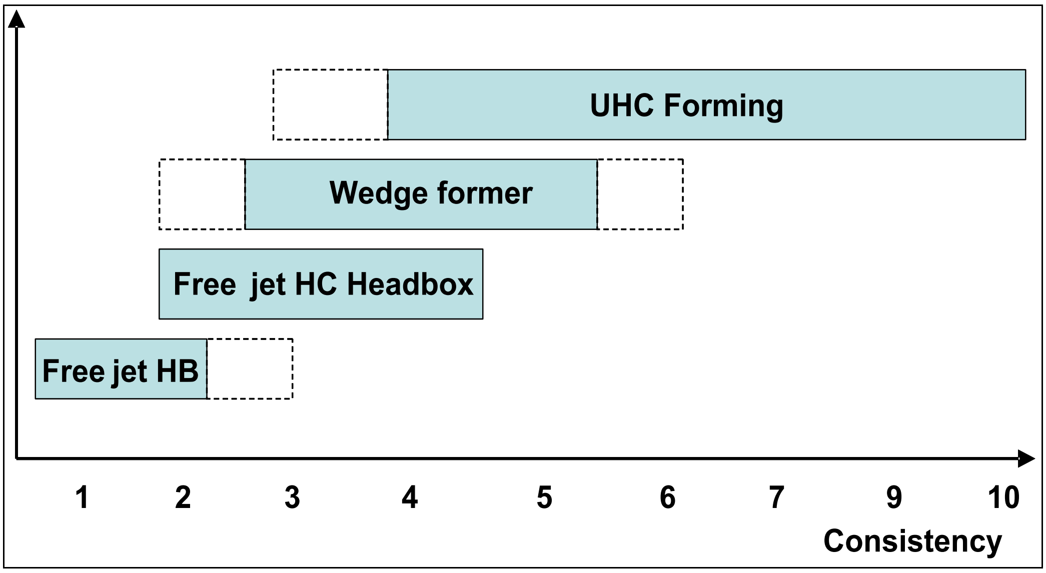


Figure 7.41: **Typical headbox consistency used in earlier HC forming studies**

A breakthrough in HC papermaking would require new technology where current unit operations, i.e. headbox, drainage and pressing, are integrated together in a compact way, resulting in the desired paper structures from a high-consistency furnish. According to the results of recent studies, HC papermaking may be regarded as feasible following further development.

The HC papermaking process would require that the approach and short circulation systems, fluidisation and dewatering processes take place at high consistency. Progress is needed in the mixing of fibres and chemicals and in screening, air removal, fluidisation, dewatering of furnish, and in process control. The development of a reliable measurement system for the process including web properties is one of the key tasks for process control.

Modelling is needed for dimensioning the process and for analysing and determining the optimal process concept. The stability of the process is one of the major concerns. With regard to raw material control, soft sensors and new measurement techniques will make it possible to identify incoming material properties, and thus make it possible to take the optimisation and control further in an adequate way. Overall dynamic energy system analysis using simulation and optimisation will provide solutions that reduce energy losses compared to what is achievable with state-of-the-art steady state analysis, e.g. the pinch method. By orchestrating the production entities dynamically, the intermediate buffers can be radically reduced. This leads to major energy savings in production systems, e.g. due to less pumping, and both energy and capital savings in new and rebuilt production systems.

Environmental implications

Fresh water is introduced to the HC process as shower water and as dilution water for the chemicals just like in modern processes. To minimise the use of fresh water, the output streams from screening and fibre recovery should be low in volume and the combination of former and fibre recovery units should result in high-quality circulation water that has a very low concentration of solids and dissolved and colloidal (DisCo) substances.

It is expected that the high-consistency forming of paper products will require new innovative process solutions that will significantly reduce the energy and water consumption in papermaking processes. HC papermaking will reduce pumping costs, increase the retention of fibres with fewer chemicals, and simplify the wet-end process. Together with closed water circulation and higher process temperature, high-consistency forming may lead to the production line's energy consumption being dramatically reduced.

Economic considerations

The HC system creates a new platform for the production of many different paper and board products which will form a paradigm shift in paper production. Pilot-scale studies aimed at HC papermaking are under way.

Modelling and simulation tools will be an integral part of the development work both at the unit process level and in analysing how mill concepts will be changed as a result of HC forming. New measurement techniques will be used in the development of models and control methods for the forming process. HC forming will give a strong advantage to the European pulp and paper industries as such a system can reduce not only energy but also the use of chemical additives. HC forming integrates well with closed water circulation and with new heat recovery techniques, and surface treatment methods. Furthermore, new types of products can be manufactured [CEPI Comments D1].

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2. Maleshenko, A., Ilmoniemi, E., Kaasalainen, H. Web-forming Unit of a Paper or Board Machine. WO 2006120294 (A1), 2008.
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7.4.3 Heat recovery with heat pumps

Description

Heat pumps are used for pumping heat from one medium (e.g. air) to another (e.g. water). Figure 7.42 shows an example application for a paper machine. The heat source consists of moist air from a paper machine.

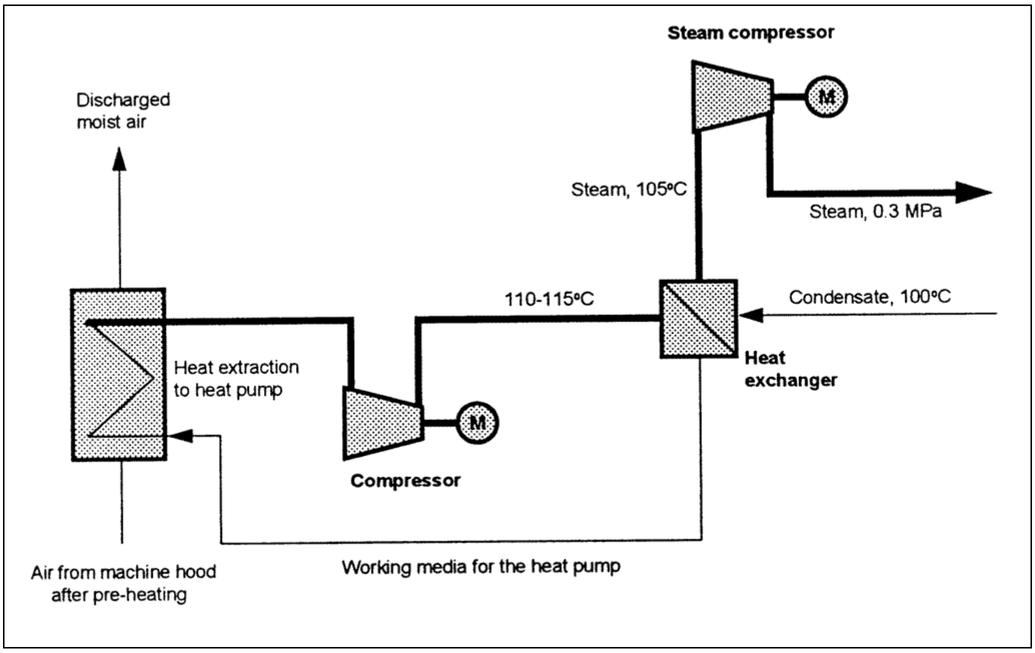

Figure 7.42: System with a heat pump for generating process steam

Status of development

There are many applications in the pulp and paper industry for heat pumps, but the investment costs are quite high which has hampered the use of this kind of equipment. Furthermore, the environmental problems that are associated with the conventional working media have made the use of heat pumps even more difficult despite the thermodynamics of the heat pump being very advantageous.

Environmental implications
As an example, the discharged moist air may hold a temperature of 105 °C with a dew point of 61 °C. In such a case, a heat pump may produce heat corresponding to 750 kWh/t or 2.7 GJ/t by means of only 1/3 or 250 kWh/t of power to the compressor motors. This is based on a coefficient of performance of 3, which is quite normal.

Economic considerations
The potential of this technique is large but the number of actual installations in the pulp and paper industry is small due to the investment cost, as well as the mentioned difficulties regarding suitable working media. Since this is a conventional technique, a breakthrough requires the discovery or development of new suitable media, and also more cost-effective equipment, especially on the compressor side.

Literature
[SEPA-Report 4713-2.1997]

7.4.4 Total site integration tools

Description
Because of the complexity of the papermaking process, technological development in the sector has been realised through step-by-step actions. The complexity of the process can be illustrated by taking the use of water as an example. The increased recycling of water will lead to a different process chemistry, lower utilisation of secondary heat, different water management practices, new reject streams, changes in the operation of effluent treatment, increased consumption of electricity and reduced consumption of heat. Meanwhile, energy consumption is also affected by the production speed of the machine and by unit operation development of the paper machine. The technological choices will have effects on the energy balance of a mill. It can be concluded that intelligent process solutions in the future will try to combine the whole energy – water – fibre – chemicals – system to bring about the good integration of the mill.

Status of development
Several computer-based tools capable of analysing the complex system, including the cross-media effects described below (items 1 to 9), are under development and the first analytical studies have been carried out with integrated paper mills. However, it has to be pointed out that total site integration tools do not fully eliminate the need for pilot plant studies.

Environmental implications
The key issue is how to come up with processes and mill concepts capable of lowering emissions to air and water and at the same time reduce the formation of solid waste and energy. The requirements for the new process are better paper quality and runnability, and better process management. This calls for more knowledge on the behaviour of the processes. Also, the changes to the process caused by the adoption of new techniques have to be identified so that compatible process technology can be developed.

Consequently, it is clear that new optimisation tools can support the development of future papermaking processes. Some computer-based tools contain the following items or functions:

1. information on contaminant concentrations in the different parts of the process;
2. behaviour models for the contaminants;
3. process parameters for separation and treatment methods;
4. methods to optimise water treatment concepts with respect to contaminant concentrations and behaviour;

5. identification of heat sinks and sources;
6. methods to optimise the use of heat through careful process integration;
7. information on the emissions from the new mill concept to air and recipient and formation of solid wastes;
8. detailed process design based on the choices made;
9. methods to analyse and to develop the operational runnability of the process.

Economic considerations

No data available. The total site integration tool software is not a big investment, but it does require that skilled people spend many man-hours to adapt the software to the given characteristics of a mill.

Literature

[27, Edelmann et al. 1999].

8 BEST AVAILABLE TECHNIQUES (BAT) CONCLUSIONS

Scope

These BAT conclusions concern the activities specified in Sections 6.1 (a) and 6.1 (b) of Annex I to Directive 2010/75/EU, i.e. the integrated and non-integrated production in industrial installations of:

(a) pulp from timber or other fibrous materials;
(b) paper or cardboard with a production capacity exceeding 20 tonnes per day,

In particular, these BAT conclusions cover the following processes and activities:

(i) chemical pulping:
    (a) kraft (sulphate) pulping process
    (b) sulphite pulping process
(ii) mechanical and chemimechanical pulping
(iii) processing paper for recycling with and without deinking
(iv) papermaking and related processes
(v) all recovery boilers and lime kilns operated in pulp and paper mills.

These BAT conclusions do not address the following activities:

(i) production of pulp from non-wood fibrous raw material (e.g. yearly plant pulp);
(ii) stationary internal combustion engines;
(iii) combustion plants for steam and power generation other than recovery boilers;
(iv) dryers with internal burners for paper machines and coaters.

Other reference documents which are relevant for the sector covered by these BAT conclusions are the following:

Reference documents	Activity
Industrial Cooling Systems (ICS)	Industrial cooling systems, e.g. cooling towers, plate heat exchangers
Economics and Cross-Media Effects (ECM)	Economics and cross-media effects of techniques
Emissions from Storage (EFS)	Emissions from tanks, pipework and stored chemicals
Energy Efficiency (ENE)	General energy efficiency
Large Combustion Plants (LCP)	Generation of steam and electricity in pulp and paper mills by combustion plants
General Principles of Monitoring (MON)	Emissions monitoring
Waste Incineration (WI)	On-site incineration and co-incineration of waste
Waste Treatments Industries (WT)	Preparation of waste as fuels

General considerations

The techniques listed and described in these BAT conclusions are neither prescriptive nor exhaustive. Other techniques may be used that ensure at least an equivalent level of environmental protection.

Unless otherwise stated, the BAT conclusions are generally applicable.

Emission levels associated with BAT

Where emission levels associated with the best available techniques (BAT-AELs) are given for the same averaging period in different units (e.g. as concentration and specific load values (that is per tonne of net production)), those different ways of expressing BAT-AELs are to be seen as equivalent alternatives.

For integrated and multi-product pulp and paper mills, the BAT-AELs defined for the individual processes (pulping, papermaking) and/or products need to be combined according to a mixing rule based on their additive shares of discharge.

Averaging periods for emissions to water

Unless stated otherwise, the averaging periods associated with the BAT-AELs are defined as follows.

Daily average	Average over a sampling period of 24 hours taken as a flow-proportional composite sample (1) or, provided that sufficient flow stability is demonstrated, from a time-proportional sample (1)
Yearly average	Average of all daily averages taken within a year, weighted according to the daily production, and expressed as mass of emitted substances per unit of mass of products/materials generated or processed
(1) In special cases, there may be a need to apply a different sampling procedure (e.g. grab sampling)	

Reference conditions for air emissions

The BAT-AELs for emissions to air refer to standard conditions: dry gas, temperature of 273.15 K, and pressure of 101.3 kPa. Where BAT-AELs are given as concentration values, the reference O_2 level (% by volume) is indicated.

Conversion to reference oxygen concentration

The formula for calculating the emissions concentration at a reference oxygen level is shown below.

$$\boxed{E_R = \frac{21 - O_R}{21 - O_M} \times E_M}$$

where:

E_R (mg/Nm^3): emissions concentration referred to the reference oxygen level O_R

O_R (vol %): reference oxygen level

E_M (mg/Nm^3): measured emissions concentration referred to the measured oxygen level O_M

O_M (vol %): measured oxygen level.

Averaging periods for emissions to air

Unless stated otherwise, the averaging periods associated with the BAT-AELs for emissions to air are defined as follows.

Daily average	Average over a period of 24 hours based on valid hourly averages measured by continuous measurement.
Average over the sampling period	Average value of three consecutive measurements of at least 30 minutes each.
Yearly average	In the case of continuous measurement: average of all valid hourly averages. In the case of periodic measurements: average of all 'averages over the sampling period' obtained during one year.

Definitions

For the purpose of these BAT conclusions, the following definitions apply:

Term used	Definition
New plant	A plant first permitted on the site of the installation following the publication of these BAT conclusions or a complete replacement of a plant on the existing foundations of the installation following the publication of these BAT conclusions.
Existing plant	A plant which is not a new plant.
Major refurbishment	A major change in design or technology of a plant/abatement system and with major adjustments or replacements of the process units and associated equipment.
New dust abatement system	A dust abatement system first operated on the site of the installation following the publication of these BAT conclusions.
Existing dust abatement system	A dust abatement system which is not a new dust abatement system.
Non-condensable odorous gases (NCG)	Non-condensable odorous gases, referring to malodorous gases of kraft pulping.
Concentrated non-condensable odorous gases (CNCG)	Concentrated non-condensable odorous gases (or 'strong odorous gases'): TRS-containing gases from cooking, evaporation and from stripping of condensates.
Strong odorous gases	Concentrated non-condensable odorous gases (CNCG).
Weak odorous gases	Diluted non-condensable odorous gases: TRS-containing gases which are not strong odorous gases (e.g. gases coming from tanks, washing filters, chip bins, lime mud filters, drying machines).
Residual weak gases	Weak gases that are emitted in ways other than through a recovery boiler, a lime kiln or a TRS-burner.
Continuous measurement	Measurements using an automated measuring system (AMS) permanently installed on site.
Periodic measurement	Determination of a measurand (particular quantity subject to measurement) at specified time intervals using manual or automated methods.
Diffuse emissions	Emissions arising from a direct (non-channelled) contact of volatile substances or dust with the environment under normal operating conditions.
Integrated production	Both pulp and paper/board are produced at the same site. The pulp is normally not dried before paper/board manufacture.

Term used	Definition
Non-integrated production	Either (a) production of market pulp (for sale) in mills that do not operate paper machines, or (b) production of paper/board using only pulp produced in other plants (market pulp).
Net production	(i) For paper mills: the unpacked, saleable production after the last slitter winder, i.e. before converting. (ii) For off-line coaters: production after coating. (iii) For tissue mills: saleable production after the tissue machine before any rewinding processes and excluding any core. (iv) For market pulp mills: production after packing (ADt). (v) For integrated mills: Net pulp, production refers to the production after packing (ADt) plus the pulp transferred to the paper mill (pulp calculated at 90 % dryness, i.e. air dry). Net paper production: same as (i).
Speciality paper mill	A mill producing numerous paper and board grades for special purposes (industrial and/or non-industrial) that are characterised by particular properties, relatively small end use market or niche applications that are often especially designed for a particular customer or end-user group. Examples of speciality papers include cigarette papers, filter papers, metallised paper, thermal paper, self-copy paper, sticking labels, cast coated paper, as well as gypsum liners and special papers for waxing, insulating, roofing, asphalting, and other specific applications or treatments. All of these grades fall outside of the standard paper categories.
Hardwood	Group of wood species including e.g. aspen, beech, birch and eucalyptus. The term hardwood is used as opposite to softwood.
Softwood	Wood from conifers including e.g. pine and spruce. The term softwood is used as opposite to hardwood.
Causticising	Process in the lime cycle in which hydroxide (white liquor) is regenerated by the reaction $Ca(OH)_2 + CO_3^{2-} \rightarrow CaCO_3\ (s) + 2\ OH^-$

Acronyms

Term used	Definition
ADt	Air Dry tonnes (of pulp) expressed as 90% dryness.
AOX	Adsorbable organic halides measured according to the EN ISO: 9562 standard method for waste waters.
BOD	Biochemical oxygen demand. The quantity of dissolved oxygen required by microorganisms to decompose organic matter in waste water.
CMP	Chemimechanical pulp.
CTMP	Chemithermomechanical pulp.
COD	Chemical oxygen demand; the amount of chemically oxidisable organic matter in waste water (normally referring to analysis with dichromate oxidation).
DS	Dry solids, expressed as weight %.
DTPA	Diethlyene triamine pentaacetic acid (complexing/chelating agent used in peroxide bleaching).
ECF	Elemental Chlorine Free.
EDTA	Ethylene diamine tetraacetic acid (complexing/chelating agent).
H_2S	Hydrogen sulphide.
LWC	Light-weight coated paper.
NO_X	The sum of nitrogen oxide (NO) and nitrogen dioxide (NO_2), expressed as NO_2.

Term used	Definition
NSSC	Neutral sulphite semi chemical.
RCF	Recycled fibres.
SO_2	Sulphur dioxide.
TCF	Totally Chlorine Free.
Total nitrogen (tot-N)	Total nitrogen (tot-N) given as N, includes organic nitrogen, free ammonia and ammonium (NH_4^+-N), nitrites (NO_2^--N) and nitrates (NO_3^--N).
Total phosphorus (tot-P)	Total phosphorus (tot-P) given as P, includes dissolved phosphorus plus any insoluble phosphorus carried over into the effluent in the form of precipitates or within microbes.
TMP	Thermomechanical pulp.
TOC	Total organic carbon.
TRS	Total reduced sulphur. The sum of the following reduced malodorous sulphur compounds generated in the pulping process: hydrogen sulphide, methyl mercaptan, dimethylsulphide and dimethyldisulphide, expressed as sulphur.
TSS	Total suspended solids (in waste water). Suspended solids consist of small fibre fragments, fillers, fines, non-settled biomass (agglomeration of microorganisms) and other small particles.
VOC	Volatile organic compounds as defined in Article 3(45) of Directive 2010/75/EU.

8.1 General BAT conclusions for the pulp and paper industry

The process specific BAT conclusions included in Sections 8.2 to 8.6 apply, in addition to the general BAT conclusions mentioned in this section.

8.1.1 Environmental management system

BAT 1. In order to improve the overall environmental performance of plants for the production of pulp, paper and board, BAT is to implement and adhere to an environmental management system (EMS) that incorporates all of the following features:

(a) commitment of the management, including senior management;
(b) definition of an environmental policy that includes the continuous improvement of the installation by the management;
(c) planning and establishing the necessary procedures, objectives and targets, in conjunction with financial planning and investment;
(d) implementation of procedures paying particular attention to:

  (i) structure and responsibility
  (ii) training, awareness and competence
  (iii) communication
  (iv) employee involvement
  (v) documentation
  (vi) efficient process control
  (vii) maintenance programmes
  (viii) emergency preparedness and response
  (ix) safeguarding compliance with environmental legislation;

(e) checking performance and taking corrective action, paying particular attention to:

  (i) monitoring and measurement (see also the Reference Document on the General Principles of Monitoring)
  (ii) corrective and preventive action
  (iii) maintenance of records
  (iv) independent (where practicable) internal and external auditing in order to determine whether or not the EMS conforms to planned arrangements and has been properly implemented and maintained;

(f) review of the EMS and its continuing suitability, adequacy and effectiveness by senior management;
(g) following the development of cleaner technologies;
(h) consideration for the environmental impacts from the eventual decommissioning of the installation at the stage of designing a new plant, and throughout its operating life;
(i) application of sectoral benchmarking on a regular basis.

Technical considerations relevant to applicability
The scope (e.g. level of details) and nature of the EMS (e.g. standardised or non-standardised) will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

8.1.2 Materials management and good housekeeping

BAT 2. BAT is to apply the principles of good housekeeping for minimising the environmental impact of the production process by using a combination of the techniques given below.

	Technique
a	Careful selection and control of chemicals and additives
b	Input-output analysis with a chemical inventory, including quantities and toxicological properties
c	Minimise the use of chemicals to the minimum level required by the quality specifications of the final product
d	Avoid the use of harmful substances (e.g. nonylphenol ethoxylate-containing dispersion or cleaning agents or surfactants) and substitution by less harmful alternatives
e	Minimise the input of substances into the soil by leakage, aerial deposition and the inappropriate storage of raw materials, products or residues
f	Establish a spill management programme and extend the containment of relevant sources, thus preventing the contamination of soil and groundwater
g	Proper design of the piping and storage systems to keep the surfaces clean and to reduce the need for washing and cleaning

BAT 3. In order to reduce the release of not readily biodegradable organic chelating agents such as EDTA or DTPA from peroxide bleaching, BAT is to use a combination of the techniques given below.

	Technique	**Applicability**
a	Determination of quantity of chelating agents released to the environment through periodic measurements	Not applicable for mills that do not use chelating agents
b	Process optimisation to reduce consumption and emission of not readily biodegradable chelating agents	Not applicable for plants that eliminate 70 % or more of EDTA/DTPA in their waste water treatment plant or process
c	Preferential use of biodegradable or eliminable chelating agents, gradually phasing out non-degradable products	Applicability depends on the availability of appropriate substitutes (biodegradable agents meeting e.g. brightness requirements of pulp)

8.1.3 Water and waste water management

BAT 4. In order to reduce the generation and the pollution load of waste water from wood storage and preparation, BAT is to use a combination of the techniques given below.

	Technique	Applicability
a	Dry debarking (description see Section 8.7.2.1)	Restricted applicability when high purity and brightness is required with TCF bleaching
b	Handling of wood logs in such a way as to avoid the contamination of bark and wood with sand and stones	Generally applicable
c	Paving of the wood yard area and particularly the surfaces used for the storage of chips	Applicability may be restricted due to the size of the wood yard and storage area
d	Controlling the flow of sprinkling water and minimising surface run-off water from the wood yard	Generally applicable
e	Collecting of contaminated run-off water from the wood yard and separating out suspended solids effluent before biological treatment	Applicability may be restricted by the degree of contamination of run-off water (low concentration) and/or the size of the waste water treatment plant (large volumes)

The BAT-associated effluent flow from dry debarking is 0.5 – 2.5 m^3/ADt.

BAT 5. In order to reduce fresh water use and generation of waste water, BAT is to close the water system to the degree technically feasible in line with the pulp and paper grade manufactured by using a combination of the techniques given below.

	Technique	Applicability
a	Monitoring and optimising water usage	Generally applicable
b	Evaluation of water recirculation options	
c	Balancing the degree of closure of water circuits and potential drawbacks; adding additional equipment if necessary	
d	Separation of less contaminated sealing water from pumps for vacuum generation and reuse	
e	Separation of clean cooling water from contaminated process water and reuse	
f	Reusing process water to substitute for fresh water (water recirculation and closing of water loops)	Applicable to new plants and major refurbishments. Applicability may be limited due to water quality and/or product quality requirements or due to technical constraints (such as precipitation/incrustation in water system) or increase odour nuisance
g	In-line treatment of (parts of) process water to improve water quality to allow for recirculation or reuse	Generally applicable

The BAT-associated waste water flow at the point of discharge after waste water treatment as yearly averages are:

Sector	BAT-associated waste water flow
Bleached kraft	25 – 50 m^3/ADt
Unbleached kraft	15 – 40 m^3/ADt
Bleached sulphite paper grade pulp	25 – 50 m^3/ADt
Magnefite pulp	45 – 70 m^3/ADt
Dissolving pulp	40 – 60 m^3/ADt
NSSC pulp	11 – 20 m^3/ADt
Mechanical	9 – 16 m^3/t
CTMP and CMP	9 – 16 m^3/ADt
RCF paper mills without deinking	1.5 – 10 m^3/t (the higher end of the range is associated with mainly folding boxboard production)
RCF paper mills with deinking	8 – 15 m^3/t
RCF-based tissue paper mills with deinking	10 – 25 m^3/t
Non-integrated paper mills	3.5 – 20 m^3/t

8.1.4 Energy consumption and efficiency

BAT 6. In order to reduce fuel and energy consumption in pulp and paper mills, BAT is to use technique (a) and a combination of the techniques given below.

	Technique	Applicability
a	Use an energy management system that includes all of the following features: i. Assessment of the mill's overall energy consumption and production ii. Locating, quantifying and optimising the potentials for energy recovery iii. Monitoring and safeguarding the optimised situation for energy consumption	Generally applicable
b	Recover energy by incinerating those wastes and residues from the production of pulp and paper that have high organic content and calorific value, taking into account BAT 12	Only applicable if the recycling or reuse of wastes and residues from the production of pulp and paper with a high organic content and high calorific value is not possible
c	Cover the steam and power demand of the production processes as far as possible by the cogeneration of heat and power (CHP)	Applicable for all new plants and for major refurbishments of the energy plant. Applicability in existing plants may be limited due to the mill layout and available space
d	Use excess heat for the drying of biomass and sludge, to heat boiler feedwater and process water, to heat buildings, etc.	Applicability of this technique may be limited in cases where the heat sources and locations are far apart
e	Use thermo compressors	Applicable to both new and existing plants for all grades of paper and for coating machines, as long as medium pressure steam is available
f	Insulate steam and condensate pipe fittings	Generally applicable
g	Use energy efficient vacuum systems for dewatering	
h	Use high efficiency electrical motors, pumps and agitators	
i	Use frequency inverters for fans, compressors and pumps	
j	Match steam pressure levels with actual pressure needs	

Description

Technique (c): simultaneous generation of heat energy and electrical and/or mechanical energy in a single process, referred to as a combined heat and power plant (CHP). CHP plants in the pulp and paper industry normally apply steam turbines and/or gas turbines. The economic viability (achievable savings and payback time) will depend mainly on the cost of electricity and fuels.

8.1.5 Emissions of odour

With regard to the emissions of malodorous sulphur-containing gases from kraft and sulphite pulp mills, see the process-specific BAT given in Sections 8.2.2 and 8.3.2.

BAT 7. In order to prevent and reduce the emission of odorous compounds originating from the waste water system, BAT is to use a combination of the techniques given below.

	Technique
I Applicable for odours related to water systems closure	
a	Design paper mill processes, stock and water storage tanks, pipes and chests in such a way as to avoid prolonged retention times, dead zones or areas with poor mixing in water circuits and related units, in order to avoid uncontrolled deposits and the decay and decomposition of organic and biological matter
b	Use biocides, dispersants or of oxidising agents (e.g. catalytic disinfection with hydrogen peroxide) to control odour and decaying bacteria growth
c	Install internal treatment processes ('kidneys') to reduce the concentrations of organic matter and consequently possible odour problems in the white water system
II Applicable for odours related to waste water treatment and sludge handling, in order to avoid conditions where waste water or sludge becomes anaerobic	
a	Implement closed sewer systems with controlled vents, using chemicals in some cases to reduce the formation of and to oxidise hydrogen sulphide in sewer systems
b	Avoid over-aeration in equalisation basins but maintain sufficient mixing
c	Ensure sufficient aeration capacity and mixing properties in aeration tanks; revise the aeration system regularly
d	Guarantee proper operation of secondary clarifier sludge collection and return sludge pumping
e	Limit the retention time of sludge in sludge storages by sending the sludge continuously to the dewatering units
f	Avoid the storage of waste water in the spill basin longer than is necessary; keep the spill basin empty
g	If sludge dryers are used, treatment of thermal sludge dryer vent gases by scrubbing and/or bio filtration (such as compost filters)
h	Avoid air cooling towers for untreated water effluent by applying plate heat exchangers

8.1.6 Monitoring of key process parameters and of emissions to water and air

BAT 8. BAT is to monitor the key process parameters according to the table given below.

I. Monitoring key process parameters relevant for emissions to air	
Parameter	**Monitoring frequency**
Pressure, temperature, oxygen, CO and water vapour content in flue-gas for combustion processes	Continuous
II. Monitoring key process parameters relevant for emissions to water	
Parameter	**Monitoring frequency**
Water flow, temperature and pH	Continuous
P and N content in biomass, sludge volume index, excess ammonia and ortho-phosphate in the effluent, and microscopy checks of the biomass	Periodic
Volume flow and CH_4 content of biogas produced in anaerobic waste water treatment	Continuous
H_2S and CO_2 contents of biogas produced in anaerobic waste water treatment	Periodic

BAT 9. BAT is to carry out the monitoring and measurement of emissions to air, as indicated below, on a regular basis with the frequency indicated and according to EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards which ensure the provision of data of an equivalent scientific quality.

	Parameter	**Monitoring frequency**	**Applicability**	**Monitoring associated with**
a	NO_X and SO_2	Continuous	Recovery boiler	BAT 21 BAT 22 BAT 36 BAT 37
		Periodic or continuous	Lime kiln	BAT 24 BAT 26
		Periodic or continuous	Dedicated TRS burner	BAT 28 BAT 29
b	Dust	Periodic or continuous	Recovery boiler (kraft) and lime kiln	BAT 23 BAT 27
		Periodic	Recovery boiler (sulphite)	BAT 37
c	TRS (including H_2S)	Continuous	Recovery boiler	BAT 21
		Periodic or continuous	Lime kiln and dedicated TRS burner	BAT 24 BAT 25 BAT 28
		Periodic	Diffuse emissions from different sources (e.g. the fibre line, tanks, chip bins, etc.) and residual weak gases	BAT 11 BAT 20
d	NH_3	Periodic	Recovery boiler equipped with SNCR	BAT 36

BAT 10. BAT is to carry out the monitoring and measurement of emissions to water, as indicated below, with the frequency indicated and according to EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality.

	Parameter	Monitoring frequency	Monitoring associated with
a	Chemical oxygen demand (COD) or Total organic carbon (TOC) (1)	Daily (2)(3)	BAT 19 BAT 33 BAT 40 BAT 45 BAT 50
b	BOD_5 or BOD_7	Weekly (once a week)	
c	Total suspended solids (TSS)	Daily (2)(3)	
d	Total nitrogen	Weekly (once a week) (2)	
e	Total phosphorus	Weekly (once a week) (2)	
f	EDTA, DTPA (4)	Monthly (once a month)	
g	AOX (according to EN ISO 9562:2004) (5)	Monthly (once a month)	BAT 19: bleached kraft
		Once every two months	BAT 33: except TCF and NSSC mills BAT 40: except CTMP and CMP mills BAT 45 BAT 50
h	Relevant metals (e.g. Zn, Cu, Cd, Pb, Ni)	Once a year	

(1) There is a trend to replace COD by TOC for economic and ecological reasons. If TOC is already measured as a key process parameter, there is no need to measure COD; however, a correlation between the two parameters should be established for the specific emission source and waste water treatment step.

(2) Rapid test methods can also be used. The results of rapid tests should be checked regularly (e.g. monthly) against EN standards or, if EN standards are not available, against ISO, national or other international standards which ensure the provision of data of an equivalent scientific quality.

(3) For mills operating less than seven days a week, the monitoring frequency for COD and TSS may be reduced to cover the days the mill is in operation or to extend the sampling period to 48 or 72 hours.

(4) Applicable where EDTA or DTPA (chelating agents) are used in the process.

(5) Not applicable to plants that provide evidence that no AOX is generated or added via chemical additives and raw materials.

BAT 11. BAT is to regularly monitor and assess diffuse total reduced sulphur emissions from relevant sources.

Description

The assessment of diffuse total reduced sulphur emissions can be done by periodic measurement and assessment of diffuse emissions that are emitted from different sources (e.g. the fibre line, tanks, chip bins etc.) by direct measurements.

8.1.7 Waste management

BAT 12. In order to reduce the quantities of wastes sent for disposal, BAT is to implement a waste assessment (including waste inventories) and management system, so as to facilitate waste reuse, or failing that, waste recycling, or failing that, 'other recovery', including a combination of the techniques given below.

	Technique	Description	Applicability
a	Separate collection of different waste fractions (including separation and classification of hazardous waste)	See Section 8.7.3	Generally applicable
b	Merging of suitable fractions of residues to obtain mixtures that can be better utilised		Generally applicable
c	Pretreatment of process residues before reuse or recycling		Generally applicable
d	Material recovery and recycling of process residues on site		Generally applicable
e	Energy recovery on- or off-site from wastes with high organic content		For off-site utilisation, the applicability depends on the availability of a third party
f	External material utilisation		Depending on the availability of a third party
g	Pretreatment of waste before disposal		Generally applicable

8.1.8 Emissions to water

Further information on waste water treatment in pulp and paper mills and process-specific BAT-AELs are given in Sections 8.2 to 8.6.

BAT 13. In order to reduce nutrient (nitrogen and phosphorus) emissions into receiving waters, BAT is to substitute chemical additives with high nitrogen and phosphorus contents by additives containing low nitrogen and phosphorus contents.

Applicability

Applicable if the nitrogen in the chemical additives is not bioavailable (i.e. it cannot serve as nutrient in biological treatment) or if the nutrient balance is in surplus.

BAT 14. In order to reduce emissions of pollutants into receiving waters, BAT is to use all of the techniques given below.

	Technique	Description
a	Primary (physico-chemical) treatment	See Section 8.7.2.2
b	Secondary (biological) treatment (1)	

(1) Not applicable to plants where the biological load of waste water after the primary treatment is very low, e.g. some paper mills producing speciality paper.

BAT 15. When further removal of organic substances, nitrogen or phosphorus is needed, BAT is to use tertiary treatment as described in Section 8.7.2.2.

BAT 16. In order to reduce emissions of pollutants into receiving waters from biological waste water treatment plants, BAT is to use all of the techniques given below.

	Technique
a	Proper design and operation of the biological treatment plant
b	Regularly controlling the active biomass
c	Adjustment of nutrition supply (nitrogen and phosphorus) to the actual need of the active biomass

8.1.9 Emissions of noise

BAT 17. In order to reduce the emissions of noise from pulp and paper manufacturing, BAT is to use a combination of the techniques given below.

	Technique	Description	Applicability
a	Noise-reduction programme	A noise-reduction programme includes identification of sources and affected areas, calculations and measurements of noise levels in order to rank sources according to noise levels, and identification of the most cost effective combination of techniques, their implementation and monitoring	Generally applicable
b	Strategic planning of the location of equipment, units and buildings	Noise levels can be reduced by increasing the distance between the emitter and the receiver and by using buildings as noise screens	Generally applicable to new plants. In the case of existing plants, the relocation of equipment and production units may be restricted by the lack of space or by excessive costs
c	Operational and management techniques in buildings containing noisy equipment	This includes: – improved inspection and maintenance of equipment to prevent failures – closing of doors and windows of covered areas – equipment operation by experienced staff – avoidance of noisy activities during night-time – provisions for noise control during maintenance activities	Generally applicable
d	Enclosing noisy equipment and units	Enclosure of noisy equipment, such as wood handling, hydraulic units, and compressors in separate structures, such as buildings or soundproofed cabinets, where internal-external lining is made of impact-absorbent material	
e	Use of low-noise equipment and noise-reducers on equipment and ducts		
f	Vibration insulation	Vibration insulation of machinery and decoupled arrangement of noise sources and potentially resonant components	

	Technique	Description	Applicability
g	Soundproofing of buildings	This potentially includes use of: – sound-absorbing materials in walls and ceilings – sound-isolating doors – double-glazed windows	
h	Noise abatement	Noise propagation can be reduced by inserting barriers between emitters and receivers. Appropriate barriers include protection walls, embankments and buildings. Suitable noise abatement techniques include fitting silencers and attenuators to noisy equipment such as steam releases and dryer vents	Generally applicable to new plants. In the case of existing plants, the insertion of obstacles may be restricted by the lack of space
i	Use of larger wood-handling machines to reduce lifting and transport times and noise from logs falling onto log piles or the feed table		Generally applicable
j	Improved ways of working, e.g. releasing logs from a lower height onto the log piles or the feed table; immediate feedback of the level of noise for the workers		

8.1.10 Decommissioning

BAT 18. In order to prevent pollution risks when decommissioning a plant, BAT is to use the general techniques given below.

	Technique
a	Ensure that underground tanks and piping are either avoided in the design phase or that their location is well known and documented.
b	Establish instructions for emptying process equipment, vessels and piping.
c	Ensure a clean closure when the facility is shut down, e.g. to clean up and rehabilitate the site. Natural soil functions should be safeguarded, if feasible.
d	Use a monitoring programme, especially relative to groundwater, in order to detect possible future impacts on site or in neighbouring areas.
e	Develop and maintain a site closure or cessation scheme, based on risk analysis, that includes a transparent organisation of the shutdown work, taking into account relevant local specific conditions.

8.2 BAT conclusions for kraft pulping process

For integrated kraft pulp and paper mills, the process-specific BAT conclusions for papermaking given in Section 8.6 apply, in addition to the BAT conclusions in this section.

8.2.1 Waste water and emissions to water

BAT 19. In order to reduce emissions of pollutants into receiving waters from the whole mill, BAT is to use TCF or modern ECF bleaching (see description in Section 8.7.2.1), and a suitable combination of the techniques specified in BAT 13, BAT 14, BAT 15 and BAT 16 and of the techniques given below.

	Technique	Description	Applicability
a	Modified cooking before bleaching	See Section 8.7.2.1	Generally applicable
b	Oxygen delignification before bleaching		
c	Closed brown stock screening and efficient brown stock washing		
d	Partial process water recycling in the bleach plant		Water recycling may be limited due to incrustation in bleaching
e	Effective spill monitoring and containment with a suitable recovery system		Generally applicable
f	Maintaining sufficient black liquor evaporation and recovery boiler capacity to cope with peak loads		Generally applicable
g	Stripping the contaminated (foul) condensates and reusing the condensates in the process		

BAT-associated emission levels

See Table 8.1 and Table 8.2. These BAT-associated emission levels are not applicable to dissolving kraft pulp mills.

The reference waste water flow for kraft mills is set out in BAT 5.

Table 8.1: BAT-associated emission levels for the direct waste water discharge to receiving waters from a bleached kraft pulp mill

Parameter	Yearly average kg/ADt (1)
Chemical oxygen demand (COD)	7 – 20
Total suspended solids (TSS)	0.3 – 1.5
Total nitrogen	0.05 – 0.25 (2)
Total phosphorus	0.01 – 0.03 (2) Eucalyptus: 0.02 – 0.11 kg/ADt (3)
Adsorbable organically bound halogens (AOX) (4) (5)	0 – 0.2

(1) The BAT-AEL ranges refer to market pulp production and the pulp production part of integrated mills (emissions from papermaking are not included).

(2) A compact biological waste water treatment plant can result in slightly higher emission levels.

(3) The upper end of the range refers to mills using eucalyptus from regions with higher levels of phosphorus (e.g. Iberian eucalyptus).

(4) Applicable for mills using chlorine containing bleaching chemicals.

(5) For mills producing pulp with high strength, stiffness and high purity properties (e.g. for liquid packaging board and LWC), emissions level of AOX up to 0.25 kg/ADt may occur.

Table 8.2: BAT-associated emission levels for the direct waste water discharge to receiving waters from an unbleached kraft pulp mill

Parameter	Yearly average kg/ADt (1)
Chemical oxygen demand (COD)	2.5 – 8
Total suspended solids (TSS)	0.3 – 1.0
Total nitrogen	0.1 – 0.2 (2)
Total phosphorus	0.01 – 0.02 (2)

(1) The BAT-AEL ranges refer to market pulp production and the pulp production part of integrated mills (emissions from papermaking are not included).
(2) A compact biological waste water treatment plant can result in slightly higher emission levels.

The BOD concentration in the treated effluents is expected to be low (around 25 mg/l as a 24-hour composite sample).

8.2.2 Emissions to air

8.2.2.1 Reduction of emissions in strong and weak odorous gases

BAT 20. In order to reduce odour emissions and total reduced sulphur emissions due to strong and weak gases, BAT is to prevent diffuse emissions by capturing all process-based sulphur containing off-gases, including all vents with sulphur-containing emissions, by applying all of the techniques given below.

	Technique	Description
a	Collection systems for strong and weak malodorous gases, comprising the following features: – covers, suction hoods, ducts, and extraction system with sufficient capacity; – continuous leak detection system; – safety measures and equipment.	
b	Incineration of strong and weak non-condensable gases	Incineration can be carried out using: – recovery boiler – lime kiln (1) – dedicated NCG burner equipped with wet scrubbers for SO_X removal; or – power boiler (2) To ensure the constant availability of incineration for odorous strong gases, back-up systems are installed. Lime kilns can serve as back-up for recovery boilers; further back-up equipment are flares and package boiler
c	Recording unavailability of the incineration system and any resulting emissions (3)	

(1) The SO_X emission levels of the lime kiln increase significantly when strong non-condensable gases (NCG) are fed to the kiln and no alkaline scrubber is used.
(2) Applicable for the treatment of weak odorous gases.
(3) Applicable for the treatment of strong odorous gases.

Applicability

Generally applicable for new plants and for major refurbishments of existing plants. The installation of necessary equipment may be difficult for existing plants due to layout and space restrictions. The applicability of incineration might be limited for safety reasons, and in this case wet scrubbers could be used.

BAT-associated emission level of total reduced sulphur (TRS) in residual weak gases emitted is 0.05 – 0.2 kg S/ADt.

8.2.2.2 Reduction of emissions from a recovery boiler

SO_2 and TRS emissions

BAT 21. In order to reduce SO_2 and TRS emissions from a recovery boiler, BAT is to use a combination of the techniques given below.

	Technique	Description
a	Increasing the dry solids (DS) content of black liquor	The black liquor can be concentrated by an evaporation process before burning
b	Optimised firing	Firing conditions can be improved e.g. by good mixing of air and fuel, control of furnace load etc.
c	Wet scrubber	Section 8.7.1.3

BAT-associated emission levels
See Table 8.3.

Table 8.3: BAT-associated emission levels for SO_2 and TRS emissions from a recovery boiler

Parameter		**Daily average (1) (2) mg/Nm^3 at 6 % O_2**	**Yearly average (1) mg/Nm^3 at 6 % O_2**	**Yearly average (1) kg S/ADt**
SO_2	**DS <75 %**	10 – 70	5 – 50	–
	DS 75 – 83 % (3)	10 – 50	5 – 25	–
Total reduced sulphur (TRS)		1 – 10 (4)	1 – 5	–
Gaseous S (TRS-S + SO_2-S)	**DS <75 %**	–	–	0.03 – 0.17
	DS 75 – 83 % (3)			0.03 – 0.13

(1) Increasing the DS content of the black liquor results in lower SO_2 emissions and higher NO_X emissions. Due to this, a recovery boiler with low emission levels for SO_2, may be on the higher end of the range for NO_X and vice versa.
(2) BAT-AELs do not cover periods during which the recovery boiler is run on a DS content much lower than the normal DS content due to shutdown or maintenance of the black liquor concentration plant.
(3) If a recovery boiler were to burn black liquor with a DS > 83%, then SO_2 and gaseous S emission levels should be reconsidered on a case-by-case basis.
(4) The range is applicable without the incineration of odorous strong gases.
DS = dry solid content of the black liquor.

NO_X emissions

BAT 22. In order to reduce NO_X emissions from a recovery boiler, BAT is to use an optimised firing system including all of the features given below.

	Technique
a	Computerised combustion control
b	Good mixing of fuel and air
c	Staged air feed systems, e.g. by using different air registers and air inlet ports

Applicability
Technique (c) is applicable to new recovery boilers and in the case of a major refurbishment of recovery boilers, as this technique requires considerable changes to the air feed systems and the furnace.

BAT-associated emission levels

See Table 8.4.

Table 8.4: BAT-associated emission levels for NO_X emissions from a recovery boiler

Parameter		Yearly average (1) mg/Nm^3 at 6 % O_2	Yearly average (1) kg NO_X/ADt
NO_X	**Softwood**	120 – 200 (2)	DS <75 %: 0.8 – 1.4 DS 75 – 83 % (3): 1.0 – 1.6
	Hardwood	120 – 200 (2)	DS <75 %: 0.8 – 1.4 DS 75 – 83 % (3): 1.0 – 1.7

(1) Increasing the DS content of the black liquor results in lower SO_2 emissions and higher NO_X emissions. Due to this, a recovery boiler with low emission levels for SO_2, may be on the higher end of the range for NO_X and vice versa.

(2) The actual NO_X emission level of an individual mill depends on the DS content and the nitrogen content of the black liquor, and the amount and combination of NCG and other nitrogen containing flows (e.g. dissolving tank vent gas, methanol separated from the condensate, biosludge) burnt. The higher the DS content, the nitrogen content in the black liquor, and the amount of NCG and other nitrogen containing flows burnt, the closer the emissions will be to the upper end of the BAT-AEL range.

(3) If a recovery boiler were to burn black liquor with a DS > 83%, then NO_X emission levels should be reconsidered on a case-by-case basis.

DS = dry solid content of black liquor.

Dust emissions

BAT 23. In order to reduce dust emissions from a recovery boiler, BAT is to use an electrostatic precipitator (ESP) or a combination of ESP and wet scrubber.

Description

See Section 8.7.1.1.

BAT-associated emission levels

See Table 8.5.

Table 8.5: BAT-associated emission levels for dust emissions from a recovery boiler

Parameter	Dust abatement system	Yearly average mg/Nm^3 at 6 % O_2	Yearly average kg dust/ADt
Dust	New or major refurbishment	10 – 25	0.02 – 0.20
	Existing	10 – 40 (1)	0.02 – 0.3 (1)

(1) For an existing recovery boiler equipped with an ESP approaching the end of its operational life, emission levels may increase over time up to 50 mg/Nm^3 (corresponding to 0.4 kg/ADt).

8.2.2.3 Reduction of emissions from a lime kiln

SO_2 emissions

BAT 24. In order to reduce SO_2 emissions from a lime kiln, BAT is to apply one or a combination of the techniques given below.

	Technique	Description
a	Fuel selection/low-sulphur fuel	See Section 8.7.1.3
b	Limit incineration of sulphur-containing odorous strong gases in the lime kiln	
c	Control of Na_2S content in lime mud feed	
d	Alkaline scrubber	

BAT-associated emission levels
See Table 8.6.

Table 8.6: BAT-associated emission levels for SO_2 and sulphur emissions from a lime kiln

Parameter (1)	Yearly average mg SO_2/Nm^3 at 6 % O_2	Yearly average kg S/ADt
SO_2 when strong gases are not burnt in the lime kiln	5 – 70	–
SO_2 when strong gases are burnt in the lime kiln	55 – 120	–
Gaseous S (TRS-S + SO_2-S) when strong gases are not burnt in the lime kiln	–	0.005 – 0.07
Gaseous S (TRS-S + SO_2-S) when strong gases are burnt in the lime kiln	–	0.055 – 0.12
(1) 'strong gases' includes methanol and turpentine		

TRS emissions

BAT 25. In order to reduce TRS emissions from a lime kiln, BAT is to apply one or a combination of the techniques given below.

	Technique	Description
a	Control of the excess oxygen	See Section 8.7.1.3
b	Control of Na_2S content in lime mud feed	
c	Combination of ESP and alkaline scrubber	See Section 8.7.1.1

BAT-associated emission levels
See Table 8.7

Table 8.7: BAT-associated emission levels for TRS and sulphur emissions from a lime kiln

Parameter	Yearly average mg S/Nm^3 at 6 % O_2
Total reduced sulphur (TRS)	<1 – 10 (1)
(1) For lime kilns burning strong gases (including methanol and turpentine), the upper end of the AEL range may be up to 40 mg/Nm^3.	

NO_X emissions

BAT 26. In order to reduce NO_X emissions from a lime kiln, BAT is to apply a combination of the techniques given below.

	Technique	Description
a	Optimised combustion and combustion control	See Section 8.7.1.2
b	Good mixing of fuel and air	
c	Low-NO_X burner	
d	Fuel selection/low-N fuel	

BAT-associated emission levels
See Table 8.8.

Table 8.8: BAT-associated emission levels for NO_X emissions from a lime kiln

Parameter		Yearly average mg/Nm^3 at 6 % O_2	Yearly average kg NO_X/ADt
NO_X	**Liquid fuels**	100 – 200 (^{1})	0.1 – 0.2 (^{1})
	Gaseous fuels	100 – 350 (^{2})	0.1 – 0.3 (^{2})

(^{1}) When using liquid fuels originating from vegetable matter (e.g. turpentine, methanol, tall-oil), including those obtained as by-products of the pulping process, emission levels up to 350 mg/Nm^3 (corresponding to 0.35 kg NO_X/ADt) may occur.
(^{2}) When using gaseous fuels originating from vegetable matter (e.g. non-condensable gases), including those obtained as by-products of the pulping process, emission levels up to 450 mg/Nm^3 (corresponding to 0.45 kg NO_X/ADt) may occur.

Dust emissions

BAT 27. In order to reduce dust emissions from a lime kiln, BAT is to use an electrostatic precipitator (ESP) or a combination of ESP and wet scrubber.

Description
See Section 8.7.1.1.

BAT-associated emission levels
See Table 8.9.

Table 8.9: BAT-associated emission levels for dust emissions from a lime kiln

Parameter	Dust abatement system	Yearly average mg/Nm^3 at 6 % O_2	Yearly average kg dust/ADt
Dust	New or major refurbishments	10 – 25	0.005 – 0.02
	Existing	10 – 30 (^{1})	0.005 –0.03 (^{1})

(^{1}) For an existing lime kiln equipped with an ESP approaching the end of its operational life, emission levels may increase over time up to 50 mg/Nm^3 (corresponding to 0.05 kg/ADt).

8.2.2.4 Reduction of emissions from a burner for strong odorous gases (dedicated TRS burner)

BAT 28. In order to reduce SO_2 emissions from the incineration of strong odorous gases in a dedicated TRS burner, BAT is to use an alkaline SO_2 scrubber.

BAT-associated emission levels
See Table 8.10.

Table 8.10: BAT-associated emission levels for SO_2 and TRS emissions from the incineration of strong gases in a dedicated TRS burner

Parameter	Yearly average mg/Nm^3 at 9 % O_2	Yearly average kg S/ADt
SO_2	20 – 120	-
TRS	1 – 5	
Gaseous S (TRS-S + SO_2-S)	-	0.002 – 0.05 (^{1})
(^{1}) This BAT-AEL is based on a gas flow in the range of 100 – 200 Nm^3/ADt.		

BAT 29. In order to reduce NO_X emissions from the incineration of strong odorous gases in a dedicated TRS burner, BAT is to use one or a combination of the techniques given below.

	Technique	Description	Applicability
a	Burner/firing optimisation	See Section 8.7.1.2	Generally applicable
b	Staged incineration	See Section 8.7.1.2	Generally applicable for new plants and for major refurbishments. For existing mills, applicable only if space allows for the insertion of equipment

BAT-associated emission levels
See Table 8.11.

Table 8.11: BAT-associated emission levels for NO_X emissions from the incineration of strong gases in a dedicated TRS burner

Parameter	Yearly average mg/Nm^3 at 9 % O_2	Yearly average kg NO_X/ADt
NO_X	50 – 400 (^{1})	0.01 – 0.1 (^{1})
(^{1}) Where at existing plants a switch to staged incineration is not feasible, emissions levels up to 1 000 mg/Nm^3 (corresponding to 0.2 kg/ADt) may occur.		

8.2.3 Waste generation

BAT 30. In order to prevent waste generation and minimise the amount of solid waste to be disposed of, BAT is to recycle dust from black liquor recovery boiler ESPs to the process.

Applicability
Recirculation of dust may be limited due to non-process elements in the dust.

8.2.4 Energy consumption and efficiency

BAT 31. In order to reduce thermal energy consumption (steam), maximise the benefit of energy carriers used, and to reduce the consumption of electricity, BAT is to apply a combination of the techniques given below.

	Technique
a	High dry solid content of bark, by use of efficient presses or drying
b	High efficiency steam boilers, e.g. low flue-gas temperatures
c	Effective secondary heating systems
d	Closing water systems, including bleach plant
e	High pulp concentration (middle or high consistency technique)
f	High efficiency evaporation plant
g	Recovery of heat from dissolving tanks e.g. by vent scrubbers
h	Recovery and use of the low temperature streams from effluents and other waste heat sources to heat buildings, boiler feedwater and process water
i	Appropriate use of secondary heat and secondary condensate
j	Monitoring and control of processes, using advanced control systems
k	Optimise integrated heat exchanger network
l	Heat recovery from the flue-gas from the recovery boiler between the ESP and the fan
m	Ensuring as high a pulp consistency as possible in screening and cleaning
n	Use of speed control of various large motors
o	Use of efficient vacuum pumps
p	Proper sizing of pipes, pumps and fans
q	Optimised tank levels

BAT 32. In order to increase the efficiency of power generation, BAT is to apply a combination of the techniques given below.

	Technique
a	High black liquor dry solid content (increases boiler efficiency, steam generation and thus electricity generation)
b	High recovery boiler pressure and temperature; in new recovery boilers the pressure can be at least 100 bars and the temperature 510 °C
c	Outlet steam pressure in the back-pressure turbine as low as technically feasible
d	Condensing turbine for power production from excess steam
e	High turbine efficiency
f	Preheating feedwater to a temperature close to the boiling temperature
g	Preheating the combustion air and fuel charged to the boilers

8.3 BAT conclusions for the sulphite pulping process

For integrated sulphite pulp and paper mills, the process-specific BAT conclusions for papermaking given in Section 8.6 apply, in addition to the BAT in this section.

8.3.1 Waste water and emissions to water

BAT 33. In order to prevent and reduce emissions of pollutants into receiving waters from the whole mill, BAT is to use a suitable combination of the techniques specified in BAT 13, BAT 14, BAT 15 and BAT 16 and of the techniques given below.

	Technique	Description	Applicability
a	Extended modified cooking before bleaching	See Section 8.7.2.1	Applicability may be limited due to pulp quality requirements (when high strength is required)
b	Oxygen delignification before bleaching		
c	Closed brown stock screening and efficient brown stock washing		Generally applicable
d	Evaporation of effluents from the hot alkaline extraction stage and incineration of concentrates in a soda boiler		Limited applicability for dissolving pulp mills, when multistage biological treatment of the effluents provides a more favourable overall environmental situation
e	TCF bleaching		Limited applicability for market paper pulp mills producing high brightness pulp and for mills manufacturing speciality pulp for chemical applications
f	Closed-loop bleaching		Only applicable to plants that use the same base for cooking and pH adjustment in bleaching
g	MgO-based pre-bleaching and recirculation of washing liquids from pre-bleaching to brown stock washing		Applicability may be limited by factors such as product quality (e.g. purity, cleanliness and brightness), kappa number after cooking, hydraulic capacity of the installation and capacity of tanks, evaporators and recovery boilers, and a possibility to clean the washing equipment
h	pH adjustment of weak liquor before/inside the evaporation plant		Generally applicable to magnesium-based plants. Spare capacity in the recovery boiler and ash circuit is needed
i	Anaerobic treatment of the condensates from the evaporators		Generally applicable
j	Stripping and recovery of SO_2 from the condensates of evaporators		Applicable if it is necessary to protect anaerobic effluent treatment
k	Effective spill monitoring and containment, also with chemical and energy recovery system		Generally applicable

BAT-associated emission levels
See Table 8.12 and Table 8.13. These BAT-associated emission levels are not applicable to dissolving pulp mills and to the manufacturing of speciality pulp for chemical applications.

The reference waste water flow for sulphite mills is set out in BAT 5.

Table 8.12: BAT-associated emission levels for the direct waste water discharge to receiving waters from a pulp mill manufacturing bleached sulphite and magnefite paper grade pulp

Parameter	Bleached sulphite paper grade pulp (1)	Magnefite paper grade pulp (1)
	Yearly average kg/ADt (2)	**Yearly average** kg/ADt
Chemical oxygen demand (COD)	10 – 30 (3)	20 – 35
Total suspended solids (TSS)	0.4 – 1.5	0.5 – 2.0
Total nitrogen	0.15 – 0.3	0.1 – 0.25
Total phosphorus	0.01 – 0.05 (3)	0.01 – 0.07
	Yearly average mg/l	
Adsorbable organically bound halogens (AOX)	0.5 – 1.5 (4) (5)	

(1) The BAT-AEL ranges refer to market pulp production and the pulp production part of integrated mills (emissions from papermaking are not included).
(2) The BAT-AELs do not apply to natural greaseproof pulp mills.
(3) The BAT-AEL for COD and total phosphorus do not apply to eucalyptus based market pulp.
(4) Sulphite market pulp mills may apply a gentle ClO_2 bleaching stage in order to meet product requirements, thus resulting in AOX emissions.
(5) Not applicable to TCF mills.

Table 8.13: BAT-associated emission levels for the direct waste water discharge to receiving waters from a sulphite pulp mill manufacturing NSSC pulp

Parameter	Yearly average kg/ADt (1)
Chemical oxygen demand (COD)	3.2 – 11
Total suspended solids (TSS)	0.5 – 1.3
Total nitrogen	0.1 – 0.2 (2)
Total phosphorus	0.01 – 0.02

(1) The BAT-AEL ranges refer to market pulp production and the pulp production part of integrated mills (emissions from papermaking are not included).
(2) Due to process-specific higher emissions, the BAT-AEL for total nitrogen does not apply to ammonium-based NSSC pulping.

The BOD concentration in the treated effluents is expected to be low (around 25 mg/l as a 24-hour composite sample).

8.3.2 Emissions to air

BAT 34. In order to prevent and reduce SO_2 emissions, BAT is to collect all highly concentrated SO_2-gas streams from acid liquor production, digesters, diffusers, or blow tanks and to recover the sulphur components.

BAT 35. In order to prevent and reduce diffuse sulphur-containing and odorous emissions from washing, screening, and evaporators, BAT is to collect these weak gases and to apply one of the techniques given below.

	Technique	Description	Applicability
a	Incineration in a recovery boiler	See Section 8.7.1.3	Not applicable to sulphite pulp mills using calcium-based cooking. These mills do not operate a recovery boiler
b	Wet scrubber	See Section 8.7.1.3	Generally applicable

BAT 36. In order to reduce NO_X emissions from a recovery boiler, BAT is to use an optimised firing system including one or a combination of the techniques given below.

	Technique	Description	Applicability
a	Optimising the recovery boiler by controlling the firing conditions	See Section 8.7.1.2	Generally applicable
b	Staged injection of spent liquor		Applicable to new large recovery boilers and major recovery boilers refurbishments
c	Selective non-catalytic reduction (SNCR)		Retrofitting of existing recovery boilers may be limited due to scaling problems and associated increased cleaning and maintenance requirements. For ammonium-based mills, no application was reported; but due to specific conditions in the waste gas, SNCR is expected to be without effect. Not applicable to sodium-based mills due to explosion risk

BAT-associated emission levels
See Table 8.14.

Table 8.14: BAT-associated emission levels for NO_X and NH_3 emissions from a recovery boiler

Parameter	Daily average mg/Nm^3 at 5 % O_2	Yearly average mg/Nm^3 at 5 % O_2
NO_X	100 – 350 (1)	100 – 270 (1)
NH_3 (ammonia slip for SNCR)		<5

(1) For ammonium-based mills, higher emission levels of NO_X may occur: up to 580 mg/Nm^3 as daily average and up to 450 mg/Nm^3 as yearly average.

BAT 37. In order to reduce dust and SO_2 emissions from a recovery boiler, BAT is to use one of the techniques given below and to limit 'acid operation' of the scrubbers to the minimum required to ensure their proper functioning.

	Technique	Description
a	ESP or multicyclones with multistage venturi scrubbers	See Section 8.7.1.3
b	ESP or multicyclones with multistage double inlet downstream scrubbers	

BAT-associated emission levels
See Table 8.15.

Table 8.15: BAT-associated emission levels for dust and SO_2 emissions from a recovery boiler

Parameter	Average over the sampling period mg/Nm^3 at 5 % O_2	
Dust	5 – 20 (1) (2)	
	Daily average mg/Nm^3 at 5 % O_2	**Yearly average** mg/Nm^3 at 5 % O_2
SO_2	100 – 300 (3) (4) (5)	50 – 250 (3) (4)

(1) For recovery boilers operated in mills using more than 25% of hardwood (potassium-rich) in raw materials, higher dust emissions up to 30 mg/Nm^3 may occur.

(2) The BAT-AEL for dust does not apply for ammonium-based mills.

(3) Due to process-specific higher emissions, the BAT-AEL for SO_2 does not apply for recovery boilers operated permanently under 'acidic' conditions, i.e. using sulphite liquor as wet-scrubber washing media as part of the sulphite recovery process.

(4) For existing multistage venturi scrubbers, higher emissions of SO_2 up to 400 mg/Nm^3 as a daily average value and up to 350 mg/Nm^3 as a yearly average may occur.

(5) Not applicable during ‘acid operation’, i.e. periods in which preventive flushing and cleaning of incrustation in the scrubbers takes place. During these periods emissions can be up to 300 – 500 mg SO_2/Nm^3 (at 5 % O_2) for cleaning of one of the scrubbers and up to 1 200 mg SO_2/Nm^3 (half-hourly mean values, at 5 % O_2) when cleaning the final washer.

The **BAT-associated environmental performance level** is a duration of acid operation of around 240 hours per year for the scrubbers, and less than 24 hours per month for the last monosulphite scrubber.

8.3.3 Energy consumption and efficiency

BAT 38. In order to reduce thermal energy consumption (steam), maximise the benefit of the energy carriers used and to reduce the consumption of electricity, BAT is to use a combination of the techniques given below.

	Technique
a	High dry solids content of bark, by use of efficient presses or drying
b	High efficiency steam boilers, e.g. low exhaust-gas temperatures
c	Effective secondary heating system
d	Closing water systems, including bleach plant
e	High pulp concentration (middle or high consistency techniques)
f	Recovery and use of the low temperature streams from effluents and other waste heat sources to heat buildings, boiler feedwater and process water
g	Appropriate use of secondary heat and secondary condensate
h	Monitoring and control of processes, using advanced control systems
i	Optimise integrated heat exchanger network
j	Ensuring as high pulp consistency as possible in screening and cleaning
k	Optimised tank levels

BAT 39. In order to increase the efficiency of power generation, BAT is to use a combination of the techniques given below.

	Technique
a	High recovery boiler pressure and temperature
b	Outlet steam pressure in the back-pressure turbine as low as technically feasible
c	Condensing turbine for power production from excess steam
d	High turbine efficiency
e	Preheating feedwater to a temperature close to the boiling temperature
f	Preheating the combustion air and fuel charged to the boilers

8.4 BAT conclusions for mechanical pulping and chemimechanical pulping

The BAT conclusions in this section apply to all integrated mechanical pulp, paper and board mills and to mechanical pulp mills, CTMP and CMP pulp mills. **BAT 49, BAT 51, BAT 52c and BAT 53** also apply to papermaking in integrated mechanical pulp, paper and board mills, in addition to the BAT conclusions in this section.

8.4.1 Waste water and emissions to water

BAT 40. In order to reduce fresh water use, waste water flow, and the pollution load, BAT is to use a suitable combination of the techniques specified in BAT 13, BAT 14, BAT 15 and BAT 16 and of the techniques given below.

	Technique	Description	Applicability
a	Counter-current flow of process water and separation of water systems	See Section 8.7.2.1	Generally applicable
b	High consistency bleaching		
c	Washing stage before the refining of softwood mechanical pulp using chip pre-treatment		
d	Substitution of NaOH by $Ca(OH)_2$ or $Mg(OH)_2$ as alkali in peroxide bleaching		Applicability for the highest brightness levels may be restricted
e	Fibre and filler recovery and treatment of white water (papermaking)		Generally applicable
f	Optimum design and construction of tanks and chests (papermaking)		

BAT-associated emission levels
See Table 8.16. The BAT-AELs also apply to mechanical pulp mills. The reference waste water flow for integrated mechanical, CTM and CTMP pulp mills are set out in BAT 5.

Table 8.16: BAT-associated emission levels for the direct waste water discharge to receiving waters from the integrated production of paper and board from mechanical pulps produced on site

Parameter	Yearly average kg/t
Chemical oxygen demand (COD)	0.9 – 4.5 (1)
Total suspended solids (TSS)	0.06 – 0.45
Total nitrogen	0.03 – 0.1 (2)
Total phosphorus	0.001 – 0.01

(1) In the case of highly bleached mechanical pulp (70 – 100 % of fibre in final paper), emission levels of up to 8 kg/t may occur.

(2) When biodegradable or eliminable chelating agents cannot be used due to pulp quality requirements (e.g. high brightness), the emissions of total nitrogen might be higher than this BAT-AEL and should be assessed on a case-by-case basis.

Table 8.17: BAT-associated emission levels for the direct waste water discharge to receiving waters from a CTMP or CMP pulp mill

Parameter	Yearly average kg/ADt
Chemical oxygen demand (COD)	12 – 20
Total suspended solids (TSS)	0.5 – 0.9
Total nitrogen	0.15 – 0.18 (1)
Total phosphorus	0.001 – 0.01

(1) When biodegradable or eliminable chelating agents cannot be used due to pulp quality requirements (e.g. high brightness), the emissions of total nitrogen might be higher than this BAT-AEL and should be assessed on a case-by-case basis.

The BOD concentration in the treated effluents is expected to be low (around 25 mg/l as a 24-hour composite sample).

8.4.2 Energy consumption and efficiency

BAT 41. In order to reduce the consumption of thermal and electrical energy, BAT is to use a combination of the techniques given below.

	Technique	Applicability
a	Use of energy efficient refiners	Applicable when replacing, rebuilding or upgrading process equipment
b	Extensive recovery of secondary heat from TMP and CTMP refiners and reuse of recovered steam in paper or pulp drying	Generally applicable
c	Minimisation of fibre losses by using efficient reject refining systems (secondary refiners)	
d	Installation of energy saving equipment, including automated process control instead of manual systems	
e	Reduction of fresh water use by internal process water treatment and recirculation systems	
f	Reduction of the direct use of steam by careful process integration using e.g. pinch analysis	

8.5 BAT conclusions for processing paper for recycling

The BAT conclusions in this section apply to all integrated RCF mills and to RCF pulp mills. For integrated RCF paper mills, **BAT 49, BAT 51, BAT 52c and BAT 53** also apply to papermaking in integrated RCF pulp, paper and board mills, in addition to the BAT conclusions in this section.

8.5.1 Materials management

BAT 42. In order to prevent the contamination of soil and groundwater or to reduce the risk thereof and in order to reduce wind drift of paper for recycling and diffuse dust emissions from the paper for recycling yard, BAT is to use one or a combination of the techniques given below.

	Technique	Applicability
a	Hard surfacing of the storage area for paper for recycling	Generally applicable
b	Collection of contaminated run-off water from the paper for recycling storage area and treatment in a waste water treatment plant (uncontaminated rainwater e.g. from roofs can be discharged separately)	Applicability may be restricted by the degree of contamination of run-off water (low concentration) and/or the size of the waste water treatment plants (large volumes)
c	Surrounding the terrain of the paper for recycling yard with fences against wind drift	Generally applicable
d	Regularly cleaning the storage area and sweeping associated roadways and emptying gully pots to reduce diffuse dust emissions. This reduces wind-blown paper debris, fibres and the crushing of paper by on-site traffic, which can cause additional dust emission, especially in the dry season	Generally applicable
e	Storing of bales or loose paper under a roof to protect the material from weather influences (moisture, microbiological degradation processes, etc.)	Applicability may be restricted by the size of the area

8.5.2 Waste water and emissions to water

BAT 43. In order to reduce fresh water use, waste water flow, and the pollution load, BAT is to use a combination of the techniques given below.

	Technique	Description
a	Separation of the water systems	See Section 8.7.2.1
b	Counter-current flow of process water and water recirculation	
c	Partial recycling of treated waste water after biological treatment	Many RCF paper mills recycle a partial stream of biologically treated waste water back into the water circuit, especially mills producing corrugated medium or Testliner
d	Clarification of white water	See Section 8.7.2.1

BAT 44. In order to maintain advanced water circuit closure in mills processing paper for recycling and to avoid possible negative effects from the increased recycling of process water, BAT is to use one or a combination of the techniques given below.

	Technique	**Description**
a	Monitoring and continuous control of the process water quality	See Section 8.7.2.1
b	Prevention and elimination of biofilms by using methods that minimise emissions of biocides	
c	Removal of calcium from process water by a controlled precipitation of calcium carbonate	

Applicability
Techniques (a) – (c) are applicable to RCF paper mills with advanced water circuit closure.

BAT 45. In order to prevent and reduce the pollution load of waste water into receiving waters from the whole mill, BAT is to use a suitable combination of the techniques specified in BAT 13, BAT 14, BAT 15, BAT 16, BAT 43 and BAT 44.

For integrated RCF paper mills, the BAT-AELs include emissions from papermaking, since the white water circuits of the paper machine are closely connected with those of the stock preparation.

BAT-associated emission levels
See Table 8.18 and Table 8.19.

The BAT-associated emission levels in Table 8.18 apply also to RCF without deinking pulp mills, and the BAT-associated emission levels in Table 8.19 apply also to RCF with deinking pulp mills.

The reference waste water flow for RCF mills is set out in BAT 5.

Table 8.18: BAT-associated emission levels for the direct waste water discharge to receiving waters from the integrated production of paper and board from recycled fibres pulp, produced without deinking on site

Parameter	**Yearly average kg/t**
Chemical oxygen demand (COD)	0.4 (1) – 1.4
Total suspended solids (TSS)	0.02 – 0.2 (2)
Total nitrogen	0.008 - 0.09
Total phosphorus	0.001 – 0.005 (3)
Adsorbable organically bound halogens (AOX)	0.05 for wet strength paper

(1) For mills with completely closed water circuits, there are no emissions of COD.
(2) For existing plants, levels up to 0.45 kg/t may occur, due to the continuous decline in the quality of paper for recycling and the difficulty of continuously upgrading the effluent plant.
(3) For mills with a waste water flow between 5 and 10 m^3/t, the upper end of the range is 0.008 kg/t.

Table 8.19: BAT-associated emission levels for the direct waste water discharge to receiving waters from the integrated production of paper and board from recycled fibres pulp produced with deinking on site

Parameter	Yearly average kg/t
Chemical oxygen demand (COD)	0.9 – 3.0 0.9 – 4.0 for tissue paper
Total suspended solids (TSS)	0.08 – 0.3 0.1 – 0.4 for tissue paper
Total nitrogen	0.01 – 0.1 0.01 – 0.15 for tissue paper
Total phosphorus	0.002 – 0.01 0.002 – 0.015 for tissue paper
Adsorbable organically bound halogens (AOX)	0.05 for wet strength paper

The BOD concentration in the treated effluents is expected to be low (around 25 mg/l as a 24-hour composite sample).

8.5.3 Energy consumption and efficiency

BAT 46. BAT is to reduce electrical energy consumption within RCF processing paper mills by using a combination of the techniques given below.

	Technique	Applicability
a	High consistency pulping for disintegrating paper for recycling into separated fibres	Generally applicable for new plants and for existing plants in the case of a major refurbishment
b	Efficient coarse and fine screening by optimising rotor design, screens and screen operation, which allows the use of smaller equipment with lower specific energy consumption	
c	Energy saving stock preparation concepts extracting impurities as early as possible in the re-pulping process, using fewer and optimised machine components, thus restricting the energy intensive processing of the fibres	

8.6 BAT conclusions for papermaking and related processes

The BAT conclusions in this section apply to all non-integrated paper mills and board mills and to the paper and board making part of integrated kraft, sulphite, CTMP and CMP mills.

BAT 49, BAT 51, BAT 52c and BAT 53 apply to all integrated pulp and paper mills.

For integrated kraft, sulphite, CTMP and CMP pulp and paper mills, the process-specific BAT for pulping also apply, in addition to the BAT conclusions in this section.

8.6.1 Waste water and emissions to water

BAT 47. In order to reduce the generation of waste water, BAT is to use a combination of the techniques given below.

	Technique	Description	Applicability
a	Optimum design and construction of tanks and chests	See Section 8.7.2.1	Applicable to new plants and to existing plants in the case of a major refurbishment
b	Fibre and filler recovery and treatment of white water		Generally applicable
c	Water recirculation		Generally applicable. Dissolved organic, inorganic, and colloidal materials may restrict the water reuse in the wire section
d	Optimisation of showers in the paper machine		Generally applicable

BAT 48. In order to reduce fresh water use and emissions to water from speciality paper mills, BAT is to use a combination of the techniques given below.

	Technique	Description	Applicability
a	Improvement of paper production planning	Improved planning to optimise production batch combinations and length	Generally applicable
b	Management of water circuits to fit changes	Adjust water circuits to be able to cope with changes of paper grades, colours and chemical additives used	
c	Waste water treatment plant ready to cope with changes	Adjust waste water treatment to be able to cope with variations of flows, low concentrations and varying types and amounts of chemical additives	
d	Adjustment of the broke system and of chest capacities		
e	Minimisation of release of chemical additives (e.g. grease-/water proof agents) containing per- or polyfluorinated compounds or contributing to their formation		Applicable only for plants producing paper with grease- or water-repellent properties
f	Switch to low AOX-containing product aids (e.g. to substitute use of wet strength agents based on epichlorohydrin resins)		Applicable only for plants producing paper grades with high wet strength

BAT 49. In order to reduce emission loads of coating colours and binders which can disturb the biological waste water treatment plant, BAT is to use technique (a) given below or, in case this is technically not feasible, technique (b) given below.

	Technique	Description	Applicability
a	Recovery of coating colours/recycling of pigments	Effluents containing coating colours are collected separately. The coating chemicals are recovered by e.g.: i) ultrafiltration; ii) screening-flocculation-dewatering process with return of the pigments to the coating process. The clarified water could be reused in the process	For ultrafiltration, the applicability may be restricted when: – effluent volumes are very small – coating effluents are generated in various places of the mill – many changes in coating occur; or – different coating colour recipes are incompatible
b	Pretreatment of effluents which contain coating colours	Effluents which contain coating colours are treated e.g. by flocculation to protect the subsequent biological waste water treatment	Generally applicable

BAT 50. In order to prevent and reduce the pollution load of waste water into receiving waters from the whole mill, BAT is to use a suitable combination of the techniques specified in BAT 13, BAT 14, BAT 15, BAT 47, BAT 48 and BAT 49.

BAT-associated emission levels
See Table 8.20 and Table 8.21.

The BAT-AELs in Table 8.20 and Table 8.21 also apply to the paper and board making process of integrated kraft, sulphite, CTMP and CMP pulp and paper mills.

The reference waste water flow for non-integrated paper and board mills is set out in BAT 5.

Table 8.20: BAT-associated emission levels for the direct waste water discharge to receiving waters from a non-integrated paper and board mill (excluding speciality paper)

Parameter	Yearly average kg/t
Chemical oxygen demand (COD)	0.15 – 1.5 (1)
Total suspended solids (TSS)	0.02 – 0.35
Total nitrogen	0.01 – 0.1 0.01 – 0.15 for tissue paper
Total phosphorus	0.003 – 0.012
Adsorbable organically bound halogens (AOX)	0.05 for decor and wet strength paper

(1) For graphic paper mills, the upper end of the range refers to mills manufacturing paper that use starch for the coating process.

The BOD concentration in the treated effluents is expected to be low (around 25 mg/l as a 24-hour composite sample).

Table 8.21: BAT-associated emission levels for the direct waste water discharge to receiving waters from a non-integrated speciality paper mill

Parameter	Yearly average kg/t (1)
Chemical oxygen demand (COD)	0.3 – 5 (2)
Total suspended solids (TSS)	0.10 – 1
Total nitrogen	0.015 – 0.4
Total phosphorus	0.002 – 0.04
Adsorbable organically bound halogens (AOX)	0.05 for decor and wet strength paper

(1) Mills having special characteristics, such as a high number of grade changes (e.g. of ≥ 5 per day as a yearly average) or producing very light-weight speciality papers (≤ 30 g/m^2 as yearly average) might have higher emissions than the upper end of the range.

(2) The upper end of the BAT-AEL range refers to mills producing highly comminuted paper which requires intensive refining and to mills with frequent changes of paper grades (e.g. ≥1 – 2 changes/day as yearly average).

8.6.2 Emissions to air

BAT 51. In order to reduce VOC emissions from off-line or on-line coaters, BAT is to choose coating colour recipes (compositions) that reduce VOC emissions.

8.6.3 Waste generation

BAT 52. In order to minimise the amount of solid waste to be disposed of, BAT is to prevent waste generation and to carry out recycling operations by the use of a combination of the techniques given below (see general BAT 20).

	Technique	Description	Applicability
a	Fibre and filler recovery and treatment of white water	See Section 8.7.2.1	Generally applicable
b	Broke recirculation system	Broke from different locations /phases of papermaking process is collected, repulped and returned to the fibre feedstock	Generally applicable
c	Recovery of coating colours/recycling of pigments	See Section 8.7.2.1	
d	Reuse of fibre sludge from primary waste water treatment	Sludge with a high fibre content from the primary treatment of waste water can be reutilised in a production process	Applicability may be limited by product quality requirements

8.6.4 Energy consumption and efficiency

BAT 53. In order to reduce the consumption of thermal and electrical energy, BAT is to use a combination of the techniques given below.

	Technique	Applicability
a	Energy saving screening techniques (optimised rotor design, screens and screen operation)	Applicable to new mills or major refurbishments
b	Best practice refining with heat recovery from the refiners	
c	Optimised dewatering in the press section of paper machine/wide nip press	Not applicable to tissue paper and many speciality papers grades
d	Steam condensate recovery and use of efficient exhaust air heat recovery systems	Generally applicable
e	Reduction of direct use of steam by careful process integration using e.g. pinch analysis	
f	High efficient refiners	Applicable to new plants
g	Optimisation of the operating mode in existing refiners (e.g. reduction of no load power requirements)	Generally applicable
h	Optimised pumping design, variable speed drive control for pumps, gearless drives	
i	Cutting edge refining technologies	
j	Steam box heating of the paper web to improve the drainage properties/dewatering capacity	Not applicable to tissue paper and many speciality papers grades
k	Optimised vacuum system (e.g. turbo fans instead of water ring pumps)	Generally applicable
l	Generation optimisation and distribution network maintenance	
m	Optimisation of heat recovery, air system, insulation	
n	Use of high efficient motors (EFF1)	
o	Preheating of shower water with a heat exchanger	
p	Use of waste heat for sludge drying or upgrading of dewatered biomass	
q	Heat recovery from axial blowers (if used) for the supply air of the drying hood	
r	Heat recovery of exhaust air from the Yankee hood with a trickling tower	
s	Heat recovery from the infrared exhaust hot air	

8.7 Description of techniques

8.7.1 Description of techniques for the prevention and control of emissions to air

8.7.1.1 Dust

Technique	Description
Electrostatic precipitator (ESP)	Electrostatic precipitators operate such that particles are charged and separated under the influence of an electrical field. They are capable of operating over a wide range of conditions
Alkaline scrubber	See Section 8.7.1.3 (wet scrubber)

8.7.1.2 NO_X

Technique	Description
Reduction of air/fuel ratio	The technique is mainly based on the following features: – careful control of air used for combustion (low excess oxygen), – minimisation of air leakages into the furnace, – modified design of the furnace combustion chamber.
Optimised combustion and combustion control	Based on permanent monitoring of appropriate combustion parameters (e.g. O_2, CO content, fuel/air ratio, un-burnt components), this technique uses control technology for achieving the best combustion conditions. NO_X formation and emissions can be decreased by adjusting the running parameters, the air distribution, excess oxygen, flame shaping and the temperature profile
Staged incineration	Staged incineration is based on the use of two burning zones, with controlled air ratios and temperatures in a first chamber. The first burning zone operates at sub-stoichiometric conditions to convert ammonia compounds into elementary nitrogen at high temperature. In the second zone, additional air feed completes combustion at a lower temperature. After the two-stage incineration, the flue-gas flows to a second chamber to recover the heat from the gases, producing steam to the process
Fuel selection/low-N fuel	The use of fuels with a low nitrogen content is applied to reduce the amount of NO_X emissions from the oxidation of nitrogen contained in the fuel during combustion. The combustion of CNCG or biomass-based fuels increases NO_X emissions compared to oil and natural gas, as CNCG and all wood-derived fuels contain more nitrogen than oil and natural gas. Due to higher combustion temperatures, gas firing leads to higher NO_X levels than oil firing
Low-NO_X burner	Low-NO_X burners are based on the principles of reducing peak flame temperatures, delaying but completing the combustion and increasing the heat transfer (increased emissivity of the flame). It may be associated with a modified design of the furnace combustion chamber
Staged injection of spent liquor	The injection of spent sulphite liquor into the boiler at various vertically staged levels prevents the formation of NO_X, and provides for complete combustion
Selective non-catalytic reduction (SNCR)	The technique is based on the reduction of NO_X to nitrogen by reaction with ammonia or urea at a high temperature. Ammonia water (up to 25 % NH_3), ammonia precursor compounds or urea solution is injected into the combustion gas to reduce NO to N_2. The reaction has an optimum effect in a temperature window of about 830 °C to 1 050 °C, and sufficient retention time must be provided for the injected agents to react with NO. Dosing rates of ammonia or urea have to be controlled to keep NH_3 slip at low levels

8.7.1.3 SO_2 /TRS emissions prevention and control

Technique	Description
High dry solid black liquor	With a higher dry solid content of the black liquor, the combustion temperature increases. This vaporises more sodium (Na), which can bind the SO_2 forming Na_2SO_4, thus reducing SO_2 emissions from the recovery boiler. A drawback to the higher temperature is that emissions of NO_X may increase
Fuel selection/low-S fuel	The use of low-sulphur content fuels with sulphur contents of about 0.02 – 0.05 % by weight (e.g. forest biomass, bark, low-sulphur oil, gas) reduces SO_2 emissions generated by the oxidation of sulphur in the fuel during combustion
Optimised firing	Techniques such as efficient firing rate control system (air-fuel, temperature, residence time), control of excess oxygen or good mixing of air and fuel
Control of Na_2S content in lime mud feed	Efficient washing and filtration of the lime mud reduces the concentration of Na_2S, thus reducing the formation of hydrogen sulphide in the kiln during the re-burning process
Collection and recovery of SO_2 emissions	Highly concentrated SO_2-gas streams from acid liquor production, digesters, diffusers or blow tanks are collected. SO_2 is recovered in absorption tanks with different pressure levels, both for economic and environmental reasons
Incineration of odorous gases and TRS	Collected strong gases can be destroyed by burning them in the recovery boiler, in dedicated TRS burners, or in the lime kiln. Collected weak gases are suitable for burning in the recovery boiler, lime kiln, power boiler or in the TRS burner. Dissolving tank vent gases can be burnt in modern recovery boilers
Collection and incineration of weak gases in a recovery boiler	Combustion of weak gases (large volume, low SO_2 concentrations) combined with a back-up system. Weak gases and other odorous components are simultaneously collected to be burnt in the recovery boiler. From the exhaust gas of the recovery boiler, the sulphur dioxide is then recovered by counter-current multistage scrubbers and reused as a cooking chemical. As a back-up system, scrubbers are used
Wet scrubber	Gaseous compounds are dissolved in a suitable liquid (water or alkaline solution). Simultaneous removal of solid and gaseous compounds may be achieved. Downstream of the wet scrubber, the flue-gases are saturated with water and a separation of the droplets is required before discharging the flue-gases. The resulting liquid has to be treated by a waste water process and the insoluble matter is collected by sedimentation or filtration
ESP or multicyclones with multistage venturi scrubbers or multistage double inlet downstream scrubbers	The separation of dust is carried out in an electrostatic precipitator or multistage cyclone. For the magnesium sulphite process, the dust retained in the ESP consists mainly of MgO but also to a minor extent, K, Na or Ca compounds. The recovered MgO ash is suspended with water and cleaned by washing and slaking to form $Mg(OH)_2$ which is then used as an alkaline scrubbing solution in the multistage scrubbers in order to recover the sulphur component of the cooking chemicals. For the ammonium sulphite process, the ammonia base (NH_3) is not recovered, as it is decomposed in the combustion process in nitrogen. After the removal of dust, the flue-gas is cooled down by passing through a cooling scrubber operated with water and it then enters a three or more staged scrubber of the flue-gas where the SO_2 emissions are scrubbed with the $Mg(OH)_2$ alkaline solution in the case of the magnesium sulphite process, and with a 100 % fresh NH_3 solution in the case of the ammonium sulphite process.

8.7.2 Description of techniques to reduce fresh water use/waste water flow and the pollution load in waste water

8.7.2.1 Process-integrated techniques

Technique	Description
Dry debarking	Dry debarking of wood logs in dry tumbling drums (water being used only in washing of the logs, and then recycled with only a minimum purge to the waste water treatment plant)
Totally chlorine free bleaching (TCF)	In TCF bleaching, the use of chlorine containing bleaching chemicals is completely avoided and thus so are the emissions of organic and organochlorinated substances from bleaching
Modern elemental chlorine free (ECF) bleaching	Modern ECF bleaching minimises the consumption of chlorine dioxide by using one or a combination of the following bleaching stages: oxygen, hot acid hydrolysis stage, ozone stage at medium and high consistency, stages with atmospheric hydrogen peroxide and pressurised hydrogen peroxide or the use of a hot chlorine dioxide stage
Extended delignification	Extended delignification by (a) modified cooking or (b) oxygen delignification enhances the degree of delignification of pulp (lowering the kappa number) before bleaching and thus reduces the use of bleaching chemicals and the COD load of waste water. Lowering the kappa number by one unit before bleaching can reduce the COD released in the bleach plant by approximately 2 kg COD/ADt. The lignin removed can be recovered and sent to the chemicals and energy recovery system
(a) Extended modified cooking	Extended cooking (batch or continuous systems) comprises longer cooking periods under optimised conditions (e.g. alkali concentration in the cooking liquor is adjusted to be lower at the beginning and higher at the end of the cooking process), to extract a maximum amount of lignin before bleaching, without undue carbohydrate degradation or excessive loss of pulp strength. Thus, the use of chemicals in the subsequent bleaching stage and the organic load of the waste water from the bleach plant can be reduced
(b) Oxygen delignification	Oxygen delignification is an option to remove a substantial fraction of the lignin remaining after cooking, in case the cooking plant has to be operated with higher kappa numbers. The pulp reacts under alkaline conditions with oxygen to remove some of the residual lignin
Closed and efficient brown stock screening and washing	Brown stock screening is carried out with slotted pressure screens in a multistage closed cycle. Impurities and shives are thus removed at an early stage in the process. Brown stock washing separates dissolved organic and inorganic chemicals from the pulp fibres. The brown stock pulp may be washed first in the digester, then in high efficiency washers before and after oxygen delignification, i.e. before bleaching. Carry-over, chemical consumption in bleaching, and the emission load of waste water are all reduced. Additionally, it allows for recovery of the cooking chemicals from the washing water. Efficient washing is done by counter-current multistage washing, using filters and presses. The water system in the brown stock screening plant is completely closed
Partial process water recycling in the bleach plant	Acid and alkaline filtrates are recycled within the bleach plant counter-currently to the pulp flow. Water is purged either to the waste water treatment plant or, in a few cases, to post-oxygen washing. Efficient washers in the intermediate washing stages are a prerequisite for low emissions. A bleach plant effluent flow of 12 – 25 m^3/ADt is achieved in efficient mills (kraft)

Technique	Description
Effective spill monitoring and containment, also with chemical and energy recovery	An effective spill control, catchment and recovery system that prevents accidental releases of high organic and sometimes toxic loads or peak pH values (to the secondary waste water treatment plant) comprises: – conductivity or pH monitoring at strategic locations to detect losses and spills; – collecting diverted or spilled liquor at the highest possible liquor solids concentration; – returning collected liquor and fibre to the process at appropriate locations; – preventing spills of concentrated or harmful flows from critical process areas (including tall oil and turpentine) from entering the biological effluent treatment; – adequately dimensioned buffer tanks for collecting and storing toxic or hot concentrated liquors.
Maintaining sufficient black liquor evaporation and recovery boiler capacity to cope with peak loads	Sufficient capacity in the black liquor evaporation plant and in the recovery boiler ensure that additional liquor and dry solids loads due to the collection of spills or bleach plant effluents can be dealt with. This reduces losses of weak black liquor, other concentrated process effluents and potentially bleach plant filtrates. The multi-effect evaporator concentrates weak black liquor from brown stock washing and, in some cases, also biosludge from the effluent treatment plant and/or salt cake from the ClO_2 plant. Additional evaporation capacity above normal operation gives sufficient contingency to recover spills and to treat potential bleach filtrate recycle streams
Stripping the contaminated (foul) condensates and reusing the condensates in the process	Stripping the contaminated (foul) condensates and reuse of condensates in the process reduces the fresh water intake of a mill and the organic load to the waste water treatment plant. In a stripping column, steam is lead counter-currently through the previously filtered process condensates that contain reduced sulphur compounds, terpenes, methanol and other organic compounds. The volatile substances of the condensate accumulate in the overhead vapour as non-condensable gases and methanol and are withdrawn from the system. The purified condensates can be reused in the process, e.g. for washing in the bleach plant, in brown stock washing, in the causticising area (mud washing and dilution, mud filter showers), as TRS scrubbing liquor for lime kilns, or as white liquor make-up water. The stripped non-condensable gases from the most concentrated condensates are fed into the collection system for strong malodorous gases and are incinerated. Stripped gases from moderately contaminated condensates are collected into the low volume high concentration gas system (LVHC) and incinerated
Evaporating and incinerating effluents from the hot alkaline extraction stage	The effluents are first concentrated by evaporation and then combusted as biofuel in a recovery boiler. Sodium carbonate containing dust and melt from the furnace bottom are dissolved to recover soda solution
Recirculation of washing liquids from pre-bleaching to brown stock washing and evaporation to reduce emissions from MgO-based pre-bleaching	Prerequisites for the use of this technique are a relatively low kappa number after cooking (e.g. 14 – 16), sufficient capacity of tanks, evaporators and recovery boiler to cope with additional flows, the possibility to clean the washing equipment from deposits, and a moderate brightness level of the pulp ($\leq$ 87 % ISO) as this technique may lead to a slight loss of brightness in some cases. For market paper pulp producers or others that have to reach very high brightness levels (> 87 % ISO), it may be difficult to apply MgO pre-bleaching
Counter-current flow of process water	In integrated mills, fresh water is introduced mainly through the paper machine showers from which it is fed upstream towards the pulping department

Technique	Description
Separation of water systems	Water systems of different process units (e.g. pulping unit, bleaching and paper machine) are separated by washing and dewatering the pulp (e.g. by wash presses). This separation prevents carry-over of pollutants to subsequent process steps and allows for removing disturbing substances from smaller volumes
High consistency (peroxide) bleaching	For high consistency bleaching, the pulp is dewatered e.g. by a twin wire or other press before bleaching chemicals are added. This allows for more efficient use of bleaching chemicals and results in a cleaner pulp, less carry-over of detrimental substances to the paper machine and generates less COD. Residual peroxide may be recirculated and reused
Fibre and filler recovery and treatment of white water	White water from the paper machine can be treated by the following techniques: a) 'Save-all' devices (typically drum or disc filter or dissolved air flotation units etc.) that separate solids (fibres and filler) from the process water. Dissolved air flotation in white water loops transforms suspended solids, fines, small-size colloidal material and anionic substances into flocks that are then removed. The recovered fibres and fillers are recirculated to the process. Clear white water can be reused in showers with less stringent requirements for water quality. b) Additional ultrafiltration of the pre-filtered white water results in super clear filtrate with a quality sufficient for use as high pressure shower water, sealing water and for the dilution of chemical additives
Clarification of white water	The systems for water clarification used almost exclusively in the paper industry are based on sedimentation, filtration (disc filter) and flotation. The most used technique is dissolved air flotation. Anionic trash and fines are agglomerated into physically treatable flocs by using additives. High-molecular, water-soluble polymers or inorganic electrolytes are used as flocculants. The generated agglomerates (flocs) are then floated off in the clarification basin. In dissolved air flotation (DAF), the suspended solid material is attached to air bubbles
Water recirculation	Clarified water is recirculated as process water within a unit or in integrated mills from the paper machine to the pulp mill and from the pulping to the debarking plant. Effluent is mainly discharged from the points with the highest pollution load (e.g. clear filtrate of the disc filter in pulping, debarking)
Optimum design and construction of tanks and chests (papermaking)	Holding tanks for stock and white water storage are designed so that they can cope with process fluctuations and varying flows also during start-ups and shutdowns
Washing stage before refining softwood mechanical pulp	Some mills pretreat softwood chips by combining pressurised preheating, high compression and impregnation to improve pulp properties. A washing stage before refining and bleaching significantly reduces COD by removing a small, but highly concentrated effluent stream that can be treated separately
Substitution of NaOH by $Ca(OH)_2$ or Mg $(OH)_2$ as alkali in peroxide bleaching	The use of $Ca(OH)_2$ as alkali results in approximately 30 % lower COD emission loads; while keeping brightness levels high. Also $Mg(OH)_2$ is used to replace NaOH
Closed-loop bleaching	In sulphite pulp mills using sodium as a cooking base, the bleach plant effluent can be treated, e.g. by ultrafiltration, flotation and separation of resin and fatty acids which enables closed-loop bleaching. The filtrates from bleaching and washing are reused in the first washing stage after cooking and finally recycled back to the chemical recovery units
pH adjustment of weak liquor before/inside the evaporation plant	Neutralisation is done before evaporation or after the first evaporation stage, to keep organic acids dissolved in the concentrate, in order for them to be sent with the spent liquor to the recovery boiler

Technique	Description
Anaerobic treatment of the condensates from the evaporators	See Section 8.7.2.2 (combined anaerobic-aerobic treatment)
Stripping and recovery of SO_2 from condensates of evaporators	SO_2 is stripped from the condensates; concentrates are treated biologically, while SO_2 is sent for recovery as a cooking chemical
Monitoring and continuous control of the process water quality	Optimisation of the entire 'fibre-water-chemical additive-energy system' is necessary for advanced closed water systems. This requires a continuous monitoring of the water quality and staff motivation, knowledge and action related to the measures needed to ensure the required water quality
Prevention and elimination of biofilms by using methods that minimise emissions of biocides	A continuous input of microorganisms by water and fibres leads to a specific microbiological equilibrium in each paper plant. To prevent extensive growth of the microorganisms, deposits of agglomerated biomass or biofilms in water circuits and equipment, often biodispersants or biocides are used. When using catalytic disinfection with hydrogen peroxide, biofilms and free germs in process water and paper slurry are eliminated by using methods that minimise emissions of biocides.
Removal of calcium from process water by controlled precipitation of calcium carbonate	Lowering the calcium concentration by controlled removal of calcium carbonate (e.g. in a dissolved air flotation cell) reduces the risk of undesired precipitation of calcium carbonate or scaling in water systems and equipment, e.g. in section rolls, wires, felts and shower nozzles, pipes or biological waste water treatment plants
Optimisation of showers in paper machine	Optimising showers involves: a) the reuse of process water (e.g. clarified white water) to reduce fresh water use, and b) the application of special design nozzles for the showers

8.7.2.2 Waste water treatment

Technique	Description
Primary treatment	Physico-chemical treatment, such as equalisation, neutralisation or sedimentation. Equalisation (e.g. in equalising basins) is used to prevent large variations in flow rate, temperature and contaminant concentrations and thus to avoid overloading the waste water treatment system
Secondary (biological) treatment	For the treatment of waste water by means of microorganisms, the available processes are aerobic and anaerobic treatment. In a secondary clarification step, solids and biomass are separated from effluents by sedimentation, sometimes combined with flocculation
a) Aerobic treatment	In aerobic biological waste water treatment, biodegradable dissolved and colloidal material in the water is transformed in the presence of air by microorganisms partly into a solid cell substance (biomass) and partly into carbon dioxide and water. Processes used are: – one- or two-stage activated sludge; – biofilm reactor processes; – biofilm/activated sludge (compact biological treatment plant). This technique consists in combining moving bed carriers with activated sludge (BAS). The generated biomass (excess sludge) is separated from the effluent before the water is discharged
b) Combined anaerobic-aerobic treatment	Anaerobic waste water treatment converts the organic content of waste water by means of microorganisms in the absence of air, into methane, carbon dioxide, sulphide, etc. The process is carried out in an airtight tank reactor. The microorganisms are retained in the tank as biomass (sludge). The biogas formed by this biological process consists of methane, carbon dioxide and other gases such as hydrogen and hydrogen sulphide and is suitable for energy generation. Anaerobic treatment is to be seen as pretreatment before aerobic treatment, due to the remaining COD loads. Anaerobic pretreatment reduces the amount of sludge generated from biological treatment
Tertiary treatment	Advanced treatment comprises techniques, such as filtration for further solids removal, nitrification and denitrification for nitrogen removal or flocculation/precipitation followed by filtration for phosphorus removal. Tertiary treatment is normally used in cases where primary and biological treatment are not sufficient to achieve low levels of TSS, nitrogen or phosphorus, which may be required e.g. due to local conditions
Properly designed and operated biological treatment plant	A properly designed and operated biological treatment plant includes the appropriate design and dimensioning of treatment tanks/basins (e.g. sedimentation tanks) according to hydraulic and contaminant loads. Low TSS emissions are achieved by ensuring the good settling of the active biomass. Periodical revisions of the design, dimensioning and operation of the waste water treatment plant facilitate achieving these objectives

8.7.3 Description of techniques for waste generation prevention and waste management

Technique	Description
Waste assessment and waste management system	Waste assessment and waste management systems are used to identify feasible options for optimising prevention, reuse, recovery, recycling and final disposal of waste. Waste inventories allow for identifying and classifying type, characteristics, amount and origin of each waste fraction
Separate collection of different waste fractions	The separate collection of different waste fractions at the points of origin and, if appropriate, intermediate storage can enhance the options for reuse or recirculation. Separate collection also includes segregation and classification of hazardous waste fractions (e.g. oil and grease residues, hydraulic and transformer oils, waste batteries, scrap electrical equipment, solvents, paints, biocides or chemical residues)
Merging of suitable residue fractions	Merging of suitable fractions of residue depending on the preferred options for reuse/recycling, further treatment and disposal
Pretreatment of process residues before reuse or recycling	Pretreatment comprises techniques such as: – dewatering e.g. of sludge, bark or rejects and in some cases drying to enhance reusability before utilisation (e.g. increase calorific value before incineration); or – dewatering to reduce weight and volume for transport. For dewatering belt presses, screw presses, decanter centrifuges or chamber filter presses are used; – crushing/shredding of rejects e.g. from RCF processes and removal of metallic parts, to enhance combustion characteristics before incineration; – biological stabilisation before dewatering, in case agricultural utilisation is foreseen
Material recovery and recycling of process residues on site	Processes for material recovery comprise techniques such as: – separation of fibres from water streams and recirculation into feedstock; – recovery of chemical additives, coating pigments, etc.; – recovery of cooking chemicals by means of recovery boilers, causticising, etc.
Energy recovery on- or off-site from wastes with high organic content	Residues from debarking, chipping, screening etc. like bark, fibre sludge or other mainly organic residues are burnt due to their calorific value in incinerators or biomass power plants for energy recovery
External material utilisation	Material utilisation of suitable waste from pulp and paper production can be done in other industrial sectors, e.g. by: – firing in the kilns or mixing with feedstock in cement, ceramics or bricks production (includes also energy recovery); – composting paper sludge or land spreading suitable waste fractions in agriculture; – use of inorganic waste fractions (sand, stones, grits, ashes, lime) for construction, such as paving, roads, covering layers etc. The suitability of waste fractions for off-site utilisation is determined by the composition of the waste (e.g. inorganic/mineral content) and the evidence that the foreseen recycling operation does not cause harm to the environment or health
Pretreatment of waste fraction before disposal	Pretreatment of waste before disposal comprises measures (dewatering, drying etc.) reducing the weight and volume for transport or disposal

9 CONCLUDING REMARKS AND RECOMMENDATIONS FOR FUTURE WORK

Timing of the review process
The key milestones of the review process are summarised in Table 9.1.

Table 9.1: Key milestones of the review process of the BREF for the Production of Pulp, Paper and Board

Key milestone	Date
Reactivation of the TWG	19 April 2006
Call for wishes	31 May 2006
Kick-off meeting	13 – 15 November 2006
First data collection	2007
Second data collection	2009
First draft of revised PP BREF	19 April 2010
End of commenting period on first draft (1 836 comments received)	21 June 2010
Third data collection (air)	Spring 2011
Second draft of revised PP BREF	4 May 2012
End of commenting period on second draft (1 451 comments received)	13 July 2012
Final TWG meeting	22 – 26 April 2013

During the review process, a total of 31 site visits in six EU Member States were carried out, covering all PP subsectors and comprising paper mills of various sizes, configurations and levels of complexity.

Sources of information and information gaps
During the review of the BREF for the Production of Pulp, Paper and Board (PP BREF), around 3 500 comments were made by the TWG. Major contributors of information were the Confederation of European Paper Industries (CEPI) and 13 EU Member States. The data collection exercise provided a large basis for emissions data and techniques in use at the mill site level: around 130 questionnaires were received. All these documents were assessed by the EIPPCB. As a result, more than 280 documents are referenced in the revised PP BREF (see REFERENCES).

Degree of consensus reached during the information exchange
A high degree of consensus was reached on the BAT conclusions. However, some dissenting views were raised, as described in the following table.

Table 9.2: Split views

Split view number	TWG member	Expression of the split view
2	ES	A dissenting view was expressed by Spain, who considers that there should not be a reference to a concentration value for BOD emissions in the BAT conclusions without providing an associated waste water flow
3	AT, DE, EEB	A dissenting view was expressed by Austria and Germany, supported by EEB, who consider that BAT-associated emission levels (BAT-AELs) for emissions to water should refer, in general, to daily averages
4	AT, DE, EEB	A dissenting view was expressed by Austria and Germany, supported by EEB, who consider that BAT-associated emission levels (BAT-AELs) for emissions to air should refer, in general, to a short-term averaging period, i.e. daily average
6	ES, PT, PL, CEPI	A dissenting view was expressed by Spain and CEPI, supported by Portugal and Poland, who consider that the upper end of the BAT-associated emission level (BAT-AEL) as a yearly average for gaseous S for recovery boilers in kraft pulp production (BAT 21) should be increased from 0.17 to 0.21 kg S/ADt
8	IT, FR, PL CEPI	A dissenting view was expressed by Italy, supported by France, Poland and CEPI, who consider that the upper end of the BAT-associated emission level (BAT-AEL) on total phosphorus for waste water discharges to receiving waters from the integrated production of paper and board from recycled fibres pulp produced without deinking on site (BAT 45) should be increased from 0.005 kg/t to 0.01 kg/t, as a yearly average

Consultation of the Forum and subsequent formal adoption procedure of the BAT Conclusions

In accordance with Article 13(3) of the Directive, the forum gave its opinion on the draft Best Available Techniques (BAT) reference document for the Production of Pulp, Paper and Board as presented at the meeting of the forum of 20 September 2013:

1. The forum welcomed the draft Best Available Techniques (BAT) reference document for the Production of Pulp, Paper and Board as presented by the Commission.
2. The forum acknowledged the discussions held at its meeting of 20 September 2013 and agreed that the changes to the draft Best Available Techniques (BAT) reference document for the Production of Pulp, Paper and Board, as proposed in Annex A, should be included in the final document.
3. The forum reaffirmed the comments in Annex B as representing the views of certain members of the forum but, on which, no consensus existed within the forum to include them in the final document.

Subsequently, the Commission took the opinion of the IED Article 13 Forum into account when preparing the draft Commission Implementing Decision establishing best available techniques (BAT) conclusions for the production of pulp, paper and board. The IED Article 75 Committee, at its meeting of 6 May 2014, gave a positive opinion on this draft Commission Implementing Decision.

Subsequently:

- the Commission Implementing Decision 2014/687/EU establishing best available techniques (BAT) conclusions for the production of pulp, paper and board was adopted on 26 September 2014 and published in the Official Journal of the European Union (OJ L 284, 30.9.2014, p. 76)

Recommendations for future work

The information exchange revealed a number of issues where further information should be collected during the next review of the PP BREF. These issues include:

- the compelling need to collect short-term emissions data for air and water pollutants, and their corresponding flows, based on a well designed and agreed questionnaire, in relation to: kraft pulp mills, sulphite pulp mills, mechanical pulp mills, RCF without deinking mills, RCF with deinking mills, non-integrated paper mills and speciality paper mills;
- the compelling need to discuss whether emissions of the relevant pollutants emitted by the sector should be expressed in concentrations and/or loads;
- the need to improve the quality and comparability of the data reported (e.g. harmonisation of methods to obtain the short- and long-term averages, distinction between new and existing mills);
- the compelling need to collect data on energy consumption with a harmonised methodology (e.g. using criteria mentioned in regulatory instruments, such as the EU Ecolabel);
- researching information about the kraft pulp mills using tertiary treatment (also including those outside the EU);
- the need to collect data on CO emissions from the lime kiln in the kraft sector and from the recovery boiler in the sulphite sector, including potential cross-media effects (NO_X, SO_X, energy efficiency);
- the need to collect data on flows associated to SO_2 and TRS emissions, and further data on NO_X emissions from dedicated TRS burners for the kraft sector;
- the compelling need to collect data on emissions from the dissolving kraft and dissolving sulphite processes;
- the need to collect contextual information in relation to COD and total nitrogen emissions for non-integrated paper and board mills (excluding speciality paper mills).

Suggested topics for future R&D work

The Commission is launching and supporting, through its Research and Technological Development programmes, a series of projects dealing with clean technologies, emerging effluent treatment and recycling technologies and management strategies. Potentially, these projects could provide a useful contribution to future BREF reviews. Readers are therefore invited to inform the European IPPC Bureau of any research results which are relevant to the scope of this document (see also the fifth section of the Preface of this document).

The 'Two-Team Project' was launched by CEPI to identify breakthrough technologies to cut the carbon footprint of pulp- and papermaking. Examples of breakthrough technologies are the use of deep eutectic solvents and flash condensing with steam.

10 ANNEXES

10.1 Annex I: Determination of emissions for specific waste water discharges from integrated chemical pulp mills and/or multiproduct mills

The method for assessing emissions for specific waste water discharges from integrated chemical pulp mills and/or multiproduct mills proposed in Section 2.1.3 is explained below using two examples.

Example 1: multiproduct mill which consists of an integrated kraft pulp and paper mill, a CTMP mill, and a RCF pulp and paper mill

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The example mill is a multiproduct mill which manufactures bleached kraft pulp and uncoated fine paper, CTMP pulp, wood-containing coated paper and deinked RCF pulp and paper. The effluents from all departments are mixed before treatment and are sent to primary and biological treatment. For assessing the environmental performance of the mill, the pollutant concentrations and the corresponding flow are measured at the final point of waste water discharge.

The production profile, the net production (2008) and the installed capacity of the mill are given in Table 10.1 (data were modified by the EIPPCB as the example is only illustrative):

Table 10.1: Production profile of the multiproduct mill

Type of production	Production capacity [ADt/day]	Net production [ADt/day]
Bleached kraft pulp from softwood and hardwood (most of the pulp is used for paper manufacturing in the same plant)	1 320	1 200
CTMP pulp (all pulp is used for the manufacturing of wood-containing paper in the same plant)	225	207
Wood-free uncoated fine paper	1 345	1 077
Wood-containing coated paper	830	600
Recovered paper-based paper with DIP	370	312
Total net production (paper and a little market pulp; some pulp is purchased to make the required fibre balance)	2 570	2 047
Source: Institute of Biopolymers and Chemical Fibres, Environmental Protection Laboratory, Lodz, Poland, 2009		

Calculation of emissions for specific waste water discharges

The method of calculation is presented for the example of COD emissions. The current BAT-AELs for COD for the types of production listed above are compiled in Table 10.2.

Table 10.2: BAT-AELs for COD for the different types of production of the multiproduct mill

Type of production	BAT-AEL$_{COD}$ BREF [kg/ADt]	BAT-AEL$_{COD}$ values used for calculations [kg/ADt]
Bleached kraft pulp	7 – 20 (Chapter 8)	It is up to the local competent authority to decide whether the lower or the upper end of the BAT-AELs, or something in between, is applied (e.g. see items I and II below)
Uncoated fine paper (wood-free)	0.15 – 1.5 (Chapter 8)	
Integrated mechanical pulp and paper	0.9 – 4.5 (Chapter 8)	
Integrated RCF pulp with DIP & paper	0.9 – 3.0 (Chapter 8)	

I. Calculation based on the upper end of the BAT-AEL range for COD:

Equation (^{1}): $\text{Load}_{\text{COD}} = 1\,200 \times 20 + 1\,077 \times 1.5 + 600 \times 4.5 + 312 \times 3 = 29\,251.5$ kg/day

Equation (^{2}) using flow values within the flow ranges shown in Sections 3.2, 7.2, 5.2 and 6.2:
$\sum flow = 1\,200 \times 40 + 1\,077 \times 12.5 + 600 \times 16 + 312 \times 11.5 = 74\,651$ m^3/day

Calculating the flow according to Equation (^{2}) and applying Equation (^{1}) gives a corresponding COD concentration of around 390 mg/l. Other readers may prefer to work with total loads and the corresponding flows only.

II. Calculation based on the lower end of the BAT-AEL range:

Equation (^{1}): $\text{Load}_{\text{COD}} = 1\,200 \times 7 + 1\,077 \times 0.15 + 600 \times 0.9 + 312 \times 3 = 10\,037.55$ kg/day

Considering the same flow calculated before, a corresponding COD concentration of around 135 mg/l for this individual multiproduct mill can be determined.

The emissions for the other pollution parameters such as BOD, TSS, AOX, tot-P, tot-N and specific waste water flow can be calculated in the same way as exemplified for COD.

Example 2: integrated kraft pulp and paper mill that produces coated and uncoated graphic papers

The example mill is located by the sea on the west coast of Finland near the city of Rauma. At the same mill site, a pulp mill, a tall oil refinery, a biofuel power plant, four paper machine lines, a fluff pulp line, a twin-line debarking plant, two grinders, three TMP plants, a surface water treatment plant, a joint biological waste water treatment plant for industrial and municipal waste water and a landfill site for industrial waste are located.

The production capacity is 600 000 tonnes/yr ECF sulphate pulp, of which 150 000 tonnes are fluff pulp and 1 280 000 tonnes are supercalendered paper and light-weight coated paper. The capacity of the tall oil refinery is 100 000 tonnes/yr. The biofuel power plant also produces district heat to the town of Rauma.

Figure 10.1 outlines the production processes and other main operations at the Rauma integrated mills. In this integrated case, the pulp and paper mills are owned and operated by different companies. Oy Metsä-Botnia Ab operates all kraft pulp mill operations whereas UPM-Kymmene Oyj operates mechanical pulping, paper mill operations, fluff pulp line and a joint waste water treatment plant. The biofuel power plant and tall oil refinery are also operated by independent companies. There is also the option for the paper mill to buy kraft pulp and fluff pulp outside (not from Metsä-Botnia).

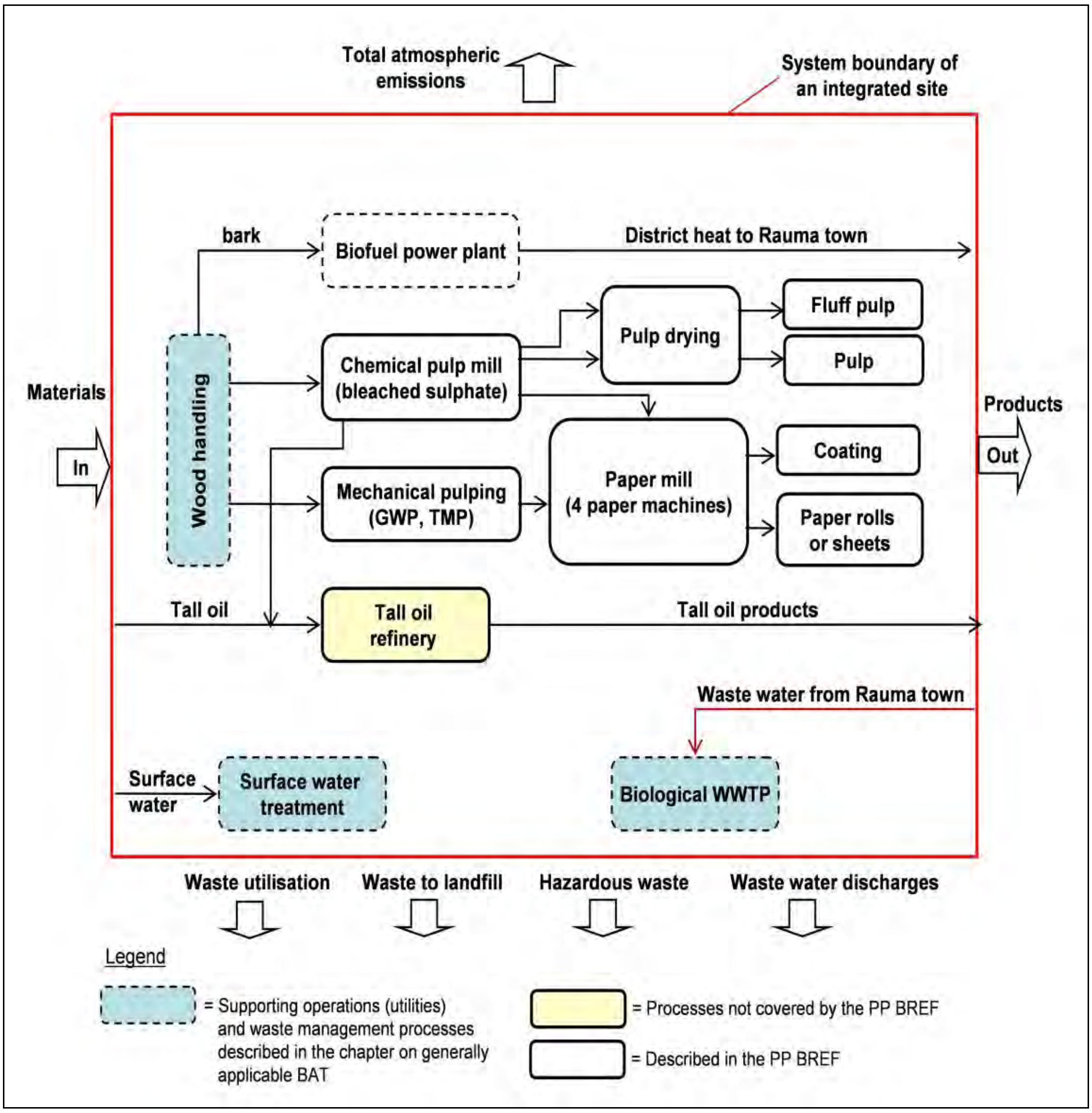


Figure 10.1: Example of an integrated pulp and paper mill: the production and supporting processes at Rauma mills

Allocating emissions from a joint waste water treatment plant at the Rauma site including a chemical pulp mill and a paper mill

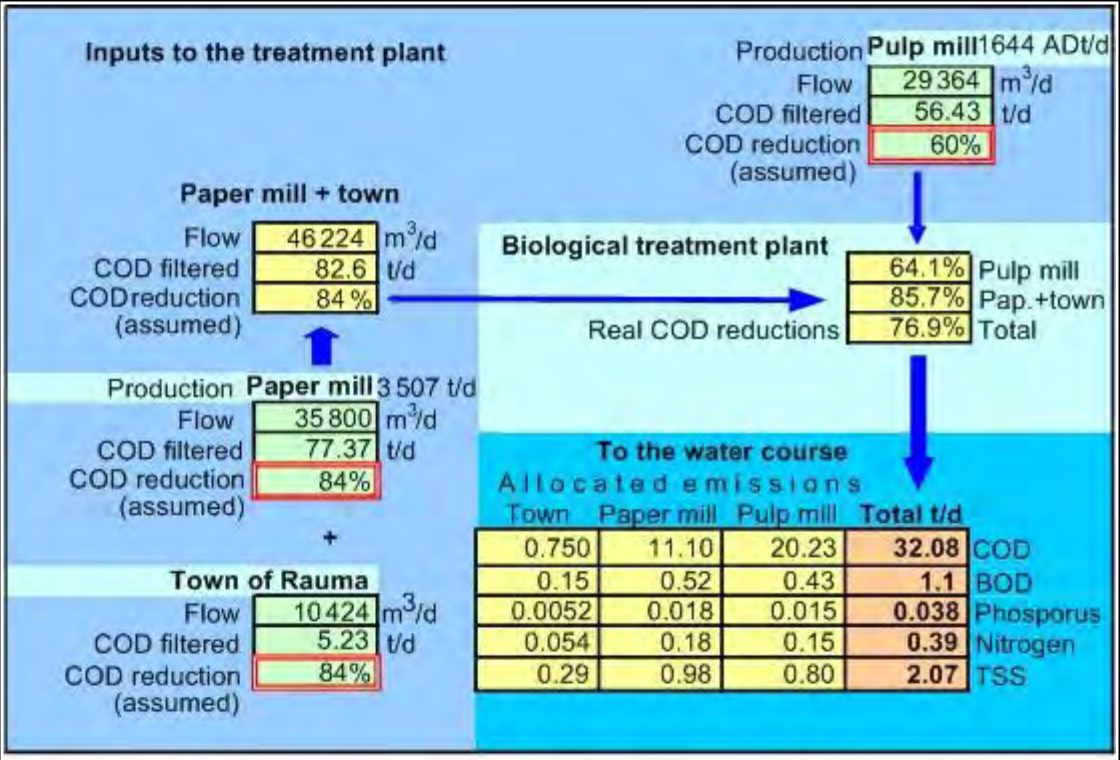
Waste waters from the two mills (and from the town) are mixed and treated in an activated sludge plant. BOD, phosphorus, nitrogen and total solids are allocated according to flow and the measured outlet concentration. The maximum flow of the pulp mill is 29 364 m^3/day (~17.8 m^3/ADt), of the paper mill 35 800 m^3/day (~10.2 m^3/ADt) and of the town of Rauma 10 424 m^3/day. This can be justified by the fact that, in a biological treatment plant, the bacteria need a certain minimum soluble concentration of biodegradable organic material and nutrients to live and this concentration is reached in a correctly dimensioned plant. The plant is designed to reach the minimum BOD concentration and nutrient concentration is controlled by adding these elements to the process for the proper functioning of the biological process. Increasing or decreasing the BOD or nutrient load for the plant moderately does not change the output concentration. Additional BOD is readily consumed by the bacteria and nutrient control determines the necessary addition to reach the targeted output level. Adding more fresh water (flow) to the processes and the treatment plant instead increases the total emission load because the concentration would remain unchanged. The solids concentration after the sedimentation process depends on flow, and increasing flow even increases the concentration and thus also the total load.

The COD emission is allocated in this case according to the soluble part of the COD (in practice filtered) of the input flows. However, the different character of chemical pulp mill COD and paper mill COD is taken into account. COD reduction for soluble COD from the paper mill in an activated sludge plant is typically 80 – 85 %. The corresponding figure for chemical pulp COD is typically 55 – 70 % depending on the subprocesses of the mill.

In the case of Rauma, certain assumed soluble COD reduction rates are set for the two mills: 84 % for the paper mill, and 60 % for the pulp mill (see Figure 10.2). As these two reduction rates never precisely meet the real total reduction of the plant over a certain period of time, they have to be adapted. This adaptation is selected so that it leads proportionally to the same emission change for both mills compared to the situation with the assumed reduction figures: in this case, the real achieved reduction rates for COD are 64 % for the pulp mill, and around 87 % for the paper mill.

A reduction of the initial COD load from the pulp mill of 56.34 tonnes/day by 64 % gives a discharge of 20.2 tonnes/day which corresponds to a product-specific value of 12.3 kg COD/ADt, if calculated with production at maximum capacity (1 644 ADt/day, 365 operating days). For the paper mill, the initial COD load of 77.37 tonnes/day is reduced to 11.1 tonnes/day (~86 %) which corresponds to a specific COD load of 3.2 kg COD/t, if calculated with production at maximum capacity (3 507 tonnes/day, 365 operating days).

Figure 10.2 summarises exemplarily the assumptions made for the allocation of the emissions from the joint waste water treatment plant for an integrated site that produces chemical pulp, mechanical pulp and printing paper.



Town	Paper mill	Pulp mill	Total t/d	
0.750	11.10	20.23	32.08	COD
0.15	0.52	0.43	1.1	BOD
0.0052	0.018	0.015	0.038	Phosporus
0.054	0.18	0.15	0.39	Nitrogen
0.29	0.98	0.80	2.07	TSS

Source: Finnish Environment Institute

Figure 10.2: Allocation of the emissions from a joint waste water treatment plant at the Rauma integrated mill site that includes a chemical pulp mill and a paper mill

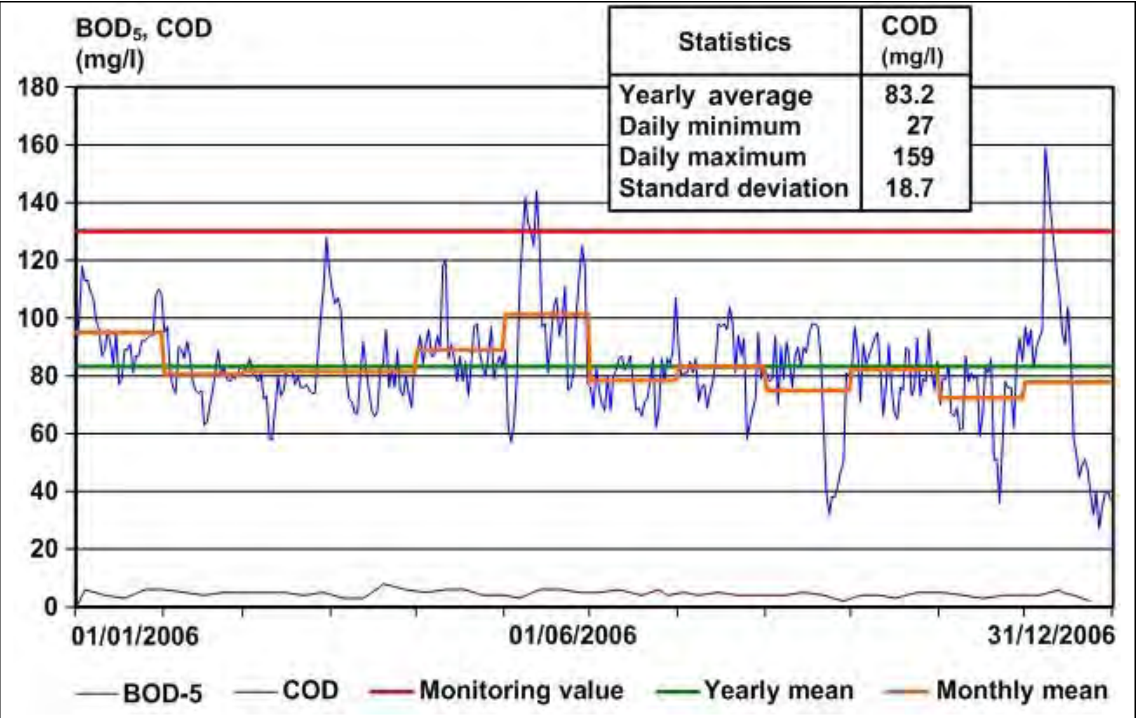
10.2 Annex II: Variations of emissions over time

10.2.1 Variation of emissions during different reference periods

In permits and for establishing permit compliance for pulp and paper mills, different concentration- or load-based emission or target values with different time references (daily, monthly, yearly means) are used. In order to facilitate the widest possible use of the presented emission data, it seems useful to discuss the relationships between the different applied reference periods in order to enable a reliable comparison of such data and to objectively interpret the BAT-AELs. Data presented in this document represent different reference periods - yearly, monthly and daily average values.

Emissions to water

The emissions to water (and air) for different reference periods vary over time and this should be borne in mind when deriving BAT-AELs for a given mill. The COD and BOD_5 emissions of an existing example mechanical pulp and paper mill are plotted in Figure 10.3 as daily, monthly and yearly mean values. The example shows the magnitude of the fluctuations of emissions over a complete year and gives an idea of the relevance of different reference periods (e.g. daily, monthly and yearly means). The standard deviation and the permit limit value (monitoring value) are also indicated in this example.



Statistics	COD (mg/l)
Yearly average	83.2
Daily minimum	27
Daily maximum	159
Standard deviation	18.7

Source: [178, R.Spörl 2009]

Figure 10.3: COD and BOD emission data after biological treatment expressed as daily, monthly and yearly means

By use of this example and other studies ([177, Spanish Ministry of Environment 2009], [178, R.Spörl 2009]), the major aspects related to the variability of emissions over time are discussed and the conclusions are presented below.

- Emission data with different reference periods show different fluctuations and have different absolute values. The longer the reference period, the lower the relevant emission limit can be.
- The yearly mean value is the average of all measured emission data over a complete year.

- The monthly average can be best expressed as a minimum - maximum range. The highest monthly average values have been taken as BAT-AEL, when provided, because a whole month is considered a significant time interval. No values are disregarded.
- Daily average values measured in 24-hour mixed samples over a complete year normally show a typical behaviour within a certain range but some higher peak values can also be seen. Taking the highest daily mean value of the entire set as a reference for the achieved emissions does not give a representative picture of the real environmental performance of the mill (in Figure 10.3 this would correspond to a COD value of 159 mg/l determined in the 24-hour mixed sample). This would overestimate the relevance of the few days where failures, disruptions or deviations from normal operating conditions occur and consequently this leads to an unreasonably high emission level. The actual plant performance achieved by normal operating conditions is not reflected by this emission level.
- Therefore, BAT-AELs for daily average reference periods are based on an outlier-adjusted data set. This approach corresponds to normal operating conditions which means that extraordinary failures or disruptions are excluded. However, typical short-term interruptions of the production process (e.g. web breaks in the paper machine) are considered to be part of a paper mill's normal operation because web breaks occur on a regular basis, for example once a day (or more). During normal operation, fluctuations in emission data are mainly of a random nature and therefore, as a rule of thumb, outliers can be rejected by dismissing all values that are above or below the yearly mean plus double the standard deviation (disregard outlier >yearly mean + 2 × STDDEV). This corresponds roughly to the 97th percentile value. In our example, see Figure 10.3, emission values >120 mg/l and <45 mg/l would be disregarded. In the example, the following values were considered atypical: increased COD values occurring on several days in June and December, when mill trials for the development of new products led to higher levels; but also lower COD values caused by standstills on several days in September and December.
- A simple method to dismiss atypical peak values to establish BAT-AELs is to calculate the 95th percentile for the daily average values. Other percentiles and approaches are also possible and are applied in Europe.
- There is no constant relationship between the emission data of different reference periods. However, approximated values can be derived with reasonable accuracy. It should be noted that all these approximations are based on a number of assumptions that should be considered when using them. The variability of emission can be characterised by using the standard deviation. Another option is the use of variability factors, meaning the ratio between the daily/monthly mean values and the yearly average value for example.
- Variability factors, i.e. regarding the ratio between the daily mean values and the yearly average, can be established which make it possible to approximately calculate or assess the corresponding emission levels of daily, monthly and yearly average values.
- A recent study on the variation of emissions during different reference periods carried out for four large and medium-sized Spanish pulp and paper mills derived variability factors between daily and yearly average values [177, Spanish Ministry of Environment 2009]. The analysed mills all apply BAT and achieve emission values within the ranges associated with the implementation of BAT as included in the BREF. The analysis focuses exclusively on TSS and COD. All measured values were taken into consideration when calculating the monthly and yearly averages, whereas only 95 % of the daily readings were used for calculating the daily mean values – the highest readings were discarded. The highest 5 % of the values were not taken into account in order to reflect a more representative situation, which can be considered normal operation. Expressed as specific emission load (kg TSS/ADt and kg COD/ADt), the variability factors or the ratio between the yearly mean and the 95th percentile value of the daily average values of the four mills were determined to be 2.3 for TSS and 1.7 for COD. In other countries and mills there are also findings with slightly higher and lower ratios. In Table 10.3 the actual measured and calculated specific COD emission load data are shown for three different reference periods (year, month, day).

Table 10.3: **Mean yearly, monthly and daily values for specific COD emissions from four mills**

Type of mill	COD kg/ADt			Daily/yearly mean variability factor
	Yearly average	Highest monthly average	95th percentile of daily mean values	
Market bleached kraft	11.15	12.82	17.12	1.53
Kraft pulp partially integrated with coated paper	7.17	7.95	14.25	1.99
Packaging paper with deinking	1.04	1.15	1.85	1.78
Coated paper	1.71	2.08	2.65	1.55
Source: [177, Spanish Ministry of Environment 2009]				

- Assuming more or less normally distributed emission values, a recent study proposed a simple formula to convert the emission concentration levels of one reference period (e.g. a day) into a monthly or yearly emission value by using the standard deviation [178, R.Spörl 2009]. However, in some cases (e.g. P, N and TSS emissions) the effluent values are positively, unevenly distributed.
- The variation of emission values varies between parameters within a certain range. Figure 10.3 shows that the BOD_5 values are rather stable and always below 25 mg/l as a daily average. COD emission levels vary over time within a certain range.
- Variations of emissions over time within a certain range are unavoidable. However, there are many measures to ensure the smoother running of processes and emission control techniques. To prevent and reduce peak emissions is considered BAT.

The reader of this document should be aware of the differences between daily, monthly and yearly average emission values. Emission values should always be interpreted together with the corresponding reference period.

Emissions to air

A Spanish report on variability analysis of air emissions from recovery boilers and lime kilns [10, Spanish Ministry of Environment 2012] shows the variations among values obtained from a daily sample and the corresponding yearly average. It is calculated as the ratio between the maximum daily values and the mean yearly value. Only 95 % of the daily readings were used for the daily values – the highest readings were discarded. Table 10.4 shows this variability in recovery boilers and Table 10.5 illustrates this variability in lime kilns.

Table 10.4: Day/year variability factors in recovery boilers

Air emissions variability in recovery boilers						
95th percentile daily value/ yearly average value						
No of Recovery Boiler	**Parameter**					**Average of day/year variability in recovery boilers**
	Dust	**NO_X**	**SO_2**	**TRS**	**SH_2**	
1	1.6	1.23	2.67		2.35	2.1
2	1.94	1.13	2.17	1.33		
3	1.96			4.2		
4	1.87		2.26	2.71	1.8	
5	2.56	1.18	2.98	1.91	2.0	
6	1.77	1.59	2.52		2.12	
7	1.32	1.27	1.94		2.6	
8	1.77		2.43	3.72	2.07	
Day/year variability average	1.85	1.28	2.42	2.77	2.16	
Source: [10, Spanish Ministry of Environment 2012]						

Table 10.5: Day/year variability factors in lime kilns

Air emissions variability in lime kilns						
95th percentile daily value/ yearly average value						
No of Lime kiln	**Parameter**					**Average of day/year variability in lime kilns**
	Dust	**NO_X**	**SO_2**	**TRS**	**SH_2**	
1	1.7	1.54	2.56		2.72	2.23
2	1.67			2.4		
3	2.34	2.17	2.81	2.91		
4	1.6	1.33	3.92	1.59	1.55	
5	2.67	1.66	1.99		2.84	
Day/year variability average	2.00	1.68	2.82	2.3	2.37	
Source: [10, Spanish Ministry of Environment 2012]						

10.2.2 Reasons for variations of emissions and counteractions

Much of the emission data presented in this document represent average situations over a complete year. In other cases, daily, monthly and yearly average values are given. There can be a significant difference between emission data based on different reference periods, e.g. daily and yearly averages can deviate by 50 % or more. The variability of individual emissions over time will depend upon the type of installation, the source of the emissions, the design and operation of the process, process control, maintenance, the substance concerned and other factors.

Variations of emissions are mainly observed for daily average values. Reasons for variations of emissions and possible counteractions [177, Spanish Ministry of Environment 2009] are given below.

I. Variability caused by the existence of intermediate stocks in the production processes. Impacts mainly on the daily average values.

II. Variability caused by differences in the raw materials (wood from different regions and countries; change of wood species; variable quality of paper for recycling). The inherent variations due to the variability of raw materials can be significant when considering daily and monthly averages.

III. Variability caused by changes in the pulp and paper grade.
In certain cases, changes in the quality grade of the paper being produced require white water and pulp circuits to be emptied and cleaned, which then generates an important increase in the pollutant load discharged. This is particularly significant in the cases of speciality and coloured papers. The frequency and scope of such changes in the paper grade being produced, as well as its organisation or relative frequency, depend to a large extent on different market factors. Grouping similar quality grades into the same production batch, ordering changes in such a way that cleaning cycles are minimised or the possibility of specialising in a certain type of product are all factors that should be taken into account. Good communication between the staff of the waste water treatment plant and the production process about significant changes in production is best practice. It allows for taking appropriate measures to guarantee the targeted quality of the discharge.
The variations associated with paper grade changes in the manufactured products are significant with regard to daily averages and may even be relevant when considering monthly averages.

IV. Variability caused by operation and process control.
These variations depend on the design of the installation, on the way it is operated, on the existing control systems and on the training, education and motivation of mill workers. The implementation of an Environmental Management System contributes to reducing such variations. When choosing which BAT to implement, it is usually preferable to select those that will provide greater stability and prioritise them over those that are more likely to generate disruptions.

V. Variability in waste water treatment plant operating performance.
The existence of an emergency basin or tank where accidental discharges can be collected before arriving at the waste water treatment plant protects the biological treatment and prevents damage to the biological system. Furthermore, homogenising the influent to the treatment plant by equalisation basins hydraulically and in terms of organic load significantly helps to improve the plant performance and reduce variations in the effluent. Possible malfunctions of the biological treatment or the secondary settler should be regularly controlled and action taken when required. The activated sludge process is vulnerable to perturbation and therefore needs supervision. The formation of 'bulking sludge' should be avoided by proper design and operation of the plant.

The variability of individual emissions over time will depend on the type of installation, the source of the emission, the pollutant concerned, the design and operation of the process, process control and maintenance, dimensioning, operation and maintenance of the abatement techniques and other factors. Care must be exercised in comparing data from different reference periods.

There is no 'rule of thumb' for converting yearly averages into monthly averages or daily composite samplings. Within a given range, it can be stated that the shorter the averaging period the greater the emissions variations. Monthly average values normally vary from month to month to a certain extent (depending on production, wood quality, climatic conditions, etc.). Normally only the statistical analysis of every case gives a reliable answer about the real range of variations.

Variability factors

The variability factor can be defined as the ratio of the maximum daily average value considered (e.g. 95th percentile) to the monthly maximum or the yearly average value. Table 10.3 above gives some examples of variability factors between daily average and yearly average values. As an average, the daily average value (95th percentile) for COD emissions was 70 % higher than the annual average value.

There is no reliable arithmetical method available which allows a direct comparison of short-term and long-term values or the derivation of one from the other. However, there are some pragmatic approaches, based on practical experiences in different countries, which can give a rough idea of the order of magnitude within which the results of measurements for different averaging periods may vary.

- In Germany, for water discharges of chemical pulp mills after biological treatment, it is assumed that the monitoring value based on a daily average sampling is about 60 % higher than the annual average value. For instance, a monitoring value based on a 24-hour sampling of 40 kg COD/t of pulp equals an annual average of 25 kg/t of pulp. The daily monitoring value is considered to be compliant if four out of five samplings are below the limit and no value exceeds the limit more than 100 %.
- In Sweden, as a rule of thumb, it is assumed that monthly averages can be expected to be up to 20 % higher than the annual average for that year.

GLOSSARY

This glossary is meant to facilitate the understanding of the information contained in this document. The definitions of terms in this glossary are not legal definitions (even if some of them may coincide with definitions given in European legislations), they are meant to help the reader understand some key terms in the context of their use in the specific sector covered by this document.

This glossary is divided up into the following sections:

I. ISO country codes
II. Units and conversion factors
III. Chemical elements
IV. Chemical formulae commonly used in this document
V. Acronyms and technical definitions

I. ISO country codes

ISO code	Country
Member States	
BE	Belgium
BG	Bulgaria
CZ	Czech Republic
DK	Denmark
DE	Germany
EE	Estonia
IE	Ireland
EL	Greece
ES	Spain
FR	France
IT	Italy
CY	Cyprus
LV	Latvia
LT	Lithuania
LU	Luxembourg
HU	Hungary
MT	Malta
NL	Netherlands
AT	Austria
PL	Poland
PT	Portugal
RO	Romania
SI	Slovenia
SK	Slovakia
FI	Finland
SE	Sweden
UK	United Kingdom
Note The protocol order of the Member States is based on the alphabetical order of their geographical names in the original language(s).	

II. Units and conversion factors

Term	Meaning
°C	degree Celsius
ADt	In this document, specific chemical and energy consumption, costs and emissions are expressed as 'per 90 % air dry pulp'.
bar	bar (1 013 bar = 100 kPa or 1 atm)
BDt	Bone dry metric tonne of pulp (used e.g. as reference unit for mechanical pulping energy consumption); dry solids content of pulp of 100 %; also called absolute dry or oven dry.
cm	centimetre
d	day
dB(A)	A-weighted decibels. Noise (unwanted sound) is expressed as a logarithmic ratio of a measured sound level. The unit for this ratio is called decibel (dB). The human ear is less sensitive to low frequency sound. In sound level meters a filter is used, which corrects the sound spectra in accordance with the ear's sensitivity. This is called the A-weighted sound level, expressed in dB(A).
DS	dissolved solid
g	gram
h	hour
J	joule
K	kelvin (0 °C = 273.15 K)
kg	kilogram (1 kg = 1 000 g)
kWh	kilowatt-hour (1 kWh = 3 600 kJ = 3.6 MJ)
l	litre
m	metre
m^3	cubic metre
m^3 svb	solid volume of wood excluding bark, → svb
mg	milligram (1 mg = 10^{-3} g)
mg/Nm^3	Mass of emitted substance related to the volume of waste gas under standard conditions (temperature of 273.15 K and pressure of 1 013 mbar), after correction for the water vapour content of the waste gases; these concentration values always refer to a defined standard O_2 content (% O_2).
MJ	megajoule (1 MJ = 1 000 kJ = 0.2778 kWh)
MWh	megawatt-hour
Nm^3	Normalised cubic metre – refers the volume of waste gas under standard conditions (273.15 K, 1 013 mbar), after correction for the water vapour content of the waste gases (dry gas).
Pa	pascal (1 Pa = 1 N/m^2)
ppm	parts per million; value multiplied by molecular weight divided by 22.41 = mg/m^3; e.g. 1 ppmv NO_2 = 2.05 mg NO_2/Nm^3, 1 ppmv SO_2 = 2.85 mg SO_2/Nm^3, 1ppmv CO = mg 1.25 CO/Nm^3, 1ppmv H_2S = mg 1.71 H_2S/Nm^3
ppmv	parts per million, by volume
s	second
svb	solid volume of wood excluding bark (m^3)
t	(metric) tonne (1 000 kg or 10^6 g)
t/yr	tonnes per year
µ	micro = 1 × 10^{-6}; e.g. µm = micrometre, µg = microgram
vol-%	percentage by volume (also % v/v)
W	Watt (1 W = 1 J/s)
yr	year

III. Chemical elements

Symbol	Name	Symbol	Name
Al	Aluminium	Hg	Mercury
C	Carbon	K	Potassium
Ca	Calcium	Mg	Magnesium
Cd	Cadmium	Na	Sodium
Cl	Chlorine	N	Nitrogen
Cu	Copper	O	Oxygen
F	Fluorine	P	Phosphorus
Fe	Iron	Pb	Lead
H	Hydrogen	S	Sulphur

IV. Chemical formulae commonly used in this document

Chemical formula	Name
CaO	Calcium oxide (burnt lime)
$CaCO_3$	Calcium carbonate
CH_3CO_3H	Peracetic acid
CH_3SH	Methyl mercaptan
CH_3SCH_3	Dimethyl sulphide
CH_3SSCH_3	dimethyldisulphide
CO	Carbon monoxide
ClO_2	Chlorine dioxide
H_2SO_4	Sulphuric acid
H_2O_2	Hydrogen peroxide
HCl	Hydrochloric acid
HF	Hydrogen fluoride (often in the aqueous form as hydrofluoric acid)
MgO	Magnesium oxide
$Mg(OH)_2$	Magnesium hydroxide
$Mg(HSO_3)_2$	Magnesium bisulphide
$MgSO_4$	Magnesium sulphate
$NaOH$	Sodium hydroxide (caustic soda)
$NaClO_3$	Sodium chlorate
Na_2S	Sodium sulphide
Na_2CO_3	Sodium carbonate
Na_2SiO_3	Sodium silicate (water glass)
$Na_2S_2O_4$	Sodium dithionite
Na_2SO_4	Sodium sulphate
$Na_2S_2O_3$	Sodium thiosulphate
NH_4-N	Ammonium (calculated as N)
NO_2-N	Nitrite (calculated as N)
NO_3-N	Nitrate (calculated as N
NO_X	The sum of nitrogen oxide (NO) and nitrogen dioxide (NO_2) expressed as NO_2
O_2	Oxygen
O_3	Ozone
SO_2	Sulphur dioxide

V. Acronyms and definitions

Abbreviations/Acronyms	
Absolute dry	Dry solids content of pulp of 100 %; also called bone dry or oven dry.
Active chlorine	Chlorine containing bleach chemicals are calculated as if they were chlorine (Cl_2), i.e. as if they had the same weight per oxidation equivalent as chlorine: 1 kg Cl_2 = 1 kg active chlorine; 1 kg ClO_2 = 2.63 kg active chlorine.
ADt	In this document, specific chemical and energy consumption, costs and emissions are expressed as 'per 90 % air dry pulp'. → air dry
Aerobic	Processes ‘requiring oxygen'. Processes in which microorganisms break down biodegradable material in the presence of oxygen. The term is used to classify aerated biological waste water treatment plants.
Aerobic waste water treatment	Biological waste water treatment that occurs in the presence of oxygen.
Air dry	Air dry tonne of pulp (ADt) meaning dry solids content of 90 %; in case of paper, air dry means paper with 6 % moisture content.
Alpha-cellulose	A highly refined, insoluble cellulose from which sugars, pectin, and other soluble materials have been removed. Also known as chemical cellulose.
Anaerobic	Processes in which microorganisms break down biodegradable material in the absence of oxygen. It is used as part of the process to treat waste water.
Anaerobic waste water treatment	Biological waste water treatment that occurs in the absence of oxygen.
AOX	Adsorbable organically bound halogens measured according to the EN ISO 9562 standard method for waste waters. The principle is to adsorb the organic constituents of the sample on activated carbon, separate the carbon from the sample by filtration, and burn the carbon with oxygen in a special AOX apparatus. HX are formed from the originally organically bound halogen and absorbed in an electrolyte in which they are determined by microcoulometric titration. The result is expressed as chloride in mg Cl/l.
Auxiliary boiler	'Auxiliary' normally means 'subsidiary', 'additional', 'extra', 'normally off-line' or 'small unit to support a main activity'. Pulp and paper mills produce most of their own heat and a large portion of their own electricity in their own power plants as part of their core business. Therefore, the term 'auxiliary boiler', often referred to in literature, may mislead when referring to steam boilers that run throughout the whole year and differ in size, fuels used or load conditions. If the term 'auxiliary boilers' is used, it refers to combustion plants of <50 MW rated thermal input including combined cycle gas turbines, fluidised bed reactors, steam blocks, combustion plants using pulp- and paper-specific residues or by-products as fuels (e.g. bark, sludge, waste paper, rejects), and combustion plants >50 MW if they are operated under sector-specific load conditions (e.g. steam blocks, combined cycle gas turbines). For conventional larger combustion plants exceeding 50 MW, reference should be made to the LCP BREF.
Availability (of NCG treatment systems)	Describes the total efficiency of gas collection and treatment systems for strong and weak NCG in kraft pulping. Treatment availability should include both primary incineration and back-up systems, i.e. the percentage of the gas flow to the treatment system no matter what the treatment system is. The back-up system is considered equal to the primary system and, when the system is needed, the exceptional emission consists of the bypass until the back-up is started. The treatment availability should cover both collection and incineration. For example, if the collection rate for weak gases is 98 % and the treatment efficiency in the treatment 99.5 %, the final availability totals 97.5 %.
BAT	Best available techniques, as defined in Article 3 (10) of the Directive 2010/75/EU on industrial emissions (IED).
BAT-AEL	Emission levels associated with the best available techniques as defined in Article 3(12) of the Directive 2010/75/EU on industrial emissions (IED).
BCTMP	Bleached CTMP.
Biocide	Active substances and preparations containing one or more active substances intended to destroy, deter or exert a controlling effect on bacteria or algae by chemical or biological means. Used for raw water treatment and prevention and control of bacteria growth in water circuits.

Abbreviations/Acronyms	
Biodegradable	Ability of an organic substance to be biologically oxidised by bacteria. It is measured by BOD tests.
Biofuels	Renewable fuels originating from plants, e.g. wood (including black liquor and bark).
Biosludge	Sludge obtained from activated sludge systems or other biological effluent treatment plants.
Black liquor	Spent kraft pulping liquor with inorganics and dissolved organics
Bleachability	The bleachability of a pulp is usually evaluated by determining the amount of bleaching chemicals required or consumed to reach a certain specified brightness.
Bleaching	Process of brightening fibres by removal of the coloured substance or by decolourising it.
BLG	Black liquor gasification.
BOD	Biochemical oxygen demand – the quantity of dissolved oxygen required by microorganisms in order o decompose organic matter in waste water. BOD is related to the content of substances that can be biochemically oxidised. BOD can be seen as the easily degradable part of COD. The unit of measurement is mg O_2/l.
$BOD_{5\text{ or }7}$	Biological oxygen demand assessed using a standard 5-day or 7-day test.
Bone dry	Dry solids content of pulp of 100 %; also called 'oven dry' or 'absolute dry'.
BREF	BAT Reference Document as defined in Article 3(11) of the Directive 2010/75/EU on industrial emissions (IED).
Broke	Paper that has been discarded anywhere in the manufacturing process.
Brown stock	The suspension of unbleached pulp.
Brown liquor	Spent sulphite pulping liquor with inorganics and dissolved organics.
C	Denotes a chlorination bleaching stage using molecular chlorine dispersed and dissolved in water. No longer used in Europe.
Causticising	Process in the lime cycle in which hydroxide (white liquor) is regenerated by the reaction $Ca(OH)_2 + CO_3^{2-} \rightarrow CaCO_3\ (s) + 2\ OH^-$. Green liquor.
CCGT	Combined Cycle Gas Turbine.
CEN	European Committee for Standardisation.
CEPI	Confederation of European Paper Industries.
CEPI-associated countries	In 2008, 18 European countries were associated to CEPI: AT, BE, CH, CZ, DE, ES, FI, FR, HU, IT, NL, NO, PL, PT, RO, SE, SK, UK. Countries among the EU-27 that were are not associated to CEPI are: BG, DK, EE, GR, IE, LV, LT, LU, MT, SI, CY. The production in the eleven outstanding EU Member States is less than 5 % of the total production for both pulp and paper manufacturing.
Change of produced paper grade	One or more changes in a product on a paper machine with the following typical circumstances: – grammage changes up and over 5 gsm; and/or – changes in more than one measurable characteristic, i.e. whiteness level, moisture content, porosity level, etc.; and/or – changes in pulp composition (different types of pulp or softwood/hardwood ratio); and/or; – - switch of functional paper chemicals (changing functionality of the product bulk and/or surface) during production.
CHP plant	Combined Heat and Power (cogeneration) plant.
Chemical pulp	Fibrous material obtained by removal from the raw material of a considerable part of those non-cellulosic compounds that can be removed by chemical treatment (cooking, delignification, bleaching).
CNCG	Concentrated non-condensable odorous gases, also referred to as strong odorous gases. They are TRS-containing gases from cooking, evaporation and from stripping of condensates.
COD	Chemical oxygen demand indicating the amount of chemically oxidisable organic matter in waste water (normally referring to analysis with dichromate oxidation).

Abbreviations/Acronyms	
Collection efficiency for NCG	Term used in kraft pulping. Collection efficiency of CNCG can be expressed as emissions of CNCG as kg S/ADt / generated amount of CNCG as kg S/ADt. Collection efficiency of DNCG can be expressed as emissions of DNCG as kg S/ADt / generated amount of DNCG as S/ADt. Pulp mills should measure/calculate/estimate the escaping gas flows periodically and record bypass time, gas flow and approximated sulphur content of the released odorous gas.
Composite sample	A composite sample refers to a water sample which is taken continuously over a given period, or a sample consisting of several samples taken either continuously or discontinuously over a given period (e.g. during 24 hours) and blended.
Condensate	Liquid, e.g. water, obtained after cooling of gas or steam/vapour.
Consistency	The weight percent of air dry (or oven dry) fibrous material in a stock or stock suspension. Low consistency (3 – 5 %, LC), medium consistency (10 – 15 %, MC) and high consistency (30 – 50 %, HC) are distinguished.
Couch pit	Chamber beneath press section end of formation table to receive edge trim and sheet breaks in papermaking.
Cross-media effect	Possible shift of environmental pressure from one environmental compartment to another. This is for example the case when a filter is installed to abate atmospheric emissions; the air is cleaned but a waste is generated.
CSF	Canadian Standard Freeness - a measure of the rate at which water drains from a pulp, the smaller the number the slower draining the pulp.
CTMP	Chemithermomechanical pulp.
D	Denotes a chlorine dioxide bleaching stage using a water solution of chlorine dioxide (ClO_2).
DAF	Dissolved Air Flotation.
Daily average value, water	Average over a sampling period of 24 hours taken as a flow-proportional composite sample. Time-proportional sampling can be used provided that sufficient flow stability is demonstrated.
Daily average value, air	Average over a period of 24 hours based on valid hourly averages measured by continuous measurement.
DAV	Daily average value.
Delignification	Dissolution and removal of lignin from wood chips (cooking: initial, bulk and residual delignification) or from fibres (oxygen stage and bleaching).
Denitrification	Biological process of nitrate reduction that may ultimately produce molecular nitrogen (N_2) through a series of intermediate gaseous nitrogen oxide products.
Deinking	Process of removing ink from printed paper for recycling, but also involving general removal of other undesirable materials.
DG	Directorate General (of the European Commission).
Diffuse emissions	Emissions arising from a direct (non-channelled) contact of volatile substances or dust with the environment under normal operating conditions. Diffuse emissions occur during regular operation in chemical pulp mills and are released as weak gases from ventilation of tanks and equipment in the fibre line, evaporation plant, tall oil cooking plant and causticising plant (e.g. smelt dissolver). Minimisation is possible by transferring them into ducted emissions (e.g. by collecting them) and subsequent treatment (incineration) of NCG.
DIP	Deinked pulp – pulp produced from recovered printing paper, e.g. newsprint, through deinking process.
Direct measurements	Specific quantitative determination of the emitted compounds at the source.
Discharge	Physical release of a pollutant through a defined outlet, i.e. channelled, system, e.g. sewer, outfall.
Disperging	Mechanical treatment of waste paper fibres to disperse ink particles
DLN	Specific type of low-NO_X burner; DLN stands for 'dry low-NO_X' technology which is mainly applied to gas turbines. It reduces NO_X emissions through lean premixed burning in multi-zone combustion liners and by control equipment which directs fuel to the different liner zones.

Abbreviations/Acronyms	
DNCG	Diluted non-condensable odorous gases, also referred to as weak odorous gases. They are TRS-containing gases which are not strong odorous gases (e.g. gases coming from tanks, washing filters, chip bins, lime mud filters, drying machines).
Dregs	Green liquor sludge.
Dry end	Part of the papermaking process after formation of the paper web.
DS	Dry solids, expressed as weight %.
DTPA	Diethlyene triamine pentaacetic acid (complexing/chelating agent used in peroxide bleaching).
DTVG	Dissolving tank vent gases. Gases with high sulphur content.
Dust	When determined from waste gases as 'mass concentration of dust' according to an appropriate standard method (e.g. gravimetric method EN 13284-1): Solid particles, of any shape, structure or density, dispersed in the gas phase which remain upstream of a specific filter and on it after drying under specified conditions.
E	Denotes an alkaline extraction stage in the bleach plant using sodium hydroxide (NaOH)
EC	European Commission.
ECF	Elemental Chlorine Free. Bleach sequence containing chlorine dioxide but not elementary chlorine gas.
ECF-light	Same as ECF but with minor use of chlorine dioxide, usually below 10 kg ClO_2/ADt. It should be noted that the term 'ECF-Light' is not well defined in the technical community.
ECO	Economiser. Device for preheating feedwater (water to the steam cycle) to a boiler by heat exchange with flue-gas.
EDTA	Ethylene Diamine Tetraacetic acid, complexing/chelating agent.
EIPPCB	European Integrated Pollution Prevention and Control Bureau.
Eliminable	Characteristic of an organic substance that shows it can be removed from the waste water e.g. by means of adsorption to the biomass; not necessarily equal to biodegradable.
EMAS	Eco-Management and Audit Scheme.
Emission	The direct or indirect release of substances, vibrations, heat or noise from individual or diffuse sources in the installation into the air, water or land (from Directive 2010/75/EU).
Emission and consumption levels associated with the use of BAT	BAT-AEL.
Emission factor	Calculated average emissions rate of a given pollutant for a given source, relative to units of activity or product, e.g. kg COD/ADt.
EMS	Environmental Management System.
EN ISO 14001	European norm (EN) published by the International Organisation for Standardisation (ISO) concerning environmental management standards.
End-of-pipe technique	Technique that reduces final emissions or consumption by an additional process but does not change the fundamental operation of the core process. Synonyms: secondary technique, abatement technique.
E/O	Extraction bleaching stage using sodium hydroxide with subsequent addition of gaseous oxygen as a reinforcing agent.
EOP	Extraction bleaching stage using sodium hydroxide with subsequent addition of oxygen and hydrogen peroxide solution as a reinforcing agent.
E/P	Extraction bleaching stage using sodium hydroxide with subsequent addition of hydrogen peroxide solution as a reinforcing agent.
EPA	Environment Protection Agency.
ESP	Electrostatic precipitator.
ETS	European Tissue Symposium, European Association of Tissue Manufacturers.
EU	European Union.
EU-10	Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia.

Abbreviations/Acronyms	
EU-15	Member States of the European Union before 1 May 2004. Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the United Kingdom
EU-25	EU-15 + EU-10: Member States of the European Union from 1 May 2004 until 31 December 2006.
EU-27	Member States of the European Union from 1 January 2007.
EUR	European currency unit.
Eutrophication	Pollution of a body of water by sewage, fertilisers washed from the land, and industrial wastes (inorganic nitrates and phosphates). These compounds stimulate the growth of algae, reducing the oxygen content in the water, and so killing animals with a high oxygen requirement.
Exhaust air	Air stream (waste gas) from an installation contaminated with gaseous components, normally with low concentrations.
FAS	Formamidine sulfonic acid; reductive bleaching agent.
FEI	Finnish Environment Institute.
FF	Fabric filter.
Fillers	Papermaking additives/pigments, usually mineral clays, chalk, talcum or calcium carbonates.
Fines	Small particle sized material in papermaking usually defined as material below 75 microns.
Flocculant	Substance that causes suspended particles to aggregate or clump.
Flocculation	Agglomeration of destabilised particles into microflocs and afterwards into bulky floccules which can be settled called floc.
Flue-gas	Off-gas that exits to the atmosphere via a flue, which is a pipe or channel for conveying exhaust gases from a fireplace, oven, furnace, boiler or steam generator.
Fly ash	Inorganic combustion residue entrained in the flue-gas from a combustion boiler, e.g. a bark boiler.
Frequent change of paper grade	One or more changes in a product on a paper machine per day as a yearly average, meeting one or more of the following features: (i) grammage changes equal to and over 5 g/m^2; (ii) changes in more than one measurable product characteristic, i.e. whiteness level, moisture content, porosity level, etc.; (iii) changes in pulp composition (different types of pulp or softwood/hardwood ratio); (iv) switch of functional paper chemicals (changing functionality of the product bulk and/or surface) during production.
FSC	Forest Stewardship Council.
FTOH	Fluorotelomer alcohols.
Fugitive emissions	Fugitive emissions happen during irregular operation from leakages. For minimisation, the first option is prevention by good maintenance, monitoring and process control.
Furnish	The mixture of various materials that are blended in the stock suspension from which paper or board is made. The chief constituents are the fibrous material (pulp), fillers, sizing agents, wet strength or other additives, dyes, and dyes.
Grammage	Weight in grams of one square meter of paper or board (g/m^2).
Green liquor	Aqueous solution of sodium sulphide and sodium carbonate. Intermediate product in kraft chemical recovery.
Green liquor sludge	Sludge from sedimentation in green liquor clarification.
GW	Groundwood pulp.
Best practice	Expression used to designate a technique, method, process or activity which is regarded as more effective at delivering a particular outcome than any other technique, method or process.
Hardwood	Group of wood species including aspen, beech, birch and eucalyptus. The term hardwood is used as opposition to softwood.
Headbox	Pulp feed to the paper machine starts here.
HexA	Hexenuronic acid.
Hexenuronic acid	Unsaturated uronic acid groups formed under alkaline cooking conditions from xylanes in the pulp.
HC	High consistency – pulp concentration in the interval 30 – 50 % dry solids content.
HHV	Higher heating value.

Abbreviations/Acronyms	
HP	High pressure (steam).
IED	Directive 2010/75/EU of the European Parliament and the Council of 24 November 2010 on industrial emissions (Integrated Pollution Prevention and Control).
Immission	Occurrence and level of polluting substance, odour or noise in the environment.
IMPEL	European Union Network for the Implementation and Enforcement of Environmental Law.
Installation	A stationary technical unit within which one or more activities listed in Annex I to the IED are carried out, and any other directly associated activities on the same site which have a technical connection with these activities and which could have an effect on emission and pollution.
Inspection	Process consisting of surveys, checks, controls and validations in an industrial unit, carried out by authorities or by internal or external experts, in order to analyse and assess procedures, operating modes, operating conditions of the process and the related equipment, mechanical integrity, level of performance, and the records and results obtained by the industrial operator.
Integrated production / integrated mill	When pulp and paper is produced at the same site. The pulp is not dried before paper manufacture. The production of paper and/or board is directly connected with the production of pulp.
IPPC	Integrated Pollution Prevention and Control.
IR	Infrared.
ISO	International Organization for Standardization.
% ISO	Brightness unit for pulp according to ISO, the International Organisation for Standardisation.
ISV	Sludge Volume Index - volume in ml occupied by 1 gram of activated sludge after settlement under specified conditions for a specified time, usually 30 minutes.
I-TEQ	International Toxicity Equivalents (used for reporting dioxins and furans).
JRC	Joint Research Centre.
Kappa number	Measures the amount of residual lignin content in unbleached pulp, determined after pulping and prior to bleaching. The lower the Kappa number, the less associated lignin. The kappa number is dimensionless.
Kraft pulp	Chemical pulp which is manufactured using sodium sulphide as the main cooking chemical. Wood chips are digested in an alkaline cooking liquor, an aqueous solution of sodium hydroxide and sodium sulphide (white liquor).
LAeq	Equivalent continuous A-weighted sound pressure level.
LC	Low consistency - pulp concentration in the interval 3 - 5 % dry solids content.
LCP	Large Combustion Plant, see LCP BREF and Annex IV of the IED.
LCA	Life cycle assessment.
LCV	Lower calorific value.
Lignin	Wood substance, an aromatic polymer in the cell wall of plants. The binding substance in natural fibres. Lignin is dissolved out along with the carbohydrates in the pulping process.
Lime kiln	Unit in the kraft recovery cycle. In this lime kiln, the lime mud is reburnt to lime: $CaCO_3$ (s) + heat → CaO(s) + CO_2.
Lime mud	Consists mainly of calcium carbonate, formed in causticising in production of white liquor.
LP	Low pressure (steam).
LVHC	Low volume high concentration non-condensable gases.
LWC	Light-weight coated paper.
Magnefite	Magnesium-based sulphite pulping process.
Make-up chemicals	Replacement chemicals purchased to cover chemical losses of various kinds.
Market pulp	Pulp manufactured and dried at one mill location for sale to paper manufacturers at other locations.
MBR	Membrane bioreactor.
MBBR	Moving bed biological reactor.
MC	Medium consistency - pulp concentration in the interval 8 – 15 % dry solids content.

Abbreviations/Acronyms	
Measure	Technique or combination of techniques.
Measured value	Result of a measurement.
Measurement	Set of operations for determining the value of a quantity.
Measuring system	Complete set of measuring instruments and other equipment, including all operating procedures used for carrying out specified measurements.
Mechanical pulp	Papermaking pulp made entirely by mechanical means from various raw materials, i.e. by grinding wood against an abrasive surface (groundwood pulp) or by processing wood chips or sawdust through a refiner (refiner mechanical pulp). Mechanical pulp contains a considerable amount of non-cellulosic compounds.
MF resin	Melamine formaldehyde resin.
MLSS	Mixed liquor suspended solids.
Moisture compensation for biomass	The ranges for total efficiency of CHP plants is calculated using the lower heating value for the fuels with moisture compensation for biomass according to $LCV_{af} = LCV_{dry} \times (1-m_w)-l_{25} \times m_w$ [168, M.Huhtinen et al. 2000], where: LCV_{af} lower heating value for as fired fuel LCV_{dry} lower heating value for dry fuel m_w mass of water in fuel (kg H_2O/kg fuel) l_{25} evaporation heat for water at 25 °C.
MS	Member State of the European Union.
Multiproduct mill	A production site where pulp, paper and wood-based products of a wide variety are manufactured (sawn goods, chemical pulps, mechanical pulps or pulp from processing of paper for recycling, different paper and board grades and wood-derived by-products). A mill might be a multiproduct mill (producing different kind of pulps), but not an integrated mill (i.e. not producing pulp and paper).
MWC	Medium-weight coated paper.
NCG	Non-condensable odorous gases referring to malodorous gases of kraft pulping. Includes CNCG (concentrated) and DNCG (diluted).
N content of the black liquor (BL)	Nitrogen content of the black liquor. N is determined by one of the following analysis methods: (modified) KCL-SFS 5507, modified Kjeldahl method, KCL method, method Buchi-O, DIN ISO 11261, method SP 0528 (elementary analysis carried out by the Sveriges Tekniska Forskningsinstitut, SE), SCN thermoconductivity cell, etc. No harmonised method applied.
Non-integrated production / non-integrated mill	'Non-integrated production' means: (a) production of market pulp (for sale) in mills that do not operate paper machines, or (b) production of paper/board using only pulp produced in other plants (market pulp).
Neutralisation	Raising the pH of acidic solutions or lowering the pH of alkaline solutions to neutral pH (pH 7).
Nitrification	Biological process facilitated by bacteria by which ammonia is converted first to nitrite and then to nitrate.
Nm^3	Normal dry gas related to standard conditions (273.15 K and 1 013 mbar, after correction for the water vapour content of the waste gases).
NPE	Non-process elements that can accumulate when closing up the water circuits in pulp mills, such as Al, Si, Ca, Mg, Mn.
NSSC	Neutral sulphite semi-chemical pulp is the most common type of semi-chemical pulp which is produced by a combination of chemical and mechanical pulping. In the process, wood chips are partially digested to weaken the bonds between fibres and lignin. The chips are then mechanically treated in a refiner.
O	Denotes delignification/bleaching stage with oxygen gas (O_2).
OTNOC	Other Than Normal Operating Conditions
Oxidised white liquor	Produced when white liquor sulphide is oxidised to thiosulphate, usually by air.
P	Denotes alkaline bleaching stage with hydrogen peroxide (H_2O_2) as liquid
Paa	Denotes bleaching stage with peracetic acid (CH_3COOOH). Used in TCF bleaching.
Paper	Sheet of fibres with a number of added chemicals. According to the basic weight, it can be distinguished as: Paper <150 g/m^2 <paperboard (or board) <250 g/m^2 <cardboard.
PCDD/F	Polychlorinated dibenzo-p-dioxins/furans.

Abbreviations/Acronyms	
PEFC	Programme for the Endorsement of Forest Certification.
PFC	Perfluorinated und polyfluorinated chemicals.
PFOA	Perfluorooctanoic acid.
PFOS	Perfluorooctanesulfonic acid / perfluorooctane sulphonate.
PGW	Pressurised groundwood (pulping).
Pinch analysis	Method for analysing and optimising energy use in processes and plants. Process-integrated method suitable to determine where and how much energy is to be used for a thermodynamically optimised system. The process data are represented as a set of energy flows, or streams, as a function of heat load against temperature. These data result in composite curves, one for all hot streams (releasing heat) and one for all cold streams (requiring heat).
Parameter	Measurable magnitude representing the main features of a statistical group.
Particulate matter	Dust. All material that is solid at the point of measurement Total particulate matter refers to all inorganic and organic solid and liquid materials (droplets and aerosols) that may be present in the flue-gas.
Pitch	A resinous material in virgin pulps.
$PM_{2.5}$	Particulate matter which passes through a size-selective inlet with a 50 % efficiency cut-off at 2.5 μm aerodynamic diameter.
PM_{10}	Particulate matter which passes through a size-selective inlet with a 50 % efficiency cut-off at 10 μm aerodynamic diameter.
Pollutant	Individual substance or group of substances which can harm or affect the environment.
Power	The term power refers to electrical energy.
Pressure diffuser	Pulp washing equipment in which pulp is washed by displacement under pressure.
Production capacity	The weight of products (air dry mass) an installation can produce during a defined period of time (day, month, year).
Pulping	Process of converting raw fibre (e.g. wood) or recycled fibre to a pulp usable in papermaking.
Q	Denotes acid bleaching stage where chelating agent EDTA or DTPA is used for removal of metals, primarily in bleaching with hydrogen peroxide.
Quality of data	Data provided in the context of the information exchange on BAT can be classified into categories depending on the quality of the data: • D: measured data based on statistical analysis • E: expert judgement based on few measurement results • M: modelled figures (e.g. results of N flow processing) • A: expert judgement based on conclusion by analogy.
RCF	Recycled fibre(s); pulp obtained from processing paper for recycling.
Recovery	Defined by the EC Waste Framework Directive as any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy.
Recovery boiler	Steam boiler and chemical reactor in the kraft and sulphite recovery system; burns black or brown liquor at high temperature and generates steam and power.
Recycling	Defined by the EC Waste Framework Directive as any recovery operation by which waste materials are reprocessed into products, materials or substances, whether for the original or other purposes.
Recycled fibre pulp	Fibrous material that has already passed through paper and/or board production.
Reuse	Defined by the EC Waste Framework Directive as any operation by which products or components that are not waste are used again for the same purpose for which they were conceived.
Reference conditions	Conditions that are specified, e.g. in connection with operating a process, when collecting samples or when determining emission levels.
Refining	Process of mechanically treating fibres to develop strength.
Removal efficiency	Expresses how efficiently a treatment process is working. It is normally expressed as removal percentage related to the initial emission load.
RMP	Refiner mechanical pulp.

Abbreviations/Acronyms	
Run-off	Part of the precipitation and snowmelt that does not infiltrate but moves as overland flow.
Save-all	An apparatus used for reclaiming fibres and fillers from white water. It usually operates on a filtration, sedimentation, flocculation, or flotation principle.
SC	Supercalendered paper.
Scalings	Inorganic deposits in process equipment (may occasionally also contain organics).
Scrubber	Equipment for gas cleaning with a liquor.
SEPA	Swedish Environmental Protection Agency.
SEC	Specific energy consumption.
SGW	Stone groundwood (pulp).
Shives	Fibre bundles, i.e. not defibrated at the cook.
Sludge volume index (SVI)	The sludge volume index is the volume in millilitres occupied by 1 g of a suspension after 30 minutes settling. SVI is typically used to monitor settling characteristics of activated sludge and other biological suspensions.
SNCR	Selective non-catalytic reduction.
Soap	The product of reaction between the alkali in kraft pulping liquor and fatty acid portions of the wood, which precipitate out when water is evaporated from the spent pulping liquor.
Softwood	Wood from conifers including pine and spruce. The term softwood is used as opposition to hardwood.
Speciality paper mills	A mill producing numerous paper and board grades for special purposes (industrial and/or non-industrial) that are characterised by particular properties, relatively small end use market or niche applications that are often especially designed for a particular customer or end-user group. Examples of this wide-ranging category of speciality papers include, but are not limited to, cigarette papers, filter papers, metallised paper, thermal paper, self-copy paper, sticking labels, cast coated paper, as well as gypsum liners and special papers for waxing, insulating, roofing, asphalting, and other specific applications or treatments. All of these grades fall outside of the standard paper categories.
Specific water consumption	The amount of fresh water used during production (surface water, ground water), which is taken from external resources. This fresh water demand is related to air dry net production and is expressed as m^3/ADt. Fresh water that is only used for cooling purposes (i.e. water that had no contact with fibres and additives) and that is directly discharged into the receiving water body is not included. Also, waste water generated in steam and power plants on site is not included.
SS	Suspended solids.
SSL	Spent sulphite liquor. Liquid that is left over from the sulphite pulping process where wood is digested to cellulose pulp with bisulphite under heat and pressure.
Stickies	Materials that stick together; adhesive contaminants in paper for recycling.
Stock	In papermaking – the mixed suspension of screened pulp(s) and added fillers and chemical additives used to form the paper.
Stripper	Distillation column for cleaning of condensate.
Sulphidity (%)	Sulphidity (%) = $(2[HS^-]/[OH^-]+ HS^-])\times100$. The ratio of hydrogen sulphide ions and the sum of hydroxide and hydrogen sulphide ions in white liquor. The ratio is expresses as mol/mol.
Sulphite pulp	Chemical pulp where various sulphites or bisulphites are used as the main cooking chemical.
Superheater	Steam tubes in the upper part of a boiler in which the temperature of generated steam is raised above the saturated steam temperature.
SUSD	Start-Up/ShutDown
Tall oil	Liquid product consisting of extractives from black liquor.
TCF	Totally Chlorine Free. Bleaching of pulp without using chlorine compound chemicals.
Techniques (from the IED)	Includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned.

Abbreviations/Acronyms	
Thermomechanical pulp	Papermaking pulp made entirely by mechanical means from various raw materials, but usually wood. In the thermomechanical pulping process the raw material is subjected to thermal pretreatment. Thermomechanical pulp contains a considerable amount of non-cellulosic compounds.
TMP	Thermomechanical pulp.
Total nitrogen (tot-N)	Total nitrogen (tot-N) given as N includes organic nitrogen, free ammonia and ammonium ($NH4^+$-N), nitrites ($NO2^-$ -N) and nitrates ($NO3^-$-N).
Total phosphorus (tot-P)	Total phosphorus (tot-P) given as P includes dissolved phosphorus plus any insoluble phosphorus carried over into the effluent in the form of precipitates or within microbes.
TOC	Total Organic Carbon; alternative measurement for COD. Analytical method used to determine the content of organics in a sampling of waste water.
Treatment efficiency for NCG	See availability.
TRS	Total reduced sulphur in flue-gas. The sum of the following reduced malodorous sulphur compounds generated in the pulping process: hydrogen sulphide, methyl mercaptan, dimethylsulphide and dimethyldisulphide, expressed as sulphur.
TSS	Total suspended solids (in waste water). Suspended solids consist of small fibre fragments, fillers, fines, non-settled biomass (agglomeration of microorganisms) and other small particles.
Turpentine	A mixture of terpenes, principally pinene, obtained by the steam distillation of pine gum recovered from the condensation of digester relief gases from the cooking of softwoods by the kraft pulping process.
TWG	Technical working group.
UASB	Upflow anaerobic sludge blanket reactor/process.
UBA	Umweltbundesamt – Federal Environment Agency, i.e. from Germany or Austria.
Viscosity of pulp	Used to evaluate the degree of cellulose degradation during cooking and bleaching. Expressed as ml/g.
VOC	Volatile organic compounds.
Vol-%	Percentage by volume.
Wet end	Part of the papermaking process prior to formation of the paper web.
White liquor	Alkaline cooking liquor, an aqueous solution of NaOH and Na_2S, for kraft pulping.
White water	General term for all process waters of a paper mill that have been separated from the stock or pulp suspension, either on the paper machine or accessory equipment, such as thickeners, washers, save-alls, and from pulp grinders. It carries a certain amount of fibre and may contain varying amounts of fillers and dyestuffs
Wood-containing paper and/or board	Paper and board containing a considerable amount of non-cellulosic compounds (more than 5 %) as an essential constituent of its fibre composition.
Wood-free paper and/or board	Paper and board containing in principle only chemical pulp in its fibre composition; in practice however it may contain a small amount of other fibres or pulps (less than 5 % non-cellulosic compounds).
WID	Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste (Waste Incineration Directive).
WWTP	Waste water treatment plant.
Yankee cylinder	Large single cylinder used mainly to dry tissue/towels.
Yearly average value, water (load)	Average (weighted according to the daily production values) of the daily averages taken with the frequency set for the relevant parameters within a year, expressed as mass of emitted substances per unit of mass of products/materials generated or processed.
Yearly average value, air	Average over a period of one year based on valid hourly averages measured by continuous measurement.
Yield	Amount of useful fibre after pulping and/or bleaching or deinking, expressed as a percentage of the useable fibre in relation to the raw material input.
Z	Denotes a bleaching stage using gaseous ozone (O_3).

Pulp and paper grade definitions according to CEPI

1. Paper definitions

1.1 Graphic papers

Newsprint: paper mainly used for printing newspapers. It is made largely from mechanical pulp and/or paper for recycling, with or without a small amount of filler. Weights usually range from 40 g/m^2 to 52 g/m^2 but can be as high as 65g/m^2. Newsprint is machine-finished or slightly calendered, white or slightly coloured and is used in reels for letterpress, offset or flexo-printing. The CEPI Harmonised Code for Newsprint is 100 000 000.

Uncoated mechanical: paper suitable for printing or other graphic purposes where less than 90 % of the fibre furnish consists of chemical pulp fibres. This grade is also known as groundwood or wood-containing paper and magazine paper, such as heavily filled supercalendered paper for consumer magazines printed by the rotogravure and offset methods. The CEPI Harmonised Code for Uncoated Mechanical is 211 000 000.

Uncoated wood-free: paper suitable for printing or other graphic purposes, where at least 90 % of the fibre furnish consists of chemical pulp fibres. Uncoated wood-free paper can be made from a variety of furnishes, with variable levels of mineral filler and a range of finishing processes such as sizing, calendering, machine-glazing and watermarking. This grade includes most office papers, such as business forms, copier, computer, stationery and book papers. Pigmented and size press 'coated' papers (coating less than 5 g per side) are covered by this heading. The CEPI Harmonised Code for Uncoated Wood-free is 231 000 000.

Coated papers: all paper suitable for printing or other graphic purposes and coated on one or both sides with minerals such as china clay (kaolin), calcium carbonate, etc. Coating may be by a variety of methods, both on-machine and off-machine, and may be supplemented by supercalendering. Coated mechanical papers are made of fibres produced mainly (90 %) by a mechanical pulping process and are also known as coated groundwood. Coated wood-free papers are made of fibres produced mainly (90 %) by a chemical pulping process and are also known as coated freesheet. The CEPI Harmonised Code for Coated Mechanical is 212 000 000 and for Coated Wood-free is 232 000 000.

1.2 Sanitary and Household

This covers a wide range of tissue and other hygienic papers for use in households or commercial and industrial premises. Examples are toilet paper and facial tissues, kitchen towels, hand towels and industrial wipes. Some tissue is also used in the manufacture of baby nappies, sanitary towels, etc. The parent reel stock is made from virgin pulp or recovered fibre or mixtures of these. It is reported in the production statistics at parent reel weight before conversion to finished products. Import and export statistics however take into account trade in both parent reels and finished products. The CEPI Harmonised Code for Sanitary and Household is 700 000 000.

1.3 Packaging

Case materials: papers and boards mainly used in the manufacture of corrugated board. They are made from any combination of virgin and recovered fibres and can be bleached, unbleached or mottled. Fluting is the middle ply with outer layers called the liners. Included are kraftliner, Testliner, semi-chemical fluting, and paper for recycling-based fluting (Wellenstoff). Main uses include corrugated boxes, transport packaging, storage and product display. Also known as containerboard, corrugated case materials, cardboard, linerboard or corrugating medium. The CEPI Harmonised Code for Case Materials is 300 000 000.

Cartonboard: may be single or multi-ply, coated or uncoated. It is made from virgin and/or recovered fibres, and has good folding properties, stiffness and scoring ability. It is mainly used in cartons for consumer products such as frozen food, cosmetics and for liquid containers. Also known as solid board, folding boxboard, boxboard or carrier board. The CEPI Harmonised Code for Cartonboard is 400 000 000.

Wrappings (up to 125 g/m^2): papers whose main use is wrapping or packaging made from any combination of virgin or recovered fibres, bleached or unbleached. They may be subject to various finishing and/or marking processes. Included are sack kraft, other wrapping krafts, sulphite and greaseproof papers. The CEPI Harmonised Code for Wrappings is 500 000 000.

Other papers mainly for packaging purposes: this category embraces all paper and board mainly for packaging purposes other than those listed above. Most are produced from recovered fibres, e.g. greyboards, and go for conversion, which in some cases may be for end uses other than packaging including book covers and games. Also known as greyboard or unlined chip. The CEPI Harmonised Code for Other Packaging is 600 000 000.

1.4 Special (Other)

Other paper and board for industrial and special purposes: This wide-ranging category includes cigarette papers, filter papers, thermal paper, self-copy paper, sticking labels as well as gypsum liners and special papers for waxing, insulating, roofing, asphalting, and other specific applications or treatments. The CEPI Harmonised Code for Special Paper and Board is 800 000 000.

2. Pulp definitions

Pulp grades are classified according to their production process. The main grades are:

2.1 Mechanical pulps

Stone groundwood: pulp produced by grinding wood into relatively short fibres. This pulp is used mainly in newsprint and wood-containing papers, like LWC (light-weight coated) and SC papers. The CEPI Harmonised Code is 923 000 000.

Thermomechanical (TMP): pulp produced in a thermomechanical process where wood particles are softened by steam before entering a pressurised refiner. TMP has mainly the same end uses as stone groundwood. Variants of the above two processes produce pressurised stone groundwood pulp and refiner mechanical pulp. The CEPI Harmonised Code is 923 400 000.

2.2 Semi-chemical pulps

Semi-chemical: pulp produced in a two-stage process which involves partial digestion with chemicals, followed by mechanical treatment in a disc refiner. This pulp is mainly used in the production of fluting medium for corrugated board. The CEPI Harmonised Code is 921 000 000.

Chemithermomechanical (CTMP): pulp produced in a similar way to TMP, but the wood particles are chemically treated before entering the refiner. This pulp has properties suited to tissue manufacture. Some CTMP is used in printing and writing grades. CTMP is classified under semi-chemical pulps in the Harmonised System of the Customs Co-operation Council. In the FAO, as well as in other industry statistics, such chemithermomechanical pulps are grouped with mechanical pulp.

2.3 Chemical pulps

Sulphite: pulp produced by cooking wood chips in a pressure vessel in the presence of bisulphite liquor. End uses range from printing and writing papers to tissue, sanitary papers, textiles and various chemicals (cellulose derivatives).

Sulphate (or kraft): pulp produced by cooking wood chips in pressure vessels in the presence of a sodium hydroxide (soda) liquor. The pulp may be unbleached or bleached. End uses are widespread, with bleached pulp particularly used for graphic papers, tissue and cartonboards. Unbleached pulp is commonly used in liner for corrugated board, wrappings, sack and bag papers, envelopes and other unbleached speciality papers. The CEPI Harmonised Code is 922 100 000.

2.4 Other pulps

Pulp produced from fibres other than wood, such as sugar cane bagasse, wheat straw, kenaf, cotton rags and hemp.

2.5 Deinked pulps

Pulp made from paper for recycling from which inks and other contaminants have been removed.

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