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Best Available Techniques (BAT) Reference Document on Surface Treatment Using Organic Solvents including Preservation of Wood and Wood Products with Chemicals

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

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Abstract

The Best Available Techniques (BAT) Reference Document (BREF) on Surface Treatment using Organic Solvents including Preservation of Wood and Wood Products with Chemicals is part of a series of documents 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 Directive 2010/75/EU on Industrial Emissions (the Directive). This document is published by the European Commission pursuant to Article 13(6) of the Directive.

The BREF on Surface Treatment Using Organic Solvents including Preservation of Wood and Wood Products with Chemicals covers the surface treatment of substances, objects or products using organic solvents as well as the preservation of wood and wood products using chemicals as specified in Sections 6.7 and 6.10 of Annex I to Directive 2010/75/EU respectively.

Important issues for the implementation of Directive 2010/75/EU in the surface treatment using organic solvents (STS) and the wood preservation with chemicals (WPC) sectors are emissions to air and water as well as energy and water consumption. Chapter 1 provides general information on the STS sector and on the main environmental issues associated with their use. Chapters 2 to 14 give the applied processes, current emission and consumption levels, techniques to consider in the determination of BAT for the STS sectors that are covered by these chapters. Chapter 15 provides general information, applied processes, current emission and consumption levels, techniques to consider in the determination of BAT for the wood preservation sector. Chapter 16 provides thumbnail descriptions of additional STS sectors, for which a data collection via questionnaires has not been carried out. General techniques to consider in the determination of BAT (i.e. those techniques to consider that are widely applied in the STS sector) are reported in Chapter 17. Chapter 18 presents the BAT conclusions as defined in Article 3(12) of the Directive, both general and sector-specific. Chapter 19 provides the emerging techniques for the STS and WPC sectors. Concluding remarks and recommendations for future work are presented in Chapter 20.

Acknowledgements

This report was produced by the European Integrated Pollution Prevention and Control Bureau (EIPPCB) at the European Commission's Joint Research Centre – Directorate B: Growth and Innovation under the supervision of Serge Roudier (Head of the EIPPCB) and Luis Delgado Sancho (Head of the Circular Economy and Industrial Leadership Unit until March 2020).

The authors of this BREF were Georgios Chronopoulos, Gizem-Ece Cakmak, Paul Tempany, Gabriele Klein, Thomas Brinkmann, Benoit Zerger and Serge Roudier.

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 EU Member States: Austria, Belgium, Czechia, Denmark, Finland, France, Germany, Greece, Italy, the Netherlands, Poland, Portugal, Romania, Slovakia, Spain, Sweden and the United Kingdom (until 31/01/2020);
- among industry: ACEA (European Automobile Manufacturers' Association), AFERA (European Adhesive Tape Association), ASD (AeroSpace and Defence Industries Association of Europe), BUSINESS EUROPE, CEFIC (European Chemical Industry Council), CEPE (European Council of the Paint, Printing Ink and Artists' Colours Industry), ECCA (European Coil Coating Association), ERA (European Rotogravure Association), ESVOC (European Solvents Downstream Users Group), EURATEX (European Apparel and Textile Confederation), EUROFER (European Steel Association), EUROMETAUX (European non-ferrous metals association), EWPM (European Wood Preservative Manufacturers Group), EWWG (Europacable Winding Wire Group), FEDUSTRIA (Belgian Federation of the textile, wood and furniture industries), FPE (Flexible Packaging Europe), INTERGRAF (European federation for print and digital communication), MPE (Metal Packaging Europe), ORGALIM (Europe's Technology Industries), SEA SMRC (Ships & Maritime Equipment Association), WEI (European Institute for Wood Preservation) and WPA (Wood Protection Association);
- among environmental non-governmental organisations: EEB (European Environmental Bureau).

Frederik Neuwahl and Michele Canova from the EIPPCB contributed significantly to the internal discussions and Task Force sessions for the development of this document.

The whole EIPPCB team provided contributions and peer reviewing.

This report was edited by Anna Atkinson and formatted by Rick Nowfer.

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

Reference Document on Best Available Techniques (BREF)	**Code**
Ceramic Manufacturing Industry	CER
Common Waste Gas Treatment in the Chemical Sector	WGC
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 or Pigs	IRPP
Iron and Steel Production	IS
Large Combustion Plants	LCP
Large Volume Inorganic Chemicals	LVIC
Large Volume Inorganic Chemicals – Ammonia, Acids and Fertilisers	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
Production of Wood-based Panels	WBP
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 including Preservation of Wood and Wood Products with Chemicals	*STS*
Tanning of Hides and Skins	TAN
Textiles Industry	TXT
Waste Incineration	WI
Waste Treatment	WT
Reference Document (REF)	
Economics and Cross-media Effects	ECM
Monitoring of emissions to Air and Water from IED Installations	ROM

Electronic versions of draft and finalised documents are publically 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 of the Council on industrial emissions (integrated pollution prevention and control) (Recast).

The original best available techniques (BAT) reference document (BREF) on Surface Treatment using Organic Solvents was adopted by the European Commission in 2007. This document is the result of a review of that BREF. The review commenced in June 2015.

This BAT reference document for the Surface Treatment Using Organic Solvents including Preservation of Wood and Wood Products with Chemicals 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 2020/2009/EU on the BAT conclusions contained in Chapter 18 was adopted on 22/06/2020 and published on 09/12/2020[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 provides general information on the surface treatment using organic solvents (STS) sector and on the general environmental issues for the sector.

Chapters 2 to 16 provide the information given below on specific sectors (i.e. vehicle coating, coating of other metal and plastic surfaces, coating of ships and yachts, coating of aircraft, coil coating industries, manufacturing of adhesive tapes, coating of textiles, foils and paper, manufacturing of winding wire, coating and printing of metal packaging, heatset offset web printing, flexography and non-publication rotogravure, publication rotogravure, coating of wooden surfaces, preservation of wood and wood products with chemicals, manufacturing of mirrors and coated abrasives), using the following structure (X is the chapter number):

- Section X.1 provides general information on the sector.

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[1] OJ L 414, 9.12.2020, p. 19

- Section X.2 provides information on applied processes and techniques.
- Section X.3 provides 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, and use of energy.
- Section X.4 describes in more detail the techniques to prevent or, where this is not practicable, to reduce the environmental impact of operating 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).

Chapter 17 provides information on the common industrial processes, abatement systems and general techniques that are used across most of the sectors of the STS activity. It describes in more detail the techniques to prevent or, where this is not practicable, to reduce the environmental impact of installations in the sector that were considered in determining the BAT. This information includes, where relevant, the environmental performance levels (e.g. emission and consumption levels) which can be achieved by using the techniques, the associated monitoring and the costs and the cross-media issues associated with the techniques. The WPC-relevant techniques are described in Section 15.4.

Chapter 18 presents the BAT conclusions as defined in Article 3(12) of the Directive, both general and sector-specific for the two activities covered.

Chapter 19 presents information on ‘emerging techniques’ for the STS and WPC activities as defined in Article 3(14) of the Directive.

Chapter 20 contains the concluding remarks and recommendations for future work.

Chapter 21 contains the Annexes with valuable information not fitted into other chapters.

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 STS and WPC activities;
- 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 the *Techniques to consider in the determination of BAT* sections. 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 Joint Research Centre (JRC) at the following address:

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Best Available Techniques Reference Document on Surface Treatment using Organic Solvents including Preservation of Wood and Wood Products with Chemicals

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SCOPE

This BAT reference document (BREF) covers the following activities specified in Annex I to Directive 2010/75/EU:

6.7: Surface treatment of substances, objects or products using organic solvents, in particular for dressing, printing, coating, degreasing, waterproofing, sizing, painting, cleaning or impregnating, with an organic solvent consumption capacity of more than 150 kg per hour or more than 200 tonnes per year.

6.10: Preservation of wood and wood products with chemicals with a production capacity exceeding 75 m^3 per day other than exclusively treating against sapstain.

6.11: Independently operated treatment of waste water not covered by Directive 91/271/EEC provided that the main pollutant load originates from activities specified in point 6.7 or 6.10 of Annex I to Directive 2010/75/EU.

These BAT conclusions also cover the combined treatment of waste water from different origins provided that the main pollutant load originates from the activities specified in point 6.7 or 6.10 of Annex I to Directive 2010/75/EU and that the waste water treatment is not covered by Directive 91/271/EEC.

For the STS activity, this BREF does not address the following:

- Waterproofing of textiles by means other than the use of a solvent-based continuous film. This may be covered by the BREF for the textiles industry (TXT).
- Printing; sizing and impregnation of textiles. This may be covered by the BREF for the textiles industry (TXT).
- Lamination of wood-based panels.
- Conversion of rubber.
- Manufacturing of coating mixtures, varnishes, paints, inks, semiconductors, adhesives or pharmaceutical products.
- On-site combustion plants unless the hot gases generated are used for direct contact heating, drying or any other treatment of objects or materials. These may be covered by the BREF for large combustion plants (LCP) or by Directive 2015/2193/EU.

The sections of this document referring to the WPC activities cover the following processes and activities (if at least one of the relevant thresholds in IED Annex I, 6.7 or 6.10 is exceeded):

- the preservation of wood and wood products using water-based preservatives, solvent-based preservatives and creosote;
- blue stain treatment for long-term protection of wood and wood products in service (e.g. window frame production);
- preservation of wood and wood products using the supercritical CO_2 process.

For the WPC activity, this BREF does not address the following:

- Chemical modification and hydrophobisation (e.g. using resins) of wood and wood products[2].

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[2] Although chemical wood modification and hydrophobisation (e.g. using resins) are considered ‘wood preservation with chemicals’, the TWG concluded during the kick-off meeting not to cover these activities in this BREF as at that time the number of plants in the EU was considered too small to justify its inclusion as a sector and, additionally, the capacity of the these installations was believed to be below

- Sapstain treatment of wood and wood products, as no information was submitted and none of the plants that took part in the data collection apply sapstain treatment associated with the WPC activities.
- Ammonia treatment of wood and wood products.
- On-site combustion plants, as only one plant reported direct drying, but no information was submitted. These may be covered by the BREF for large combustion plants (LCP) or by Directive 2015/2193/EU.

Other reference documents which could be relevant for the activities covered by this BREF are the following:

- Economics and Cross-Media Effects (ECM);
- Emissions from Storage (EFS);
- Energy Efficiency (ENE);
- Waste Treatment (WT);
- Large Combustion Plants (LCP);
- Surface Treatment of Metals and Plastics (STM);
- Monitoring of Emissions to Air and Water from IED Installations (ROM).

The scope of the BREF does not include matters that concern:

- off-site transport of raw materials or finished products;
- the quality assurance of products produced;
- the marketing and distribution of products.

The scope of the 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.

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the IED Annex I activity 6.10 threshold. However, impregnation with hydrophobisation agents such as oils, waxes or silicon compounds for waterproofing is covered in this BREF.

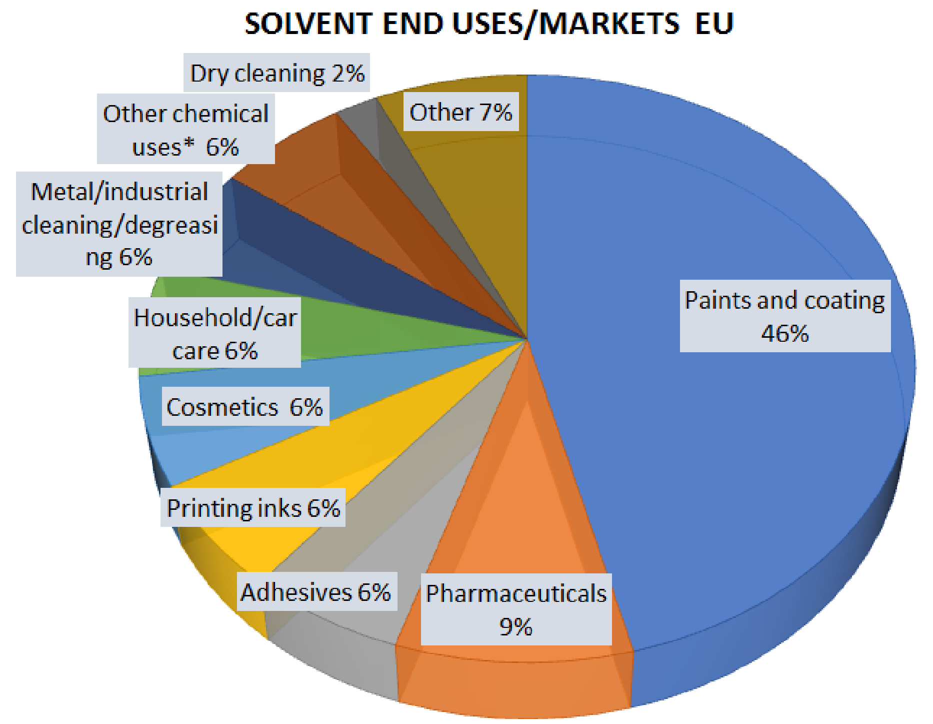
1 GENERAL INFORMATION ON SURFACE TREATMENT USING ORGANIC SOLVENTS

[78, TWG 2005]

Where this document refers to solvents, it means organic solvents (unless further clarification is given such as ‘water-based’, etc.)

1.1 Organic solvents and surface treatment

Organic solvents are largely derived from the petroleum industry and made by established producers (although there are alternatives, such as vegetable oil esters). A total of 5.1 million tonnes of solvents are sold and used in Europe on an annual basis [263, ESIG 2019] and by far the largest demand for solvents (about 46 % for oxygenated and hydrocarbon ones) comes from the paint and coatings industry (see Figure 1.1).



*other chemical use including rubber/polymerisation -oil & seed/food extraction - agrochemicals

Source: [263, ESIG 2019]

Figure 1.1: End uses of solvents in EU Member States

Organic solvents are usually categorised into classes of products. The most important classes are:

- oxygenated solvents: this includes esters, ketones, alcohols and glycol ethers (and their acetate derivatives);
- hydrocarbon solvents: aromatic (e.g. toluene, xylene), aliphatic and paraffinic hydrocarbon solvents;
- chlorinated solvents (not included in these statistics).

Within the solvents family, there has been a tendency to move away from aromatic and white spirit types of solvents, and to use less volatile products (less combustible, less potential exposure, less VOC release) where possible.

The European solvent production industry has an annual turnover of EUR 4 billion, with about EUR 28 million being directed to R&D projects. The total number of direct employees in Europe is estimated to be 7 500 [263, ESIG 2019].

Solvent usage involves about 10 million jobs in more than 500 000 companies in the EU-25 (2005 data), most of which are SMEs representing a global turnover of about EUR 200 billion [78, TWG 2005].

In this IED sector, the industries described use solvents for a wide range of activities. They are used in cleaning the surfaces to be treated and the process equipment, as well as as a carrier for the treatment (such as ink, paint, preservative, insulation, adhesive). The industries themselves use the treatments for one or a combination of:

- communication (printing);
- decoration;
- prevention of corrosion and/or decay of surface or product;
- product preservation and delivery (such as food and drink cans, food packaging, aerosol cans, toiletries, drums);
- the application of a layer with a special function (e.g. electrical insulation, abrasion, adhesion).

1.2 General environmental issues related to installations for surface treatment using organic solvents

1.2.1 General

The STS coating industries have a major role to play in extending the life of substrates, such as for automotive bodies, ships, aircraft and construction materials, as well as providing means of preserving and delivering food and other products in packaging. The main environmental issues relate to solvent emissions to air, water and soil, particulate emissions to air, energy usage, waste minimisation and management, and site condition on cessation of activities.

Because of the flammable nature of solvents, their potential impact on the health and safety of workers and their often-offensive odours, they have been controlled and extracted from the processes for many years. The industry can also discharge particles from the processes, especially from spraying and sanding. The extraction and, where applied, treatment of solvents and particles uses large fans and other equipment that can be major sources of noise. Many installations also use production equipment that is inherently noisy. Solvents may be used not only in cleaning the substrates but also equipment, giving rise to wastes containing solvents which may need special management for recovery and disposal. The sector uses significant energy both in the production processes, and in end-of-pipe waste gas collection and treatment. The following issues are crucial:

- minimisation of the consumption of raw materials and energy;
- minimisation of emissions by process design, management and maintenance and by off-gas treatment;
- assuring chemical safety and prevention of environmental accidents.

The measures to achieve better environmental performance are frequently complex and have to be assessed in respect of their potential impacts on workplace health and safety, on the quality of the product and other processes, on the age and type of installation, as well as on the benefits to the environment as a whole. Best available techniques will be balanced against these criteria and therefore include changes within process units as well as end-of-pipe abatement techniques.

Sophisticated process control and treatment techniques play an important part in achieving improved environmental performance. However, competent operation, regular maintenance and a desire for improvement are as essential as the choice of technology, particularly in reducing fugitive and untreated emissions of VOCs. Important considerations therefore include good management and working practices, good process and site design, education of the workforce on environmental and process performance, workplace safety and accident prevention, and finally, monitoring of the process and environmental performance.

1.2.2 Solvents

The following definitions are given in the IED and are considered in the context of this BREF:

A. ‘organic solvent’ means any volatile organic compound which is used for any of the following:
(a) alone or in combination with other agents, and without undergoing a chemical change, to dissolve raw materials, products or waste materials;
(b) as a cleaning agent to dissolve contaminants;
(c) as a dissolver;
(d) as a dispersion medium;
(e) as a viscosity adjuster;
(f) as a surface tension adjuster;

(g) as a plasticiser;
(h) as a preservative;

B. ‘volatile organic compound’ means any organic compound as well as the fraction of creosote, having at 293.15 K a vapour pressure of 0.01 kPa or more, or having a corresponding volatility under the particular conditions of use.

Different definitions are given in other pieces of legislation or registers, as shown by the examples below:

In Directive 2004/42/CE[3] (‘the Paints Directive’), ‘volatile organic compound (VOC)’ means any organic compound having an initial boiling point less than or equal to 250 °C measured at a standard pressure of 101.3 kPa.

In the E-PRTR[4], emissions of NMVOC (non-methane volatile organic compounds) are considered. NMVOC are defined in Directive (EU) 2016/2284[5] as all organic compounds other than methane that are capable of producing photochemical oxidants by reaction with nitrogen oxides in the presence of sunlight.

Because of their properties and the quantities involved, solvents are the key materials of concern:

- VOCs react with NO_X in the presence of sunlight to form ozone in the troposphere. This usually refers to NMVOC (non-methane volatile organic solvents).
- Halogenated solvents are toxic and have an impact on reducing ozone in the lower stratosphere.
- Some solvents are toxic to aquatic organisms.
- Some solvents are not readily biodegradable, so they have the potential to contaminate soils. Traditional solvents are not PBT (persistent, bioaccumulative, toxic) and none are vPvB (very persistent, very bioaccumulative). However, solvents can readily spread through soil to groundwater, where there are limited or no mechanisms for their removal or breakdown. There are numerous reports of aquifers used for drinking water being contaminated by solvents (although not necessarily from these industries).

Surface treatment using solvents was the second largest source of VOC emissions from EU-28 industries in 2016, according to the E-PRTR, see Figure 1.2 [207, EEA 2019].

The E-PRTR contains data from sites with NMVOC emissions above 100 tonnes per year. Therefore, there is a risk that a number of IED installations (with a solvent consumption capacity of more than 200 tonnes per year or 150 kg per hour) will not have reported. Although not a perfect match, this fits relatively well for some STS sectors, e.g. with the group of vehicle coating installations falling under the IED (> 200 tonnes per year solvent consumption). Therefore E-PRTR data can be considered to give a rough estimate of the environmental impact of the STS activities regulated by the IED.

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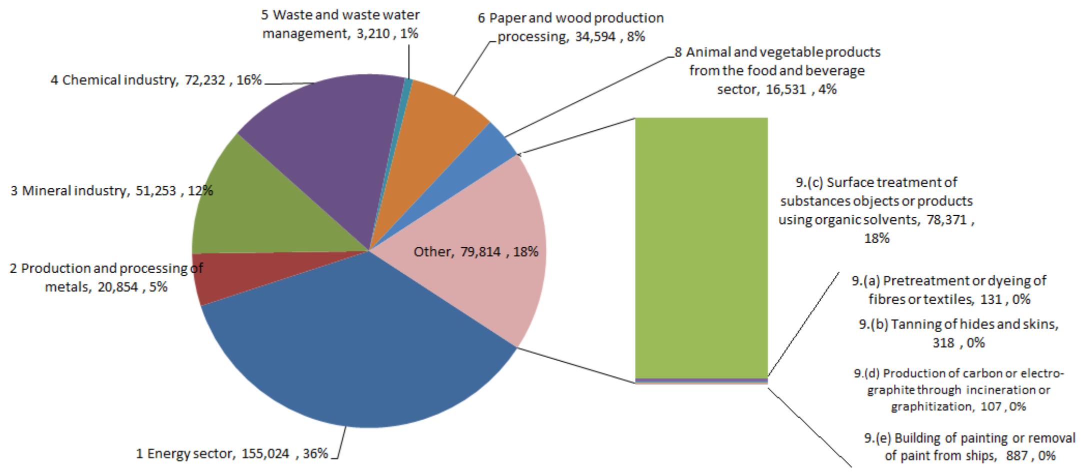
[3] Directive 2004/42/CE of the European Parliament and of the Council of 21 April 2004 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain paints and varnishes and vehicle refinishing products and amending Directive 1999/13/EC.
[4] The European Pollutant Release and Transfer Register (E-PRTR) (prtr.eea.europa.eu).
[5] Directive (EU) 2016/2284 of the European Parliamet and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC.



NB: Values in tonnes.
Data retrieved on 8.2.2019.
Source: [207, EEA 2019]

Figure 1.2: Non-methane volatile organic solvent emissions from industrial activities for 2016

1.2.2.1 CMR solvents

The IED requires the replacement of substances or mixtures which, because of their VOC content, are classified as CMR by less harmful substances within the shortest possible time. Most such solvents, particularly halogenated ones, have been replaced in industrial uses.

DMF (N,N-dimethylformamide) is used for the coating of textiles with polyurethane (PU) and in solvent mixtures when coating with polyvinylchloride (PVC) and this is discussed in Chapter 8.

1.2.3 Dust

This arises from some of the processes (such as sanding of wood and other substrates) and as liquid paint particles from spray coating processes (paint overspray).

1.2.4 NO_X and CO

NO_X and CO emissions occur from thermal off-gas treatment techniques and sometimes from dryers. They cannot be reduced easily and in the STS plants their generation is controlled by correct design of the off-gas treatment systems including low-NO_X burners and optimisation of the operating conditions. When adjusting the off-gas treatment systems, a balance must be found between VOC abatement efficiency, energy consumption and the process-related formation of secondary pollutants NO_X and CO, especially as there is a reverse temperature - concentration dependence of NO_X and CO [169, VDI 2013].

1.2.5 Metals

Toxic metals such as cadmium, lead, chromium and nickel are often referred to as occurring in water-based pretreatment and pigments for inks and paint. However, these have long been controlled by legislation such as Regulation (EC) No 1907/2006 (REACH[6]) [47, EU 2006], the End-of-Life Vehicles Directive [52, COM 2000] and the Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment [53, COM 2003], etc. Cadmium and lead are not used in large-scale surface treatments using organic solvents and are not used by the printing processes discussed in detail in this document.

Zinc and nickel (with manganese and iron) are used in phosphate conversion coatings in vehicle manufacture and other metal surfaces, to improve corrosion resistance and paint adhesion.

Water-based conversion coatings on zinc or zinc alloy or phosphated surfaces prior to painting was a widespread use of hexavalent chromium (Cr(VI)). This is discussed in the STM BREF [23, COM 2006], together with its substitution. As a result of the End-of-Life Vehicles Directive[7], the use of Cr(VI) has ceased in vehicle coatings.

Cr(VI) substances used in conversion coatings had a sunset date under the REACH Regulation [47, EU 2006] of 21 September 2017 and, as they are listed as Annex XIV substances, will require specific authorisation for each use.

There was a REACH sunset date of 22 January 2019 for various Cr(VI) substances potentially used in paint pigments, some having slight solubility in water. Until October 2017, there were applications from about 10 manufacturers for CAS number 7789-06-2 (strontium chromate) for use in aerospace coatings and one for CAS 11103-86-9 (potassium hydroxyocta-oxodizincatedichromate) for unspecified use in primers, sealers and coatings.

Until 12.10.2017, only 4 authorisations had been granted to 9 different applications of chromic acid (Cr(VI)) for surface treatment. A total of 21 applications were still pending for approval. Until October 2017, authorisation had been granted to bright-chrome plating, pretreatment for electroplating, hard chrome plating and for oxidation and hardening of stainless steel. Furthermore, authorisation has been granted for pretreatment of metals for coating of items used in harsh environments (for aviation, automotive industry, power stations).

Until October 2017, there was no authorisation for passivation of standard metal components before coating. For this application, several alternatives are available with different chemistry (including chemicals such as zirconium, titanium, fluoride, sulphuric acid, phosphoric acid, nitric acid, silanes). These new processes may result in a different waste water composition where new treatment processes and water-saving methods may be required.

For the status of authorisations applied or granted, the reader is invited to check the website of the European Chemical Agency (echa.europa.eu) and the European Commission’s REACH web page (ec.europa.eu/environment/chemicals/reach/reach_en.htm).

Dibutyl tin oxide is used as a catalyst in electrocoat paint systems for coating vehicles and other metal surfaces.

Small amounts of copper are used in copper phthalocyanine blue pigments for inks, but they are not water-based. The copper in these pigments is however bound very strongly and cannot be found in waste water.

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[6] Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC. OJ L 396, 30.12.2006, p. 1–850.

[7] Commission Directive (EU) 2017/2096 of 15 November 2017 amending Annex II to Directive 2000/53/EC of the European Parliament and of the Council on end-of-life vehicles.

1.2.6 Other pollutants

Biocides are used to provide long service times for aqueous degreasing and electrocoat solutions and for wet overspray scrubbers.

In the coating of ships, the removal of old, and the application of fresh, antifouling coating can give rise to contaminants such as TBTO (tributyl tin oxide) and other biocides. New types of antifouling coatings are controlled by the IMO (see Chapter 4).

Ammonia is used as a stabiliser in some water-based solutions.

1.2.7 Energy

All the sectors are significant users of energy throughout the activities: in the surface treatment processes, in associated activities, and in the pollution abatement equipment. Significant amounts of energy are used to extract solvent-contaminated air, and natural gas may be used as a support fuel for thermal destruction of VOCs at low concentrations. The balance of energy usage and VOC abatement, and if possible energy recovery, must be carefully considered. In many cases, integrated solutions, such as better control of fugitive emissions and planned maintenance may abate significantly more VOCs, in a more energy-efficient way, than solutions based on off-gas treatment alone.

1.2.8 Raw material usage

High-efficiency techniques can be used to reduce material consumption generally. The emission of solvents can be significantly reduced by high-efficiency application techniques and coating materials with a high solids to solvent ratio.

1.2.9 Water usage

Water is used in cooling and in other processes, in particular water-based pretreatments and coatings. Minimising water consumption is important and is therefore dealt with in this document and in the STM BREF.

1.2.10 Solid and liquid wastes

Where solvents are used, the wastes generated may often be classified as hazardous. Waste management and monitoring as well as techniques for the minimisation of waste generation are also discussed.

1.2.11 Odour emissions

Many processes using solvent have odour impacts / odour nuisance.

2 COATING OF VEHICLES

2.1 General information on the coating of vehicles

[142, ACEA 2016] [146, ACEA 2018] [170, OICA 2017] [200, ACEA 2016]

2.1.1 General

This section (2.1) gives a general introduction to the large-scale coating of the vehicle types in Table 2.1 as classified by the automotive industry [146, ACEA 2018]. Not included in these data and also not covered in Chapter 2 are the coating of motorcycles, trailers, agricultural and construction equipment (these are covered in Chapter 3 if above the IED thresholds).

Table 2.1: Vehicle types

Abbreviation	Vehicle type	Vehicle Category (1)	Terms used in this chapter
PC	Passenger cars (≤ 9 seats)	M1	PC, cars
LCV(2)	Light commercial vehicles up to 3.5 t, also called 'vans'. See Section 2.2.4 for more details on the definition of vans	N1	Vans
MHCV (or CV)	Medium and heavy commercial vehicles over 3.5 t, also called ‘trucks’	N2 and N3	CV: trucks CAB: truck cabins
BC	Buses and coaches > 9 seats	M2 and M3	Buses

(1) As defined in Directive 2007/46/EC establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles.
(2) Some LCVs (N1) are car-based and use similar paint processes to M1 and may be produced together with M1 bodies in the same plant.

2.1.2 Number, size and distribution of installations

There are 221 motor vehicle assembly plants in Europe (not including other separate plants for engine or components production, such as gearboxes, transmission) of which about 103[8] are covered by point 6.7 of Annex I to the IED (see Table 2.2). In some of the large vehicle manufacturing sites, in addition to vehicle coating, other painting activities are undertaken such as engine, bumper or wheel rim painting. These activities are covered in Chapter 3, Coating of other metal and plastic surfaces.

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[8] Figure from ACEA initial position information (2015) and updated information (2018).

Table 2.2: a) Motor vehicle production sites in the EU (2015 data), b) Motor vehicle paint shops above the capacity threshold of activity 6.7 of Annex I to the IED in the EU

Country	a) Motor vehicle production sites in the EU					b) Motor vehicle paint shops above the capacity threshold of activity 6.7 of Annex I to the IED					
	PC	LCV	MHCV	BC	Total	PC	Vans	Trucks	Truck cabins	Buses	Total
Germany	24	5	4	2	41	21	2	3	2	2	30
France	12	7	7	3	33	9	3	-	1	-	13
United Kingdom	19	1	2	4	33	8	1	1	-	-	10
Italy	10	5	3	1	23	4	2	-	1	-	7
Spain	9	5	2	1	14	9	1	1	3	1	15
Sweden	3	-	2	2	9	1	-	-	2	-	3
Belgium	3	-	4	2	8	2	-	-	1	-	3
Czech Republic	4	-	1	2	8	4	-	-	-	1	5
Other MS	20	4	11	9	52	12	1	2	2		17
European Union	104	27	36	26	221	70	10	7	12	4	103

Source: a) [171, ACEA 2016], b) [212, TWG 2018] updated data from ACEA.

2.1.3 Geographic distribution

The motor vehicle production in the European Member States (EU) is concentrated in five countries which together represent 75 % of the total production.

Table 2.3: Production of motor vehicles in the EU in 2014 (vehicles/year)

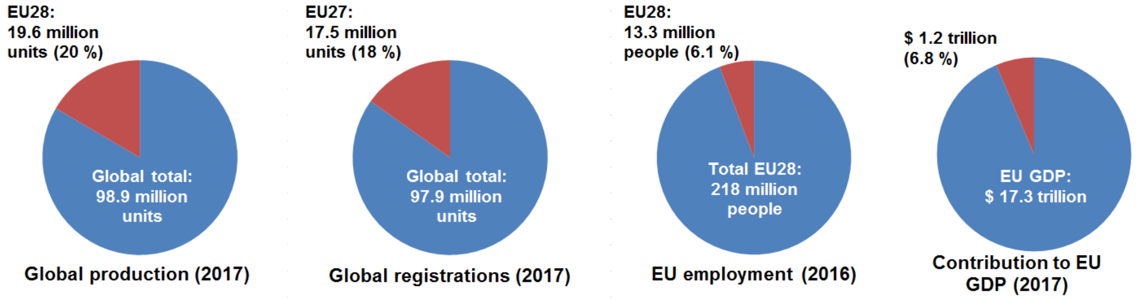
Country	PC	LCV	MHCV	BC	Total	Share
Germany	5 604 026	174 966	121 755	6 801	5 907 548	34 %
Spain	1 898 342	477 097	27 539	1 095	2 404 073	14 %
France	1 499 464	274 915	43 396	3 689	1 821 464	11 %
United Kingdom	1 528 148	55 294	12 610	2 827	1 598 879	9 %
Czech Republic	1 128 473	0	821	3 893	1 133 187	7 %
Other MS	3 721 088	424 922	126 170	17 499	4 289 679	25 %
European Union	15 379 541	1 407 194	332 291	35 804	17 154 830	100 %

NB: Data for commercial vehicles are estimated to compensate for data gaps in the OICA statistics.
Source: [170, OICA 2017]

2.1.4 Economic significance

The automobile industry is one of the major manufacturing industries in Europe and of international importance. It makes significant contributions to the EU economy in terms of GDP and trade balance, employment, industrial R&D and capital investment.

GDP and trade balance



NB: Data for EU total GDP are taken from World Bank (https://data.worldbank.org/region/european-union).
Sources: [145, ACEA 2019] [146, ACEA 2018]

Figure 2.1: European automotive industry economic data

Source: [146, ACEA 2018]

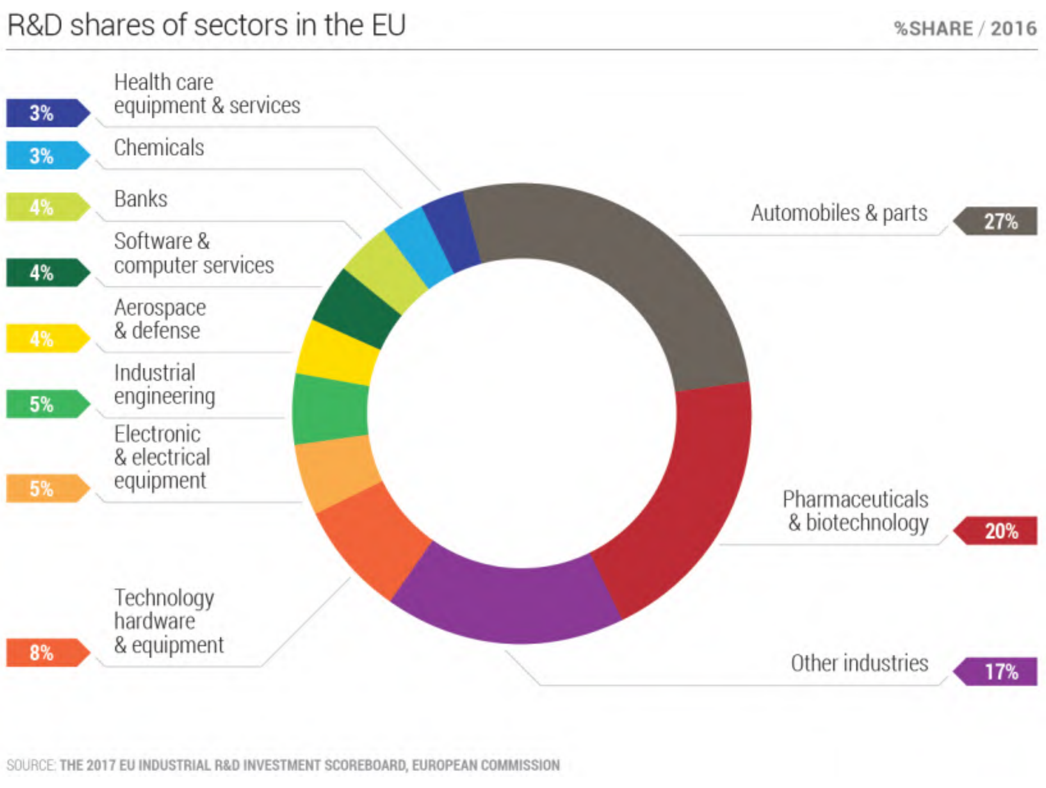
Figure 2.2: EU automotive industry balance of trade

Employment

Almost 11 % of EU manufacturing employment is in the automotive sector: 2.5 million employed in direct manufacturing and 0.9 million employed in indirect manufacturing [146, ACEA 2018].

R&D investment

The EU is the world's largest investor in automotive R&D and the automotive sector is the EU's biggest private investor in R&D, with EUR 53.8 billion invested in 2016 (see Figure 2.3) [146, ACEA 2018].



Source: [146, ACEA 2018]

Figure 2.3: EU industrial R&D spend, 2016

Investment economics

Investment costs for a new passenger car paint shop range between EUR 150 million and EUR 500 million. Investment cycles are therefore a key factor for vehicle manufacturers. The optimal time to make environmental investments is when the renewal of equipment takes place within the normal investment cycle. Generally, major investment cannot be made in an existing installation, except when opportunities for major modifications of the paint shop facilities arise. These opportunities tend to occur after the normal lifetime of the paint shop (between 20 and 40 years) or when there is a step change in production volumes, which is often associated with a new product launch. Investment opportunities for new and existing installations are limited because the capital investment for building and equipment required is extremely high and ROI (return on investment) is low, giving long return on capital times. Investments usually depreciate over 20 years.

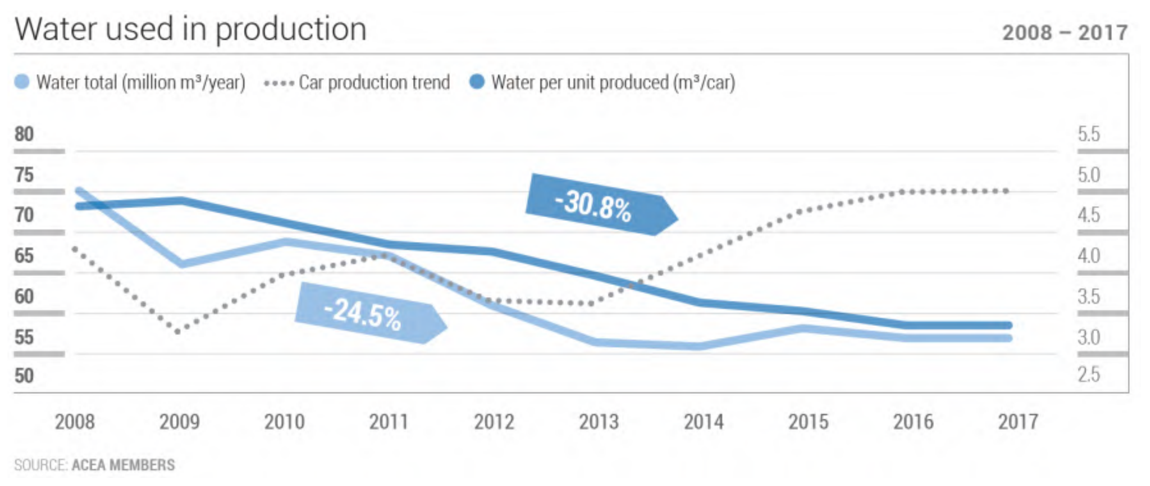
The expense for a specific project depends very much on site-specific requirements (greenfield, space constraints, brownfield), production capacity, availability of utility supply, and market situation. As a rule of thumb, due to demolition costs and integration into existing infrastructure, the replacement of spray booths / technical equipment or the extension of existing lines with additional equipment (such as off-gas treatment systems) is 20 % to 40 % more expensive compared to greenfield projects.

On existing sites, the implementation of a new paint shop will often lead to substantial downtimes in production because the very specific building requirements of the new paint shop (e.g. building ventilation, substantial foundations, free height under truss) also have to be implemented prior to the actual installation of the equipment.

2.1.5 Key environmental issues

2.1.5.1 Water consumption

Long-term strategies for reducing water consumption (including minimisation and recycling) reduced the total[9] average consumption of water per car by 30.8 % between 2008 and 2017. This includes the application of recirculation strategies.



Source: [146, ACEA 2018]

Figure 2.4: Water consumption for the EU automotive industry

Prior to painting, bodies and body components in white[10] are cleaned by aqueous-alkali solutions of detergents. This is followed by pretreatment using aqueous solutions of zinc, manganese and nickel phosphates to ensure both reliable subsurface corrosion prevention and good paint adhesion.

In some cases, loads of zinc and nickel, as well as phosphate and fluoride from the same processes, exceed the E-PRTR reporting thresholds[11]. This may be due to relatively high flow volumes (of the order of 200 000 m^3 a year) multiplied by low concentration values (usually well below ELVs).

2.1.5.2 Energy consumption

The complexity of cars has increased significantly, which has had an effect on energy demand. Nevertheless, the industry has reduced the energy consumed per car by 15.7 % over the last decade. Of this, paint shops account for about 30 % (based on 2012 data). Fluctuations in energy consumption can be explained by lower production volumes, especially during the economic crisis, as well as variable weather conditions in some years (see Figure 2.5).

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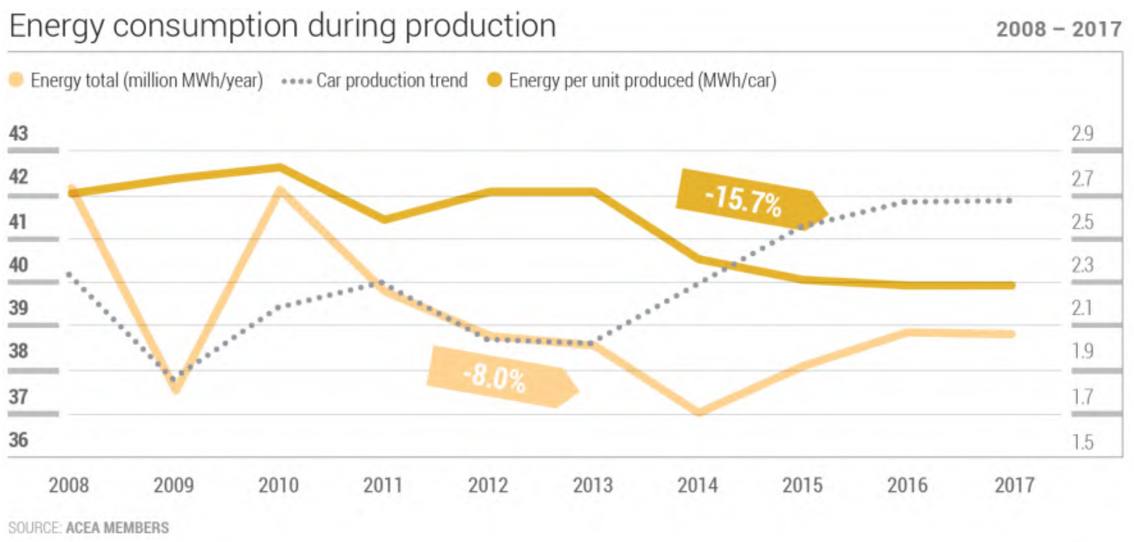
[9] The water consumption applies to the total production usage, including production of car bodies as well as pretreatment activities of the bodies in paint shops.

[10] 'Body in white' refers to the bare metal body.

[11] Thresholds for release to water bodies or transfers to waste water treatment in Regulation (EC) No 166/2006 concerning the establishment of a European Pollutant Release and Transfer Register and amending Council Directives 91/689/EEC and 96/61/EC.

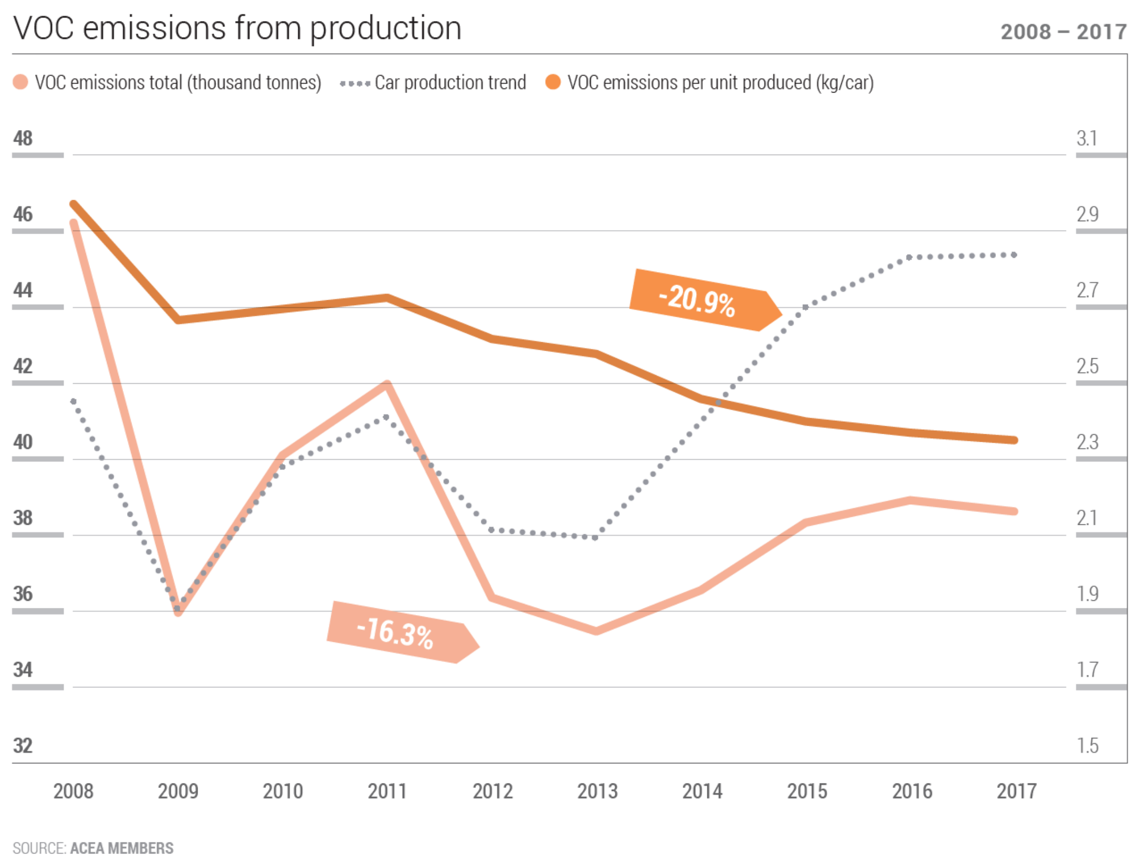


Source: [146, ACEA 2018]

Figure 2.5: Energy consumption for the EU automotive industry

2.1.5.3 VOC emissions to air

The most important environmental issue related to the coating of new vehicles is the emission of VOC solvents mainly from paint shops. Figure 2.6 shows the evolution of VOC emissions per car produced and the total emissions of all car manufacturers combined. With new technologies, such as the replacement of solvent-based paints with solvent-free or water-based equivalents or more efficient solvent-based technologies and the installation of additional off-gas treatment units, manufacturers have reduced unit emissions by 21 % per car over the last 10 years. This is likely to have been influenced by the implementation of the Solvent Emissions Directive (SED) in 1999, the exchange of information for the STS BREF (2004 to 2006) and the closure of older and less efficient sites during the 2008 economic crisis.



Source: [146, ACEA 2018]

Figure 2.6: VOC emissions from the EU automotive industry

2.1.5.4 Other emissions to air

Off-gas streams are treated for particles of paint overspray, while NO_X and CO are emitted as combustion products of thermal off-gas treatments (see Table 2.4).

Table 2.4: Air pollutants other than VOCs from passenger car paint shops compared with EU-28 EMEP data

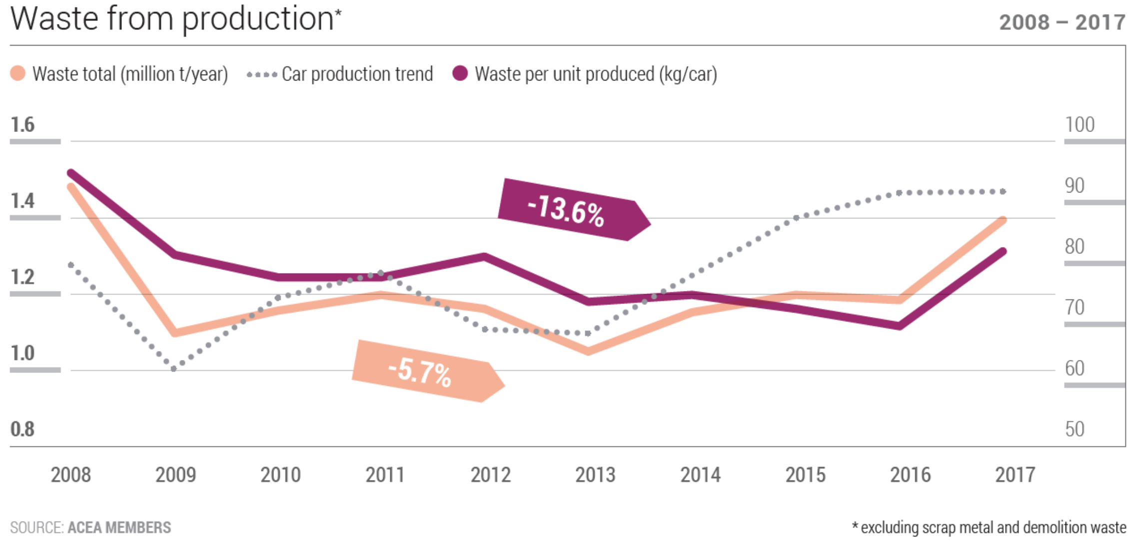
Pollutant	Specific emission from passenger car paint shops [kg/vehicle]	Total emission from all paint shops [Mg/yr]	EU-28 EMEP data [Gg/yr]	Paint shop share [%]
PM(dust)*	0.03	440#	1 934	0.025
NO_X as NO_2	0.11	1 610	8 459	0.019
CO	0.10	1 460	22 046	0.007

* Paint shop emissions are measured and reported as TPM (total dust); EMEP data are figures for PM_{10}. From particle size measurements of paint overspray, it is known that paint shop dust is nearly 100 % PM_{10}.
# Alternatively, a calculation based on estimates on painted surface, coat layer thickness, transfer efficiencies and an assumed efficiency of the off-gas treatment system of 90 % results in annual emissions of 1 300 mg/yr paint particles. Even with these figures, the contribution of paint shop emissions to the EMEP EU-28 data is well below 0.1 %.
Source: [142, ACEA 2016] p.109

2.1.5.5 Waste generation

Figure 2.7 shows the trend in waste generation for the complete car production process (note: specific data on waste generation from the coating activities are presented in Section 2.3.2.6). The waste generated per unit produced by the manufacturing of passenger cars fell by 13.6 % over 10 years. Waste fluctuations, both in absolute and per unit terms, can be explained by the occurrence of singular events, such as a fall in total production during the economic crisis.

Note that the data shown in the figure below refer to the waste production for the entire car production process and not only for the paint shop.



Source: [146, ACEA 2018]

Figure 2.7: Waste generation from passenger car production (excluding scrap and demolition waste)

2.2 Applied processes and techniques for the coating of vehicles

[142, ACEA 2016] [169, VDI 2013] [201, ACEA 2016]

2.2.1 General

This section briefly describes the current production process and the directly associated activities for the serial painting of cars, vans, trucks (truck chassis), truck cabins and buses. It also indicates the main integrated techniques applied for the prevention and reduction of emissions.

The information is primarily based on cars, as their coating covers the full range of applied processes and techniques. The painting processes for the coating of vans, trucks and truck cabs have many similarities with the painting of cars and can have similar environmental impacts, but they also exhibit some differences, with for example truck units (cabs and chassis) being painted separately. Significant deviations can be experienced from the serial painting of cars due to the use of different coating materials, processes, application techniques and layer constructions. Although optical surface qualities are as important as for cars, corrosion protection is more important for vans and trucks than in other sectors. Differences include different body designs and sizes, lower production volumes, the different end uses, and therefore different quality and other customer criteria. These differences are explained in separate sections for vans (Section 2.2.4), trucks (Section 2.2.5), truck cabins (Section 2.2.6) and buses (Section 2.2.7).

2.2.2 Overview of paint shop investment, design and operation

Each manufacturer has its own company- or brand-specific priorities and targets for the various quality demands and customer expectations for passenger cars, vans, trucks or buses. However, there are other objectives to be met, such as shareholder expectations and legal requirements including environmental issues.

These factors all influence the ‘company philosophies’ about how to design and operate a paint shop, so both the technical layout of the installations and the chosen corrosion protection and paint systems vary. The timing of investments, costs and differences between existing and new sites is discussed in Section 2.1.4. The choice of paint systems and paint shop type are crucial to the reduction of VOC emissions and energy usage and are a 20- to 40-year commitment. While some retrofitting and updating of technologies may be carried out, this has a more limited effect on emissions and consumption.

Vehicle paint shops can be seen as belonging to three ‘families’ (see Section 2.2.3.8). The decision to invest in a particular family is irreversible until a paint shop is rebuilt. Note that not all techniques can be combined and not all techniques are interchangeable, as the choice of compatible techniques is limited within a particular family.

Vehicle manufacturers with installations of this size are large companies and (predominantly) multinational or part of multinational groups. Such companies have well-developed management systems to balance and integrate the competing objectives outlined above. Those that may have the most significant impacts on consumption and emissions from production are:

- capital and business planning;
- operational management including quality systems and maintenance;
- environmental management systems.

In paint shops for passenger cars, the process steps are carried out in sequential lines and each subprocess is applied in a separate section of a line. Standard line capacities are between 30 and 60 units per hour. Normally the number of shifts per day is varied (one, two, three) to adjust the paint shop output to customer demand, rather than changing the line speed. If higher output is required, additional lines are operated in parallel.

Paint shops are large and complex installations. Together with workstations for body preparation, inspection sections, body and material storage areas, ventilation equipment, paint overspray scrubbers, VOC abatement systems, and staff and maintenance areas, an installation with one paint shop line with a capacity of 30 units per hour stretches over several floors with a total area of 70 000 m^2 to 100 000 m^2. The total line length of these different production segments is about 1.5 km. The estimated investment costs for a new paint shop of this size are between EUR 150 million and EUR 250 million (2018 values). The processing time of a body in the paint shop is between 6 and 11 hours.

The heart of the paint shop, the spray booths, are very large units with at least three floors and cabin lengths between 60 m and 90 m per subprocess. In order to implement such a spray booth, a free building height under truss of at least 14 m is required to accommodate the key elements of the booth (overspray scrubber, application zone with service and technical cabinet area and plenum).

2.2.3 Coating of passenger cars

This chapter discusses the large-scale coating of new passenger cars, (category M1, see Section 2.1.1). Some N1 vehicles (vans), which are produced in the same installation, may be based on cars and use similar production techniques.

Source: [142, ACEA 2016] [© Volkswagen AG, 2015; Daimler AG, 2014.]

Figure 2.8: Examples of passenger car bodies showing the spread from very large to very small car bodies

2.2.3.1 Raw materials, handling, storage and paint mixing room

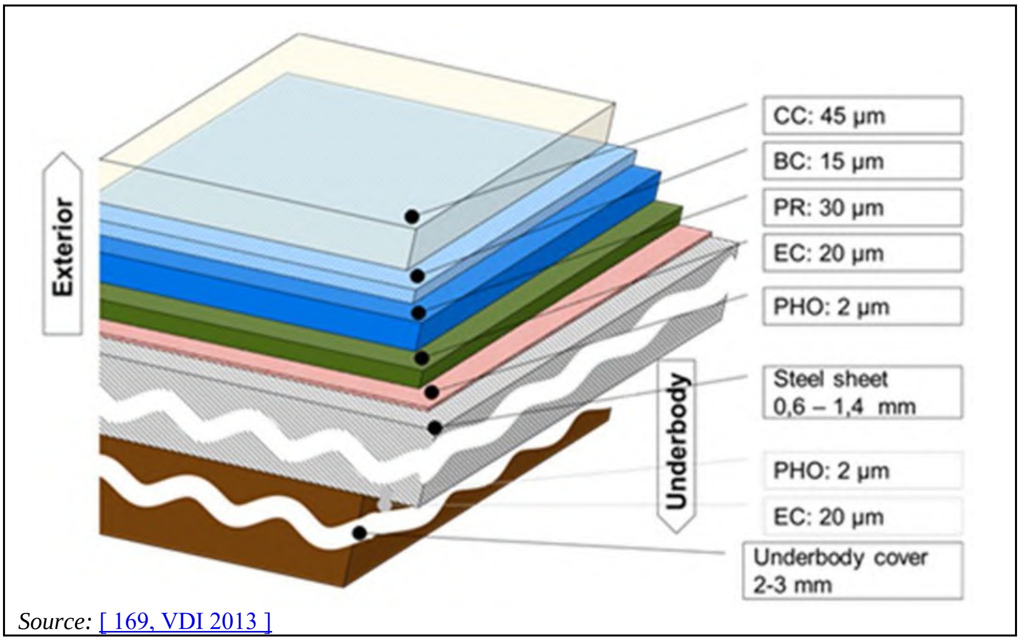
The main production raw materials (apart from the vehicle bodies) are paints and other coating materials, solvents for viscosity adjustment and cleaning and other cleaning materials. The materials are unloaded in specially designed logistics areas with chemical-resistant flooring and/or technical equipment for the retention of leaked liquids. Storage rooms and the paint kitchen are ventilated and often air conditioned and equipped to prevent soil and groundwater contamination from spillages. Leakages will be detected by technical monitoring systems and manual control routines. Waste materials will also be stored and handled in a similar manner.

2.2.3.2 Standard coating process

The following requirements have to be fulfilled by the coated car bodies and, therefore, by the paints:

- Long-term protection against corrosion, weather, chemical influence (e.g. bird droppings, acid rain), chipping, sun, abrasion in car washes. Body warranties have now increased from 10 to 15 years.
- Ideal optical surface properties: polish, colour depth, free of cloudiness, faultlessness, therefore producing homogeneity and a consistency in colouring and formation of effects (such as metallic finishes, pearlescence, multiple coloured panels, etc.) Such quality requirements can increase the number of paint layers, and potentially the VOC emissions from a plant.

These high requirements can only be achieved by four or maybe even five paint layers designed to complement each other (see Figure 2.9). They are applied in several successive steps.



Source: [169, VDI 2013]

Figure 2.9: Layer sequence and typical thickness of passenger car coatings

A typical process flow is shown in Figure 2.10 and described in the paragraphs below. The abbreviations refer to stages shown in Figure 2.10.

2.2.3.2.1 Aqueous pretreatments and e-coat

The following pretreatment and e-coating activities are water-based and operate together with techniques that aim to prolong the service life of treatment or rinsing baths, minimise water consumption, optimise material usage and minimise discharges to water. In many cases, waste water treatment is carried out in a separate treatment plant where waste water from other manufacturing activities is treated together with paint shop waste water. General information on the aqueous pretreatments and associated techniques, together with the relevant waste water treatments, can be found in the STM BREF [23, COM 2006].

The bodies pass through the pretreatment and e-coat stages by conveyor systems. With pendulum or rotation conveyors, the bodies can be swivelled and turned upside down in the treatment and rinsing tanks, to ensure all possible surfaces are treated.

Pretreatment (PT)

This consists of cleaning and degreasing, and phosphating or other conversion coating systems.

Cleaning and degreasing (CLE)

From the body welding shop lines, the metal body in white is delivered to the pretreatment (PT-CLE) segment of the paint shop where weld dust, dirt, oil, grease and adhesive residues from the stamping, welding, bonding and grinding operations are removed in the spray and dip cleaning stations. Cleaning agents are aqueous-alkaline detergent solutions which are applied at elevated temperatures (40-60 °C), followed by cascading rinse baths. Currently, demulsifying systems are generally used. These systems are described in the STM BREF [23, COM 2006].

Phosphatation / Phosphate coating (PHO)

To improve corrosion resistance and enhance the adhesion of the subsequent organic coat, a phosphatation and passivation process is standard. The process solution with pH values between 2.8 and 3.8 contains phosphates of nickel, manganese and zinc at temperatures between 35 °C and 55 °C. The passivation is usually carried out using zirconium salts[12]. Generally, a two- or three-step cascade rinsing follows, the last step with deionised water. As an alternative to phosphatation, nickel-free zirconium- or silane-based treatments, which are applicable at room temperature, have been developed in the last 10 years. However, the process parameters of this type of pretreatment are much more delicate to control and the additional costs for these products are not compensated by the energy saving from the reduction of the process temperature. Most passenger car manufacturers have not yet approved these systems for pretreatment of multi-metal passenger car bodies.

E-coat (EC)

E-coat (EC), short for cathodic electrodeposition, electrolytic coating or cathodic dip coating, is an immersion process where the pretreated body is moved through an aqueous coating. The coating delivers corrosion protection and is electrically deposited in an even film as substrate for the following spray applications. The car body acts as cathode (negatively charged) and the anodes are positioned at the bottom and side walls of the tank. At high amperages, 5-10 kWh of energy per vehicle body is introduced into the EC bath and cooling is necessary to keep the bath temperature below 30 °C. The surplus coat is rinsed off the car body. Paint particles which have not been electrically deposited are removed by reverse cascade rinsing with ultrafiltrate and deionised (DI) water as the final step. The e-coat film is then cured in a drying oven. Generally, the e-coat tank has a separate exhaust air system and in some installations the off-gases from the e-coat cabin is conducted to the e-coating drying oven to abate the VOCs (see Section 2.2.3.5).

Sealing, noise-damping and underbody cover (SD)

After drying the e-coat, the bodies continue to the quality check and repair stations and are transferred to workplaces, where sealers, underbody protection and noise-damping material is applied. These are pasty substances and are applied manually or with robots using airless spraying or extrusion. Noise-damping materials are also available as prefabricated blanks, which are mixed with hot melts. These coats are often gelified in a separate oven before the bodies enter the spray-painting unit.

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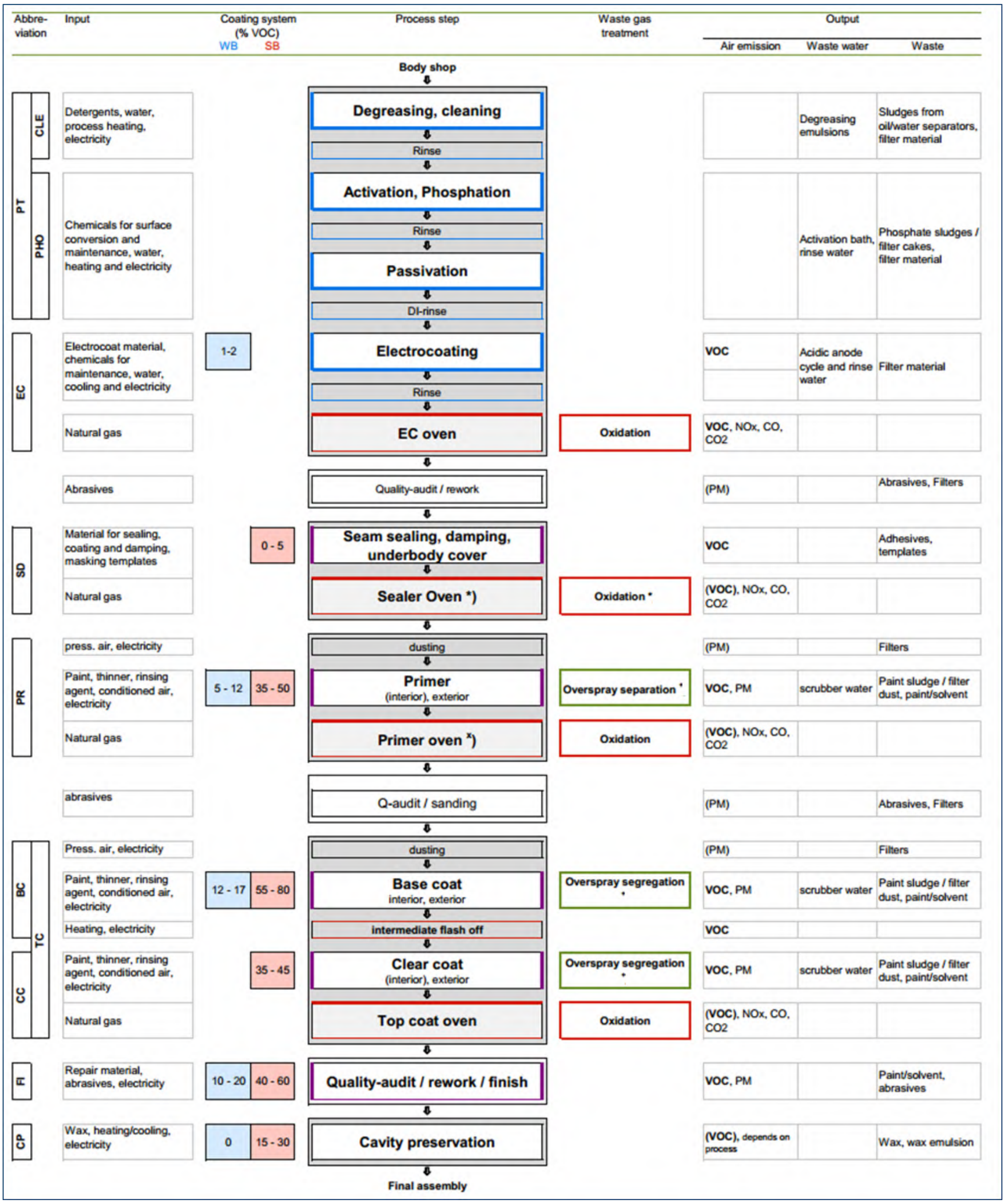
[12] Chromium VI passivation is no longer used to comply with Directive 2000/53/EC on end-of-life-vehicles and (the ‘ELV Directive’).



NB:

Main environmental impacts (consumption, emission) of the single subprocesses are included.

* Optional.

x Not in paint shops with integrated processes.

\+ In exceptional cases with additional VOC oxidation. In some cases, dry filter techniques are used instead of venturi scrubbers.

PT: Pretreatment; CLE: Cleaning and degreasing; PHO: Phosphating; EC: E-coat; SD: Sealing and damping; PR: Primer; TC: Topcoat; BC: Base coat; CC: Clear coat; FI: Finish (Rework); CP: Cavity preservation.

Source: [201, ACEA 2016]

Figure 2.10: Standard process flow for coating of passenger cars (PC)

2.2.3.2.2 Spray booths

After sealing and noise-damping, the bodies continue to the spray booths where the primer and topcoats (base coat and clear coat) are applied.

To remove dust and residues from the upstream body rework and preparation operations, the car bodies pass through ionised air blow-off stations, and/or are brushed with rotating feathers or robot-operated suction brushes and then transferred via airlocks to the spray booth.

Paint and solvents are generally stored in a separate room and pumped through ring lines to the spray cabins. Paint overspray is transferred with the downstream cabin air to particle filters or scrubbers which are placed below the open grating flooring of the paint cabin.

Spray coating needs closed booths and requires controlled booth-air conditions (the ‘paint window’, i.e. humidity, temperature and laminar downdraft). Compared to solvent-based paints, the paint window for water-based paints is smaller, which might cause higher energy consumption for cooling or dehumidifying in regions with extreme climatic conditions. A constant laminar downward airflow of 0.15 m/s to 0.4 m/s is necessary to ensure stable and reproducible application conditions in the immediate vicinity of the body surface and to transfer paint particle overspray to the particle separator systems under the paint booth. Additionally, the air exchange rate must be high enough to keep the VOC concentration safely below the lower explosive limits (LELs) and in the case of manual application below the occupational exposure limits. Cabin air recirculation may not be allowed in combination with manual spray coating due to health and safety considerations.

2.2.3.2.3 Application of paint and coatings

Automation

Automation usually greatly improves the application efficiency, using less paint or sealer and therefore using and emitting less VOCs. Originally all paint operations were done manually using handheld spray guns with pneumatic atomisers. Today this is only done in European passenger car paint shops in special cases. From about 1980 to 2000, exterior painting was automated with paint machines in the form of gantries, while interior coating and additional exterior painting remained manual (see also Section 2.4.4.1). From 2000 to 2005, robots replaced painting machines and eliminated manual exterior painting (see also Section 2.4.4.2). Robots were introduced in around 2010 to replace manual interior painting and this is ongoing.

Atomisation techniques and paint transfer

There are different atomising techniques used to disperse the liquid paint and transfer the paint aerosol to the body surface. The optimisation of the paint transfer reduces paint and solvent usage, therefore reducing VOC emissions.

- Airless spraying where compressed paint is pumped through a spray nozzle. This is not widely used in serial coating of passenger cars. However, airless application is standard in underbody coating (PVC).
- Air spraying or pneumatic spraying, in which a mixture of paint and pressurised air (sometimes at elevated temperature or with nitrogen instead of air) is forced through the paint nozzle and expands to a fine paint aerosol (pneumatic atomisation). In the automotive industry this concept is widely used with reduced air pressure as HVLP (high-volume low-pressure) atomisation.
- Pneumo-electrostatic guns may also be used, where the pneumatically atomised paint spray is electrically charged and attracted to an earthed body.
- High-speed rotational bell spraying with electrostatic charging is used in most vehicle paint shops.

If an electrostatic spray application with internal charging is used, paint supply systems with water-based paints need special electrical (galvanic) decoupling arrangements (e.g. cartridge systems). Alternatively, electrostatic spray bells with external charging can be used for water-based paints.

The paint aerosol is transferred to the coating surface by its own particle momentum, in a directional airflow, along an electric field gradient, or a combination of these forces. By changing operational parameters, such as paint flow rate, bell rotation, voltage, and directional airflow, the shape of the spray jet can be adapted to the body surface and used for optimising the transfer efficiency. For painting of interior body parts, the electrostatic charging can be reduced or switched off.

Colour change and cleaning

Reductions in paint waste and solvent emissions from cleaning are achieved by optimisation of paint colour supply and changing, and cleaning methods used.

In some existing paint shops, the car bodies are sorted by colour in large storehouses in order to supply the base coat cabin with the largest possible blocks of car bodies of the same colour (see Section 17.6.2.1). However, the introduction of low-loss colour change techniques (see Section 17.2.4) has reduced the importance of high colour block lengths as a means to reduce material consumption and solvent emissions.

In mass volume vehicle paint shops, paint is generally stored in a paint supply centre and pumped to the spray booths by steel ring lines, where each line is dedicated to one paint type and colour. Low-use colours are very often supplied from small paint distribution systems close to the booth. For base coat and primer (if more than one primer colour is used in the paint shop), these ring lines are connected to colour change devices for each single application unit (robot with one atomiser or paint machine with several atomisers). Colour changers either are placed at the side walls of the paint cabin or can be integrated onto the final robot arm. Alternatively, separate paint cartridges are filled with paint (0.5-1.0 l) in a docking station and automatically docked to the application robot on demand. Several other systems are used.

Paint supply ring lines are only occasionally emptied and cleaned with solvent. Removed paint and cleaning agents are collected and disposed of as waste. Cleaning and colour change processes in the colour change devices and spray heads are more frequent and have more environmental relevance. Colour change includes (a) removing the old colour, (b) cleaning the supply system and (c) filling the new colour. For cleaning, either organic solvents or solvent-free cleaning agents and/or pressurised air may be used. Spray guns, nozzles and the cones of paint bells are cleaned on demand. Used solvents are captured, and with paint residues from colour change and cleaning operations, generally collected and disposed of as waste.

To reduce paint losses, several different pigging and cleaning techniques have been developed in the last 20 years. They are used for cleaning and refilling the ring pipes or the atomiser feed line after the colour change switch.

2.2.3.3 Coatings

E-coat (EC)

The organic coating is based on amine-modified epoxy resins which are made water-soluble through neutralisation with organic acids. The application concentrations are 16-20 % solids and 1-2 % organic solvents.

Sealing and damping (SD)

The highly viscose coatings for stone-chip protection (generally PVC plastisols) and seam sealants are applied manually or with robots by several extruding techniques and airless spraying. In most cases, noise-damping material either as custom-tailored pads or as extrudable paste is also applied in this section. The materials have very low VOC contents (2–5 %); nevertheless, the workplaces with high plastisol application are in cabins with enhanced ventilation. Equipping the body with noise-absorbing coatings improves the acoustic properties in the vehicle interior. The demand for greater performance (and further sealing) is continuously increasing. This can in turn increase emissions of VOCs.

Gelification (jellification/gelling) starts in the dedicated sealer oven and is ultimately completed in the next oven (primer or topcoat).

At some sites, materials for underbody and chip protection are applied at the final assembly section of the vehicle production facility.

Spray coating
Paints for spray coating are mixtures of organic resins with additives, organic or inorganic colour pigments (except for clear coat) and solvents, and are designed as one-component (1K) or two-component (2K) systems.

Spray coating is done in three consecutive steps, primer, base coat and clear coat. For each coating process the material consumption depends on the amount of solids to be transferred to the substrate surface. Therefore the solvent consumption depends on the mass of solids used and the solvents to solids ratio of the respective coating material. Neither the solvent content of a coating material alone nor its solids content is a suitable indicator for the environmental relevance with regard to solvent consumption (and emission).

Primer (PR)
Primer provides stone-chip protection, avoidance of UV-induced decomposition of the underlying e-coat, and filling in of any small unevenness or rolling textures of the subsurface. Primer systems are based on polyester, melamine, and/or polyurethane resins. Primers are usually applied in two (maximum four) different tones fitted to the particular base coat colour. Coloured primers with up to four different tones are standard and help to reduce the thickness of the base coat. Primer systems are either solvent-based or water-based. Powder primers were used in some installations in Europe until 2015 when the last powder primer line was closed. The primer layer is cured after a preceding solvent flash-off in the primer oven. A quality check of the result of the upstream coating steps and manual rework of surface defects by sanding and sometimes recoating is done before the bodies enter the topcoat line.

Topcoat (TC)
This is usually made up of two layers: base coat (BC) and clear coat (CC). Some passenger cars and many commercial vehicles are coated without clear coat, and in those cases the base coat is the last coat which is applied to the body [265, TWG 2019].

Base coat (BC)
This layer determines the colour and effect (metallic, pearlescent) of the coat. For passenger cars, generally five different tones cover more than 90 % of the product volume (high runners) and the manufacturer's colour portfolio for a certain car model rarely exceeds 40 different colours. Binder systems are polyester and melamine resins. In water-based coats, acrylates and polyurethanes are also used. Pigments can be either organic or inorganic (oxides of titanium or iron, silicates, aluminium flakes) and are free of heavy metals like lead, cadmium and chromium. Organic pigments may contain small amounts of copper or nickel bound in complexes or halogenated compounds. Both solvent-based and water-based systems exist in the automotive industry worldwide.

The wet paint is dried (but not cured) in a flash-off zone and then transferred to the clear coat zone. Some colours (special fleet colours or white tones) are applied without an additional clear coat as solvent-based one-layer topcoats (monocoats).

The term 'effect colour' is used as an umbrella term for base coat systems with several special polychromatic effects like metallic, pearlescent, or colour flip effect. These systems are applied wet on wet in two or three steps and are always combined with a clear coat layer.

Effect coatings and metallic coatings are applied in two steps: first by high-rotation electrostatic bells; secondly by high-rotation electrostatic bells, pneumatically or electro-pneumatically. Compared to one-step application with pneumatic atomisers with lower transfer efficiency, less material is consumed and solvent emissions are lower. However, additional layering or the application of multiple colour schemes per vehicle has the potential to increase emissions.

Clear coat (CC)

The final paint layer is the clear coat which provides for high lustre and colour depth, optimum appearance, and chemical and scratch resistance. The chemical composition is based on a combination of acrylate and polyester resins. One-component (1K) solvent-based or two-component (2K) solvent-based clear coats are used. 2K systems use isocyanate hardeners which are added in a mixer as close to the spray system as possible.

The application of the clear coat is followed by a flash-off zone and subsequent topcoat oven (also known as a clear coat oven).

Water-based clear coats (2K systems or 1K systems) as well as powder clear coats or powder slurries are no longer in use in passenger car and van paint shops. In passenger car and van paint shops, a 1K water-based clear coat system was used in one plant until 2010, when it was replaced by a 2K solvent-based clear coat system. Powder clear coat and powder slurry were replaced by solvent-based 2K high-solids systems between 2010 and 2013. The reasons for these decisions were that the increasing quality requirements of the customers could no longer be met with the existing paint systems, and, in the opinion of the parties involved, a successful further development was improbable and economically unjustifiable. In a few cases, powder coats are still used in commercial vehicle paint shops.

A final painting step may be undertaken through the application of blackout paint around the wheel arches and/or in the engine bay of the vehicle.

Finish (rework) (FI)

A quality check and in-plant paint repair (if necessary) are carried out in special inspection zones and repair booths in what is generally called the finish zone. Materials used for these types of repairs are either paint repair systems (as used in retail repairs) or the same or similar paints as in the main line. Bodies with larger defects are sanded and after masking the good parts, the whole body is put back into the topcoat line (second run).

Cavity preservation (CP)

Additional corrosion protection of inner surfaces of cavities (which exist for constructional reasons) is delivered by a wax film. This coating can be carried out with two techniques:

- spraying, using wax solutions (solvent-based), wax emulsions (water-based) or 100 % wax (liquid pre-polymers that gel on contact with air);
- flooding the cavities with pure (100 %) heated wax.

2.2.3.4 Overspray separation

Despite the improvements in automation and paint transfer techniques, some paint particles do not hit the vehicle body and are extracted with exhaust air. To minimise air pollution, various techniques are applied.

In existing installations, cross-flow venturi scrubbers are standard. In these systems, a vigorous mixing of cabin air and water droplets takes place at the venturi nozzle and the paint particles are transferred into the scrubber water. The paint particles are separated and managed as waste, and the water is recycled.

In recent greenfield installations and if paint lines in existing paint shops are completely rebuilt, alternative capture techniques are usually used:

- dry scrubbing with limestone: the paint adheres to limestone powder and is then separated using a rigid particle filter;
- electrostatic scrubbing (rinsed electric filter);
- labyrinth filters (boxes made of cardboard);
- in small paint cabins (spot repair and paint touch-up) labyrinth filters (cardboard boxes or plastic dry filter systems (paint-stop filters)).

2.2.3.5 Drying

After the application of the paint/coating, the wet paint film is dried in ovens. This is a combination of:

- physical drying, where the wet film solidifies because of evaporation of water and/or organic solvents;
- chemical cross-linking/reticulation (baking/curing) by polymerisation, polycondensation, polyaddition, or oxidative drying.

These processes start at room temperature immediately after the mixing of the components or after application but a predefined curing temperature must be reached and maintained for sufficiently long to achieve a complete hardening of the coat.

Ovens are long tunnels with thermal isolation (60 m to more than 180 m in length). After the exit airlock, the car bodies pass through a cooling zone with outdoor air. Generally, convection dryers are used, sometimes in combination with IR radiation sources. Dryers are heated with natural gas, and in many cases heat is recovered from recuperative oxidisers simultaneously working as oxidisers of the VOC content of the dryer exhaust air.

2.2.3.6 VOC removal from off-gases

VOC removal from off-gases consumes large amounts of energy in extraction and treatment. It is generally applied to cleaning of exhaust air from dryers, because:

- most of the combustion energy can be used for heating the curing ovens (depending on the chosen design of the dryer-oxidiser combination);
- of high raw gas concentrations (200-500 mg C_{tot}/Nm^3) in combination with low off-gas volumes (5 000-15 000 Nm^3/h);
- it prevents the release of unpleasant smelling components (decomposition products from paint curing).

Dryer air is circulated (internal accumulation of solvents) before it is finally discharged as waste gas. Typically, recuperative or regenerative thermal oxidisers are used, very often attached to the particular dryers as oven heating units. In some cases, if the solvent load is low and energy reuse from off-gas treatment is not possible, dryer ovens are operated without off-gas treatment.

2.2.3.7 Waste management

Plant-specific waste management measures aim to reduce waste and to achieve a high recycling or recovery rate. This means reducing the waste produced during the coating activities, recycling where possible, separation of different kinds of wastes and sometimes it includes waste treatment processes like dewatering (paint sludge, phosphate sludge) or compacting (foils, packaging waste).

2.2.3.8 Paint shop families

Depending on the type of solvents, paint systems are called (organic) solvent-based (SB), water-based (WB) or (no solvent) powder coats (PO). The term ‘water-based paint’ means that in the ready-for-use material a fraction (not necessarily 100 %) of the organic solvents is replaced by water. Relevant data for the most commonly used coats are presented in Table 2.5.

Table 2.5: Characteristics of typical spray coats for passenger car coating

Coating	VOC content (%)	Solids content (%)	VOC/ Solids ratio	Material consumption (kg/unit)	Dry-film thickness (µm)
SB primer	35-50	50-65	0.5-1.0	1.1-2.8	20-40
WB primer	5-12	45-55	0.1-0.26	1.2-2.4	20-40
SB medium-solids (MS) base coat *	78-82 (60)	18-22 (40)	3.6-4.5	1.4-3.5	10-15 (25)
SB high-solids (HS) base coat *	55-65 (50)	35-45 (50)	1.3-1.8	1.5-2.2	12-20 (25)
SB very-high-solids topcoat (UHS-TC)	20-25	75-80	0.25-0.33	2.9-3.8	35-45
WB base coat *	12-17	16-22 (40)	0.6-1.0	2.3-3.5	10-15 (25)
WB topcoat (MHTC)	18-22	45-50	0.36-0.49	1.9-2.1	35-45
SB 1K clear coat	40-50	50-60	0.66-1.00	2.0-3.0	40-45
SB high-solids (HS) 2K clear coat	35-45	55-65	0.7-0.8	1.4-2.4	30-55

* Figure in brackets is for colours with low opacity.
Source: [142, ACEA 2016]

Historically, paint systems have been solvent-based with solvent contents up to 85 %, with a specific VOC emission of about 300 g/m^2. Water-based coatings were developed in the late 1970s, with the aim of reducing the solvent emissions without the need to operate expensive and energy-consuming off-gas treatment systems. For some decades in the EU, water-based clear coat was used in car paint shops and powder coats were used as primers and clear coats by some manufacturers, but these materials could not comply with the steadily rising quality demands and their use in car and van paint shops finally stopped by 2015 (see Section 2.2.3.3).

Over time, two basic coating system concepts have emerged: solvent-based coatings (SB) and water-based coatings (WB). The choice of the coating system entails fundamental and mostly irreversible differences in the design of the paint shop, although at first sight the subprocesses are identical. Due to these differences in paint shop design, a change from solvent-based to water-based spray coats cannot be made without radical modification of the paint shop. Each combination of paint system, associated paint shop design, and paint application technique is called a ‘paint shop family’ and each individual paint shop belongs either to the WB or SB paint shop family.

Table 2.6: Technical differences between the SB and WB paint shop families

Spray coating system	Solvent-based	Water-based (except clear coat)
Intermediate dryer between base coat and clear coat	Short flash-off zone (not in all cases)	Intermediate dryer (with T = 50-80 °C, t = 5-10 minutes) and in/out airlocks necessary, typical length: 35-55 m (+ 75 % of total length of a topcoat line)
Primer dryer oven heating curve	No temperature hold below 100 °C necessary	5-10 minute temperature hold necessary to evaporate water before surpassing the boiling point temperature
Construction material for paint booths	Standard galvanised steel	Stainless steel for all parts in contact with paint
Use of electrically charged bells	Automatic application no restrictions	Automatic application. It is necessary an electrically-separated paint supply system which is slightly less efficient
Paint window	Broader than for water-based paints	Restrictions in range of humidity. Depending on local climate conditions, additional equipment for air conditioning is necessary

Source: [142, ACEA 2016]

In existing sites, changing from one family to the other (SB to WB) can be done only if there is room to build a second paint shop (or paint shop line) in parallel without interrupting the production in the existing one, and where the new paint shop can be linked to the body shop and to the assembly shop. Due to these constraints, such a transformation is very expensive and is rarely made. Where these changes are implemented, these are mostly restricted to one subprocess. This type of paint shop is then called a SB-MIX paint shop. The actual situation in the EU is shown in Table 2.7.

Table 2.7: Estimated percentage of different paint shop families in the EU

Paint shop family	Subprocess			Installations	Process	Installations
	PR *	BC *	CC			
WB	WB	WB	SB	57 %	Standard	42 %
					Integrated	15 %
SB-MIX	WB SB	SB WB	SB	28.5 %	Standard	27 %
					Integrated	1.5 %
SB	SB	SB	SB	14.5 %	Standard	13 %
					Integrated	1.5 %
					Standard (all families)	82 %
					Integrated (all families)	18 %

* Different names and abbreviations are used for the various versions of integrated processes (see Section 2.2.3.9). NB: The three-wet process is included under the term ‘integrated process’.
PR: primer; BC: base coat; CC: clear coat; WB: water-based; SB: solvent-based; SB-MIX: solvent-water mix.
Source: [201, ACEA 2016], based on a sample of 67 (out of a total of 74) passenger car paint shops.

2.2.3.9 New paint shop concepts

In the last 10 to 15 years new paint shop concepts have evolved, which has led to considerable energy savings:

- Elimination of the primer oven by using either:
  - wet-in-wet-in-wet (three-wet), application of primer, base coat and clear coat without intermediate drying/curing;

  - integrated processes (IP), combining the functions of primer and base coat in one new base coat type applied in two steps.

Both coating concepts are operated with solvent-based or water-based paints; however, clear coat is always solvent-based.

- Spray booth air recirculation, usually in combination with dry separation of paint overspray.

Because of multiple technical constraints, these concepts are generally not possible in existing installations at a reasonable cost, but do offer additional options for the design of new paint shops or in the case of the total refurbishment of existing ones. Currently, 18 % of all EU passenger car paint shops already use either a three-wet process or an integrated process and many manufacturers consider it the future standard for new greenfield projects. Dry separation of paint overspray is also installed in 18 % of all EU paint shops in at least one of several spray booths [201, ACEA 2016].

The total VOC emissions are not significantly affected by these techniques; the main environmental advantages are savings in water (for air humidification) and energy (no primer oven heating, significantly less booth air to condition and move). They also save on floor space (no primer oven, no workplaces between primer (PR) and base coat (BC)).

2.2.3.10 Special products in passenger car paint shops

Paint shop operators are faced with a rising demand for two-tone cars. After the body has been completely coated with one colour, part of the surface is masked and the body is reintroduced to the base coat line to apply the second colour. This results in additional solvent consumption, VOC emissions, waste generation and energy consumption (see also Sections 2.3.1 & 2.3.2).

In some installations, N1 category vans are painted together with passenger cars. In contrast to passenger cars, where most of the interior surface of the body in white (BIW) is eventually covered by plastic parts, fabric or carpet, vans typically have no or only small windows in the cargo compartment and large visible interior surfaces that need to be coated with the same layers and be of the same quality as exterior surfaces. This leads to higher emissions compared to the coating of passenger cars.

Usually, hang-on parts (e.g. bumpers) that are attached to the car body in the final assembly line are painted in separate paint shops. However, in some cases these parts and spare parts for after-sales service are mounted on the car body skids or on separate skids and are coated together with the car bodies in the same paint shop.

2.2.4 Painting of vans

Figure 2.11 demonstrates the large variety of the product category ‘van’. Classically, these kinds of vehicle present a large combination of bodies/designs which covers mainly category N1 according to Directive 2007/46/EC [13], but also derived variants for passenger transport (M1), and, depending on the size, products that fall under the categories N2 and M2 (minibuses) as well. For the smaller products, their construction principle is generally derived from passenger cars (integral monocoque/unibody), although some manufacturers produce chassis-built vans based on truck design principles.

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[13] The Type Approval Directive: Directive 2007/46/EC establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles.

Generally, the layout and paint application technologies of paint shops for vans are very similar to those of passenger cars, especially as vans are produced and sold in large numbers and are mostly manufactured in high-volume paint shops with a line structure, short cycles and high automation levels.

Source: [142, ACEA 2016]

Figure 2.11: Examples of vehicles defined as vans

The following specific aspects can have an impact on VOC emissions and should be taken into account:

- Coating of large interior surfaces, which leads to higher paint consumption per vehicle and higher specific VOC emissions in g/m^2 compared to passenger cars.
- In many cases, robots and electrostatically assisted bells cannot be used in interior coating. Often, an additional paint spray booth for the interior coating is required due to the increased cycle time.
- A high proportion of one-layer topcoats, which are available only as solvent-based systems.
- A much larger range of colours are ordered by customers. This includes special fleet colours prescribed by the customers.
- Paint supply systems must be able to provide many colours in any production period.
- Increased cleaning.
- Specific requirements for corrosion protection (wax, layer thickness, etc.), due to different levels of corrosion protection guarantees, lead to a greater diversity in coating concepts in van painting installations than in passenger car paint shops.
- Larger installations due to the size of the vehicles.

The coating concepts used are summarised in Table 2.8.

Table 2.8: Coating concepts for vans

Layer	EC	PR	BC	CC	TC	Comments
Layer options	WB	WB	WB	SB		
	WB	WB	(WB)	(SB)	WB	BC/CC only for metallic/special colours
	WB	WB	(SB)	(SB)	SB	BC/CC only for metallic/special colours
	WB	SB	(SB)	(SB)	SB	BC/CC only for metallic/special colours
	WB	NA	SB	SB	NA	
	WB	NA	NA	NA	SB	

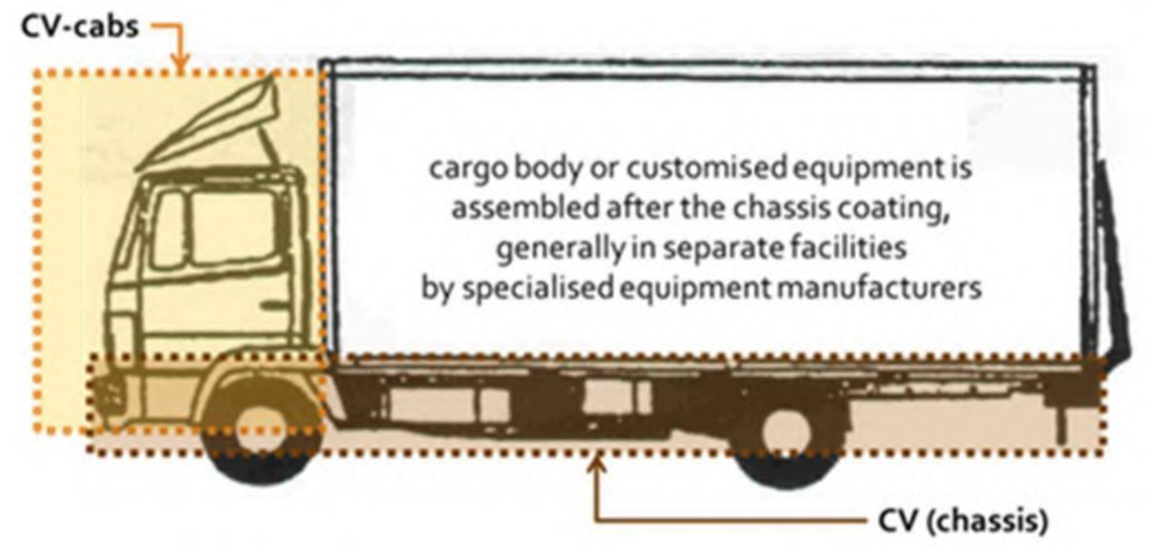
NB:
NA: Not applicable.
EC: e-coat; PR: primer; BC: base coat; CC: clear coat; TC: topcoat; WB: water-based; SB: solvent-based.
Brackets means optional layer, see comments.
Source: [142, ACEA 2016], data from Volkswagen AG, Daimler AG, Fiat Chrysler Automobiles N V, Renault, PSA, Iveco, Dürr Systems GmbH, Eisenmann Anlagenbau GmbH & Co KG.

2.2.5 Painting of trucks (truck chassis)

Trucks are manufactured in three parts (see Figure 2.12):

- chassis;
- cab;
- cargo compartment / customised equipment.

The truck manufacturer produces and coats the chassis and cabs separately and assembles the cab, engine and transmission onto the chassis, with associated equipment. The production of the truck cargo body (cargo box, tipper, tank, etc.) and trailers and semi-trailers is carried out by specialised manufacturers separate to the truck assembly facility[14].



Source: [201, ACEA 2016]

Figure 2.12: Typical design of a truck (separate compartments for driver and cargo)

Quality requirements are important for trucks:

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[14] Painting of the cargo body is not covered by IED Annex VII activity 3 (a) iii (coating of vans and trucks). Coating of these parts or products (where solvent consumption exceeds the IED Annex I thresholds) is included in Chapter 3 ‘Coating of other metal and plastic surfaces’.

- Long-term protection against corrosion, weather, chemical influence (e.g. bird droppings, acid rain), chipping protection, sun, abrasion in car washes, etc.
- Ideal optical surface properties: polish, colour depth, free of cloudiness, faultlessness, therefore producing homogeneity and a consistency in colouring and formation of effects (such as metallic finishes).

These high requirements can only be achieved by at least three, often four or maybe even five paint layers designed to complement each other. These are applied on body parts pressed and assembled from pretreated steels to increase the long-term corrosion resistance [201, ACEA 2016].

In Europe, the following paint layer construction has become predominant:

- pretreatments are applied on plastics and body parts assembled from metals (e.g. steels are pretreated with phosphate to increase long-term corrosion resistance);
- cathodic electrocoating primer coating;
- underbody protection/seam sealing;
- primer;
- topcoat (can be made up of base coat and clear coat);
- cavity conservation and, if necessary, conservation for transport.

The truck frame (chassis) is riveted from rails and cross members pre-coated with electrocoat, primer and sometimes also topcoat. After the assembly of the drivetrain and other parts onto the frame, the final truck chassis paint operation is to coat the remaining uncoated parts of the chassis, for scratch repair, or for colouring the product according to the customer's requirements. If the coating of the single components or bolt-on parts is done at the same site (which is the case in some large truck plants), these coating operations are included as truck coating operations in the solvent balance boundary of the installation. The coating concepts used are given in Table 2.9.

The following additional factors affect VOC emissions:

- The number of colours other than black or dark grey is lower than for passenger cars, but is steadily rising, as more and more customers want the truck chassis and cabin in identical or matching colours.
- Due to the complex geometries and the many different chassis types produced by one manufacturer, automation is normally not applied in truck paint shops.

Table 2.9: Coating concepts for trucks

Layer	EC	PR	BC	CC	TC	Comments
Layer options	*	NA	NA	NA	SB	Final paint is only for colour match and repair
	*	NA	NA	NA	WB	
	*	SB	NA	NA	WB	
	WB	NA	NA	NA	SB	

NB:
NA: Not applicable.
* Parts are delivered with EC (sometimes also with TC) and assembled in the truck factory on the vehicle chassis.
Source: [142, ACEA 2016] Data from Iveco, Daimler, MAN, Dürr Systems GmbH, Eisenmann Anlagenbau GmbH & Co KG

Painting may be manual or robotic. Advantages of using robots include a reduction of overspray and material consumption due to higher transfer efficiencies and a uniform, reproducible coating. Furthermore, the technology has ergonomic advantages.

For drying, the coated chassis are first transported to a flash-off zone with a maximum temperature of 40 °C and a low air velocity. Afterwards, the paint is dried in a forced air dryer at air temperatures of 85-100 °C. The topcoat may be a 2K high-solids, low-VOC solvent-based paint. After drying, the chassis are cooled down to ambient temperature and demasked. Axles will be painted with a topcoat as a part of the chassis painting and hence will undergo a similar process.

Source: [201, ACEA 2016]

Figure 2.13: Painting of a truck

2.2.6 Painting of truck cabins

Driver cabins for trucks are coated separately and are mounted to the truck chassis afterwards. Generally, the paint shop design and the paint application technologies are very similar to those of passenger car paint shops. However, the following specific aspects must be taken into account:

- Many colours exist, which are very often available only as solvent-based topcoats. Very often special fleet colours are prescribed by the customers and there may be up to 300 colours for a given cabin model.
- Up to 50 % of the cabin surface is covered with plastic parts (mainly polyethylene/ethylene-propylene-diene (PE/EPDM) injection moulded parts), therefore paint systems that work for both surfaces are favoured.
- The diversity in coating concepts in truck cabin painting installations is larger than in passenger car paint shops.

These challenges lead to a high percentage of solvent-based base coats or topcoats. With modern solvent-based very-high- or ultra-high-solids paints (SB-VHS/UHS), the same or an even lower VOCs to solids ratio as water-based paints can be achieved. The VOCs to solids ratio, rather than just the VOC content, should be considered as the best indicator for the comparison of paint systems. The VOCs to solids ratios found in CV truck painting are:

- 0.25-0.33 SB-VHS/UHS;
- 0.60-1.00 WB BC;
- 0.36-0.49 WB TC (medium/high-solids).

See also Table 2.5.

Since the application window for solvent-based systems is much wider than for water-based paints and because the flash-off zones and dryer ovens are shorter and consume less energy, these paint shops have a better performance in terms of energy consumption compared to those with water-based paints especially in regions with long periods of high temperatures and humidity.

There are many different coating concepts which are embedded in the overall assembly and production logistics strategy of the respective manufacturer (see Table 2.10). Paint systems that have curing temperatures of 80 °C to 90 °C and are equally applicable for metal and plastic surfaces (so plastic part painting can be integrated into the cabin paint shop) are already frequently used for cabin painting in non-EU installations and will certainly be introduced in more EU paint shops in the future.

Table 2.10: Coating concepts for truck cabins

Layer	EC	PR	BC	CC	TC	Comments
Layer options	NA	PO	WB	SB 2K	(WB)	TC for non-metallics at the same line
	NA	NA	SB	SB		Cabin + plastic parts, 80 °C process
	WB	WB	NA	NA	WB	
	WB	WB	WB	SB	(WB)	TC for non-metallics at the same line
	WB	WB	WB	SB		
	WB	WB	NA	NA	SB	
	WB	SB	WB	SB	(WB)	TC for non- metallics at the same line
	WB	WB	SB	SB	NA	
	WB	NA	NA	NA	SB	
	WB	SB	SB	SB	NA	
	WB	NA	SB	SB	NA	

NB:
NA: Not applicable, PO: powder coating.
For layer options in brackets see comments
Source: [201, ACEA 2016] Data from Dürr, Scania, Iveco, Daimler, MAN Trucks&Buses, Volvo Group, Nissan

Most paint shops have automatic application systems (robots) and paint supply systems that are adapted to supply small quantities (consumption 100 kg/d to 200 kg/d) and permit the rapid change of many different colours, in some cases more than 300 for a given cabin model.

Source: [201, ACEA 2016]

Figure 2.14: Truck cabin painting

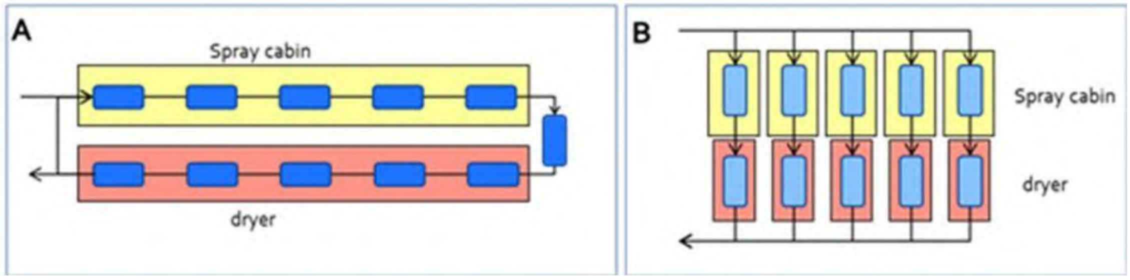
2.2.7 Coating of buses

In principle, the descriptions of processes and techniques in Section 2.2.3 are valid for bus coating as well. Major differences are outlined here.

Compared to passenger cars, the production volumes of buses are much smaller. Consequently, paint shops are generally designed for lower outputs (< 20 units per day). Two design and operating principles can be found:

- Instead of separate spray booths for each coat layer, one multifunctional paint line is used and the bodies are transferred repeatedly through the same line until all necessary coat layers are applied.
- Painting is done in paint boxes instead of sequential paint lines (see Figure 2.15, a general description of this concept was recently published15).

In some cases, the coating process of a bus is split over two or three different production sites, with each site operating a bus paint shop which is responsible for the application of one or more paint layers. This is generally not found in the mass production of passenger cars.



Source: [201, ACEA 2016]

Figure 2.15: Different design concepts for large (A: sequential paint line) and medium or small (B: paint boxes) production capacities

An important feature in bus coating is the customer demand for brand-specific colours, so paint shops have to handle more than 400 different tones and very often multicoloured buses and coaches are ordered.

Not all bus bodies are electrocoated. The interior surfaces of city buses are generally coated whereas coaches, especially in the luxury sector, are almost completely covered with interior plastic parts and need no topcoat. Therefore the painted surfaces and the VOC emission in g/m^2 are very different in both groups. For touring buses, different floor coverings are used; these materials are fixed with double-sided adhesive foils or bonded via dispersion adhesives, which are in some cases solvent-based. Underbody protection is very often applied as an undercarriage coat after the final assembly of the bus.

The coating material is applied using HVLP, conventional airmix or airless spray guns. Overspray is separated with wet scrubbers or dry filters.

For drying, the coated chassis are first transported to a flash-off zone with a maximum temperature of 40 °C and low air velocity. Afterwards, the paint is dried in a forced air dryer at air temperatures of 85-90 °C. After drying, the chassis are cooled down to ambient temperature.

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[15] Svejda, P. Paint box concept or painting line. Modular systems increase flexibility and cut costs. Int. Surf. Techn. 2011, 4 (2), 26–29; DOI 10.1365/s35724-011-0034-2.

Source: [201, ACEA 2016]

Figure 2.16: Coating operations for buses: e-coat (left) and topcoat (right)

Table 2.11: Coating concepts for buses

Layer	**EC**	**PR**	**BC**	**CC**	**TC**	**UC**	**Comments**
Layer options	WB	NA	NA	NA	NA	NA	After E-coat transfer to other paint shop
	WB	*	*	*	SB	NA	Finish after assembly of bus
	*	SB	WB	SB	(SB)	NA	Topcoat only for non-metallics
	WB	WB	SB	SB	NA	NA	
	-	SB	WB	SB	(SB)	SB	Topcoat only for non-metallics
	SB	WB	NA	NA	SB	NA	Epoxy primer as substitute for electrocoating
	SB	SB	NA	NA	SB	NA	
	WB	SB	SB	SB	NA	SB	
	*	SB	SB	SB	(SB)	SB	Topcoat only for non-metallics

NB: * Done in a separate paint shop.
NA: Not applicable, UC: Undercarriage coat for stone-chip protection.
Source: [201, ACEA 2016] Data from Iveco S.p.A., MAN Truck & buses, Daimler AG, Scania AB

Off-gas treatment is applied to reduce the VOC emission of dryer oven off-gases (EC oven, TC oven) at large installations. For smaller installations, no abatement techniques are used.

2.3 Current consumption and emission levels in the coating of vehicles

[155, TWG 2016] [142, ACEA 2016] [147, TFTEI 2016] [145, ACEA 2019] [146, ACEA 2018]

A significant number of installations for the coating of passenger cars (PC) participated in the data collection. The number of installations for the coating of vans (VAN), trucks (CV) and truck cabins (CAB) was significantly lower, seven in total, and there was only one installation for the coating of buses [155, TWG 2016]. Additional data for a second bus coating plant were submitted in mid-2018 [223, Spain 2018]. Consumption and emission data were completed using other sources [142, ACEA 2016] [147, TFTEI 2016].

Nominal values for layer thickness, material solids and VOC contents, material consumption and emission contribution are presented in the following table.

Table 2.12: Solvent and solids contents of coating materials

Coating material	Dry-film thickness (µm)	Solids content (1) (% m)	VOC content (1) ready for use (% m)	Material consumption (2) (kg/body)	Emission contribution (3) (g/m^2)
Cathodic dip paint, replenishment material	NI	38 - 42	2 - 4	6.0 - 7.0	NI
Cathodic dip paint, dip tank	18 - 22 exterior > 10 interior	16 - 20	1 - 2	NI	0.6 - 1.0
Solvent-based primer	20 - 40	50 - 65	35 - 50	1.4 - 2.8	4.0 - 8.0
Water-based primer	20 - 40	45 - 55	5 - 12	1.2 - 2.4	0.5 - 1.5
Powder-based primer	60 - 90	100	0	2.0 - 2.5	0
Solvent-based base coat (4)	10 - 15 (25)	18 - 22 (40)	78 - 82 (60)	2.5 - 3.5	20 - 30
Solvent-based base coat (4) (high solid)	12 - 20 (25)	35 - 45 (50)	55 - 65 (50)	1.5 - 2.2	10 - 15
Water-based base coat (4)	10 - 15 (25)	16 - 22 (40)	12 - 17	2.5 - 3.5	3.0 - 6.5
Integrated process (entire coat without clear coat)	15 - 30 (35)	16 - 30 (40)	10 - 18	3.0 - 5.0	3.0 - 7.5
Solvent-based clear coat	30 - 55	47 - 54	46 - 53	2.1 - 3.0	7.0 - 12.0
Clear coat (high solid, 1K)	30 - 55	55 - 60	40 - 45	1.8 - 2.4	6.0 - 10.0
Clear coat (high solid, 2K)	30 - 55	55 - 65	35 - 45	1.6 - 2.4	5.0 - 9.0
Water-based clear coat (2K)	30 - 45	45 - 50	8 - 15	2.2 - 2.8	1.5 - 4.0
Powder slurry	30 - 40	37 - 40	< 1	2.3 - 2.8	0.5 - 1.0
Powder-based clear coat	60 - 80	100	0	1.4 - 1.8	0
Solvent-based topcoat (1K)	35 - 50	45 - 60	40 - 55	2.8 - 4.0	9.0 - 18.0
Solvent-based topcoat (2K)	35 - 50	55 - 70	30 - 45	2.4 - 3.5	7.0 - 14.0
Water-based topcoat (1K)	35 - 50	45 - 55	5 - 13	3.1 - 4.5	1.5 - 4.5
Water-based topcoat (2K)	35 - 50	45 - 50	12 - 18	3.4 - 5.0	3.5 - 7.0
Undersealing	200 - 1 000	95 - 98	2 - 5	1 - 5	0.2 - 3.0
Weld sealing	Ø: (2 - 10) mm	95 - 98	2 - 5	3 - 9	0.7 - 4.0
Sprayable damping material	1 500 - 5 000	79 - 99	0 - 3	2 - 8	0 - 2
Cavity preservation material, VOC-free	NI	Various	0	1 - 2	0
Cavity preservation material, with VOCs	NI	70 - 85	15 - 30	1 - 2	2.0 - 5.0
Rinsing agent for solvent-based primer	NI	0	100	Per sprayer: *colour change:* 15 ml paint 200 ml rinsing agent (5) *short rinse:* BC: after (1 - 5) bodies CC: after (5 - 10) bodies (20 - 30) ml solvent	Depending on the process and mode of operation of the painting plant
Rinsing agent for water-based primer	NI	0	10 - 15		
Rinsing agent for solvent-based BC	NI	0	100		
Rinsing agent for water-based BC	NI	0	10 - 15		
Surfactant-based rinsing agent	NI	0	0		
Rinsing agent for CC	NI	0	100		
Plant cleaning, diluent, mixing chamber, laboratory	NI	0	0 - 100	< 1	

(1) When ready for use.
(2) Sprayed paint quantity per body; the overall usage may be higher due to colour-change losses and second runs.
(3) Acc. to 31. BimSchV (Federal Immision Control Ordinance), guide values for usual application conditions and plant configurations (no treatment of booth exhaust).
(4) Values in parentheses apply for low-opacity colour shades, such as white or beige (German taxi colour).
(5) In a so-called soft purge procedure, a new primer colour is fed while still painting the rear of the preceding vehicle. This eliminates the need for rinsing when changing colours.
NB: General reference values for medium-sized passenger cars. Other conditions may apply from case to case for quality reasons, depending on the vehicle type. In particular, different requirements are usually valid for exterior and interior painting.
Source: [169, VDI 2013]

2.3.1 Consumption

2.3.1.1 Energy consumption

Energy consumption in the painting process represents about 40 % to 50 % of the total energy consumption in car manufacturing (vehicle assembly site) and this energy-intensive step is potentially the most environmentally significant in vehicle production after considering solvent use and emissions. The main share of consumed energy is supplied as natural gas and used for heating of dryers and thermal abatement of solvent-containing off-gases.

The energy consumption data for the paint shops do not include the energy required for building services. However, depending on local conditions and technical opportunities, the possible heating/cooling of the building will lead to a reduction in the energy consumption of the paint shop. Therefore, the figures from different locations may show a very wide range of variations.

Table 2.13 provides the analysis of energy consumption in the individual segments of a paint shop per process step (design scenario for a paint shop with a capacity of 30 vehicles/hour, and water-based coat for primer and base coat) [169, VDI 2013].

Table 2.13: Typical energy consumption of car paint shops

Parameter	Unit	Reference plant	Variant A (no primer)	Variant B (wet-on-wet)	Variant C (reference plant with dry scrubber)	Variant D (no primer with dry scrubber)	Variant E (wet-on-wet with dry scrubber)
Cleaning and pretreatment (plant) – PT							
Electrical power	kWh/vehicle	22	22	22	22	22	22
Natural gas	kWh/vehicle	NA	NA	NA	NA	NA	NA
Water (hot/cold)	kWh/vehicle	26/0	26/0	26/0	26/0	26/0	26/0
Dip coating (paint and dryer) – CDC							
Electrical power	kWh/vehicle	46	46	46	46	46	46
Natural gas	kWh/vehicle	80	80	80	80	80	80
Water (hot/cold)	kWh/vehicle	0/17	0/17	0/17	0/17	0/17	0/17
Sealing, damping, masking (workplaces and dryers) – US/WS							
Electrical power	kWh/vehicle	30	30	30	30	30	30
Natural gas	kWh/vehicle	55	55	55	55	55	55
Water (hot/cold)	kWh/vehicle	1/2	1/2	1/2	1/2	1/2	1/2
Primer (spray booth and dryer)							
Electrical power	kWh/vehicle	36	NA	21	36	NA	21
Natural gas	kWh/vehicle	65	NA	11	65	NA	11
Water (hot/cold)	kWh/vehicle	60/1	NA	60/1	1/11	NA	1/11
Base coat (spray booth and dryer) – BC							
Electrical power	kWh/vehicle	30	30	24	30	30	24
Natural gas	kWh/vehicle	27	27	10	27	27	10
Water (hot/cold)	kWh/vehicle	60/1	60/1	60/1	1/12	1/12	1/12
Clear coat (spray booth and TC dryer) – CC							
Electrical power	kWh/vehicle	35	35	35	35	35	35
Natural gas	kWh/vehicle	63	63	63	63	63	63
Water (hot/cold)	kWh/vehicle	75/1	75/1	75/1	1/9	1/9	1/9
Cavity preservation (plant + preheating/dryer) - CP							
Electrical power	kWh/vehicle	8	8	8	8	8	8
Natural gas	kWh/vehicle	15	15	15	15	15	15
Water (hot/cold)	kWh/vehicle	0/1	0/1	0/1	0/1	0/1	0/1
Workplaces (all other, including rework, excluding sealing)							
Electrical power	kWh/vehicle	28	23	19	28	23	19
Natural gas	kWh/vehicle	41	35	30	41	35	30
Water (hot/cold)	kWh/vehicle	3/2	2/2	2/1	3/2	2/2	2/1
Total							
Electrical power	**kWh/vehicle**	**235**	**194**	**205**	**235**	**194**	**205**
Natural gas	**kWh/vehicle**	**346**	**275**	**264**	**346**	**275**	**264**
Water (hot/cold)	**kWh/vehicle**	**250**	**188**	**248**	**87**	**74**	**85**
Total energy	**kWh/vehicle**	**831**	**657**	**717**	**668**	**543**	**554**

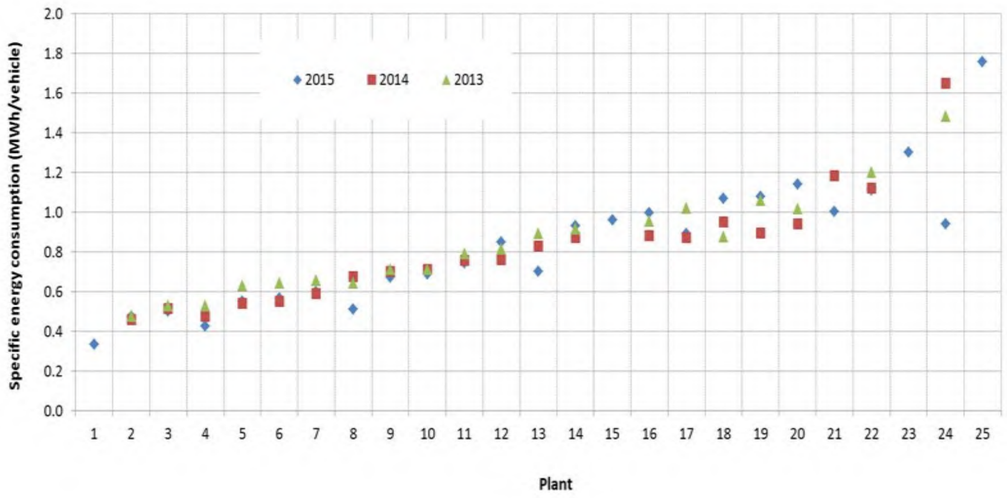
Source: [169, VDI 2013]

It is difficult to quantify the impact of climatic conditions on the overall energy consumption of the paint shop. This is due mainly to lack of energy metering systems that cover specific aspects of the paint shop and all the potential forms of input energy (electricity, gas). Sporadic reported data indicate a range between 1 % and 16 % of the total energy consumption being related to local climatic conditions (e.g. for heating/cooling or dehumidifying the process air).

Energy consumption could be measured by using utility meters connected to a main data acquisition system. When dedicated metering is not available, the paint-shop-related energy consumption can be calculated by using broader energy consumption data and suitable correction factors (see also [109, COM 2009]).

2.3.1.1.1 Passenger car coating

Figure 2.17 shows the reported data for the specific energy consumption of passenger car plants (PC paint shops), expressed in MWh/vehicle.



Source: [155, TWG 2016] [219, ACEA 2018]

Figure 2.17: Specific energy consumption (MWh/vehicle) for passenger car plants (PC paint shops)

The following table summarises the reported data on specific energy consumption for passenger car coating plants.

Table 2.14: Specific energy consumption for passenger car coating plants (PC paint shops)

Product type	Reported data (1) 2013-2015				Industry report (2) 2012			
	No of plants	Average (MWh /vehicle)	50 % middle range (MWh /vehicle)	Min./Max. (MWh /vehicle)	No of plants	Average (MWh /vehicle)	50 % middle range (MWh /vehicle)	Min./Max. (MWh /vehicle)
PC	25	0.85	0.61-1.01	0.33/1.76	68	0.87	0.64-1.04	0.32/3.53

Source: (1) [155, TWG 2016] [219, ACEA 2018], (2) [142, ACEA 2016]

For passenger car paint shops, most of the reported specific energy consumption values are below 1 MWh/vehicle, with an average value of 0.85 MWh/vehicle.

Significant yearly deviations in the specific energy consumption are not observed, except in one plant reporting a significant increase (more than triple) in the throughput figure which is associated with the increase in the utilisation of the installed paint shop capacity and the more efficient use – in energy consumption terms – of the available infrastructure.

An industry report summarising data from 68 paint shops shows an average specific energy consumption of 0.87 MWh/vehicle [142, ACEA 2016]. The main factors identified that determine the energy consumption of a passenger car paint shop are as follows:

Internal (technical):

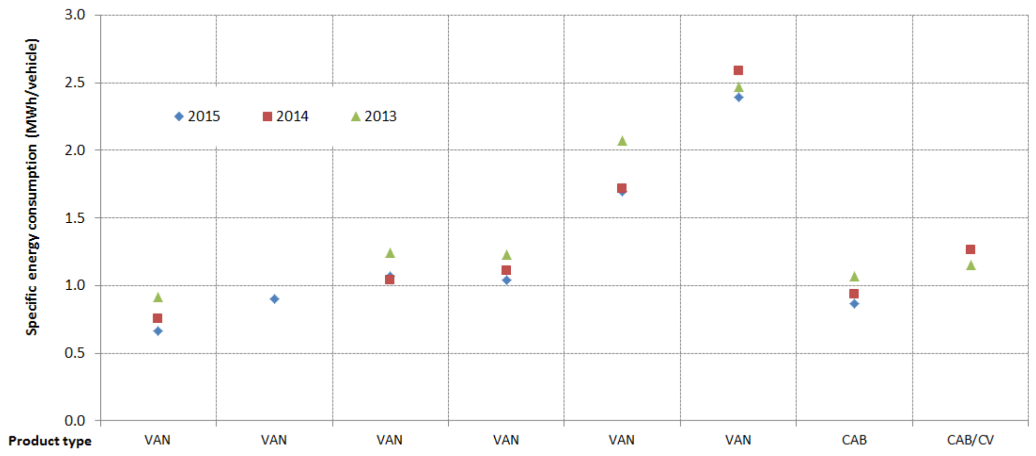
- Paint material (WB, SB) and concept (classical, three-wet, IP).
- Dryers: PVC oven (yes/no), primer oven (yes/no).
- Dryer oven off-gas treatment (yes/no); if yes, energy reuse for process heating?
- Spray booth off-gas recycling (internal accumulation) (yes/no - where?)
- Spray booth off-gas treatment (yes/no).

External (including climatic conditions):

- Number of heating degree days[16] (HDD).
- Number of days with spray booth cooling.
- Relative ambient air humidity.
- Availability of cheap cooling energy like surface water.
- Availability of surplus heat from nearby large combustion plants (replaces cooling tower capacities) [ACEA comment #119 in [212, TWG 2018]].

2.3.1.1.2 Coating of vans, trucks, truck cabins and buses

Figure 2.18 shows the reported data for the specific energy consumption in van, truck and truck cabin coating plants (Van, CV and CAB paint shops), expressed in MWh/vehicle.



Source: [155, TWG 2016] [219, ACEA 2018]

Figure 2.18: Specific energy consumption (MWh/vehicle) for van, truck and truck cabin coating plants

The following table summarises the reported data on specific energy consumption per product type.

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[16] Heating degree days (HDDs) and cooling degree days (CDDs) are proxies for the energy demand needed to heat or cool, respectively, a home or a business. Both variables are derived from measurements of outside air temperature. More information can be found in: www.eea.europa.eu/data-and-maps/indicators/heating-degree-days-2

Table 2.15: Specific energy consumption for van, truck, truck cabin and bus coating plants

Product type	Reported data (1) 2013-2015				Industry report (2) 2012			
	No of plants	Average (MWh /vehicle)	50 % middle range (MWh /vehicle)	Min./Max. (MWh /vehicle)	No of plants	Average (MWh /vehicle)	50 % middle range (MWh /vehicle)	Min./Max. (MWh /vehicle)
Van	6	1.37	0.95-1.65	0.78/2.48	9	1.70	1.12-3.00	0.85/3.49
Cab/ CV	2	1.08	NA	0.96/1.21	Cab: 8	1.33	0.88-1.88	0.56/6.23
					CV: 4	0.31	NA	0.27/0.44
Bus	2	NA	NA	4.6/14.1*	8	14.9	3.0-21.8	1.7/37.1

* Value 14.1 includes STS and non-STS activities.
NB:
NA: Not applicable/available.
Source: (1) [155, TWG 2016] [219, ACEA 2018] [223, Spain 2018] (2) [142, ACEA 2016]

Among the reported energy-saving techniques, the most commonly applied are:

- thermal insulation of tanks and vats containing cooled or heated liquids;
- heat recovery from off-gas treatment;
- adjustment of the flow according to need; reduced air ventilation at idle operation or maintenance;
- air extraction with energy recovery from the dryer ovens;
- air extraction with energy recovery from the cooling zone;
- central off-gas treatment with variable frequency drives;
- pressurised air: efficiency/pressure level;
- spray booth air recirculation.

2.3.1.2 Water consumption

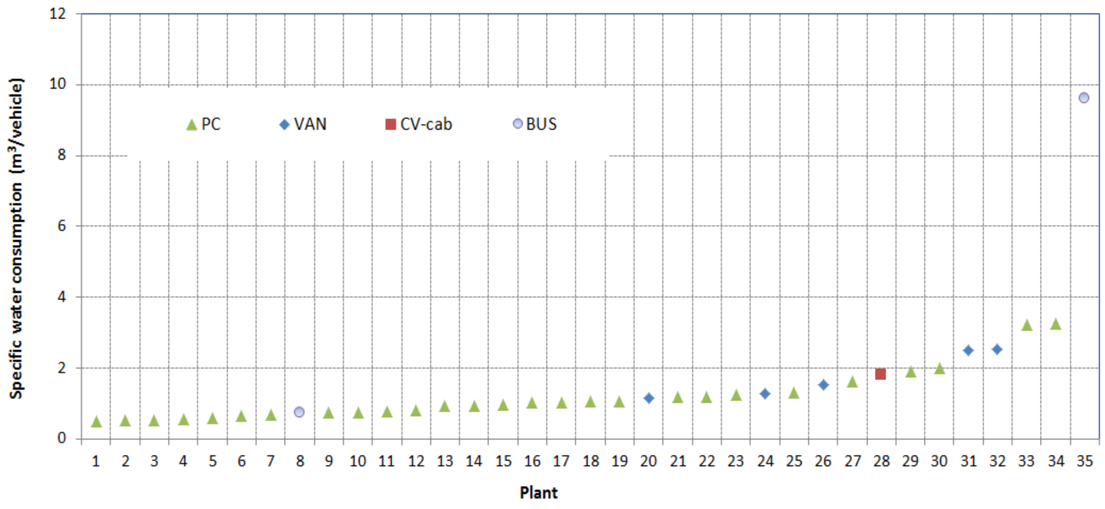
Water consumption in vehicle paint shops is mainly related to the:

- supply of rinsing water in cleaning and pretreatment processes;
- replenishing of degreasing and pretreatment tanks and wet scrubber systems;
- evaporation losses from wet scrubber systems and air humidification.

Bath maintenance with the objective to reduce water consumption and to reclaim treatment chemicals is an important part of paint shop management. Rinsing tanks are generally operated as cascading vats [142, ACEA 2016].

Figure 2.19 and Table 2.16 show data on the specific water consumption (expressed in m^3/vehicle) reported by various installations. Most of the reported specific water consumption values are below 1.3 m^3/vehicle.

An industry report indicates a specific water consumption between 0.9 m^3/vehicle and 1.8 m^3/vehicle, with consumption values below 0.4 m^3/vehicle reported from paint shops with a special body design (small vehicles) or from installations with dry particle separation [142, ACEA 2016].



Source: [155, TWG 2016] [219, ACEA 2018] [223, Spain 2018]

Figure 2.19: Specific water consumption (m^3/vehicle) for automotive paint shops (2015 data)

The following table summarises the reported data on specific water consumption for automotive paint shops per vehicle type.

Table 2.16: Specific water consumption for automotive paint shops

Product type	**Reported data (1) 2015**				**Industry report (2) 2012**			
	No of plants	Average (m^3/vehicle)	50 % middle range (m^3/vehicle)	Min./Max. (m^3/vehicle)	No of plants	Average (m^3/vehicle)	50 % middle range (m^3/vehicle)	Min./Max. (m^3/vehicle)
PC	27	1.15	0.71-1.22	0.49/3.26	47	1.18	0.90-1.82	0.22/3.47
Van	5	1.80	NA	1.15/2.54	3	2.05	NA	0.96/3.26
Cab/CV	1	1.81	NA	NA	Cab:7	2.63	0.66-2.78	0.15/7.61
					CV: 5	4.21	0.15-0.56	0.1/6.98
Bus	2	5.18	NA	0.73/9.63	5	14.6	4.1-29.9	10.6/54.6

NB:
NA: Not applicable/available.
(1) *Source*: [155, TWG 2016] [219, ACEA 2018] [223, Spain 2018] (2) [142, ACEA 2016]

The main reported techniques for minimising water consumption are:

- reuse and/or recycling of water;
- control of water usage;
- reverse cascade rinsing;
- bath desludging;
- ion exchange;
- membrane filtration;
- oil skimmer;
- particle filter;
- magnet separator;
- decanter centrifuging for paint shop overspray waste waters;

- neutralisation.

2.3.2 Emissions

2.3.2.1 Total emissions of VOCs

In vehicle coating, VOCs represent the most significant emission source. The activity emits VOCs originating mainly from the spray booths, the drying ovens and the cleaning of application equipment.

Usually, application and drying of primer and topcoat/clear coat contribute to approximately 80 % of the VOC emissions originating from the painting sector of car production. The topcoat refinishing (rectification) and cleaning procedures as well as additional sources (e.g. coating of small parts, application of underbody protection) are responsible for the remaining 20 %. Approximately 70-90 % of the total VOC emissions generated during the application and drying procedure originate from the painting booth, the remaining 10-30 % from the dryer. The indicated percentage rates generally depend on the solvent types used, the painting systems and the application efficiency factor of the technique. Off-gas from the dryer loaded with VOCs is usually directed to a thermal off-gas treatment system.

VOC emissions in the vehicle coating sector are expressed as specific emissions in g VOCs/m^2 of coated surface. The coated surface area is calculated according to Part 3.2 of Annex VII to the IED (see also Annex 21.5.1.5.6.).

2.3.2.1.1 Coating of passenger cars

Figure 2.20 presents the reported total emissions from 28 paint shops in Europe dedicated to the coating of passenger cars (PC) and light commercial vehicles (LCV). According to the type of coating used for the various coating layers (primer, base coat, clear coat), paint shops are classified as SB (solvent-based: use of solvent-based coat for all layers), SB-MIX (use of water-based coat for either the primer or base coat, and solvent-based for the other coats) and WB (water-based: use of water-based coating for all layers except clear coat). Another option, the integrated system, exists, but was not identified in reports from the 28 paint shops. According to ACEA, the VOC emissions from integrated systems are similar to those of other well-performing systems and these systems are implemented for other reasons (see Section 2.2 and [142, ACEA 2016]).

An industry report analysing data from 74 passenger car paint shops shows an average value of 25.1 g/m^2 and a 50 % mid range between 16 g/m^2 and 33 g/m^2 [142, ACEA 2016].
The TFTEI[17] report analysing data from 60 reference paint shops in Europe provides the emission values that are presented in Table 2.17 in relation to the paint shop type [147, TFTEI 2016].

Table 2.17: Total emissions of VOCs for various paint shop types

Paint shop type VOC Emission (g/m^2)	SB	SB-MIX	WB	Integrated system
Average	37.8	28.7	18.6	20.5
Min.-Max.	16.8-50.3	12.5-48.2	6.0-30.5	8.9-32.1
Source: [147, TFTEI 2016]				

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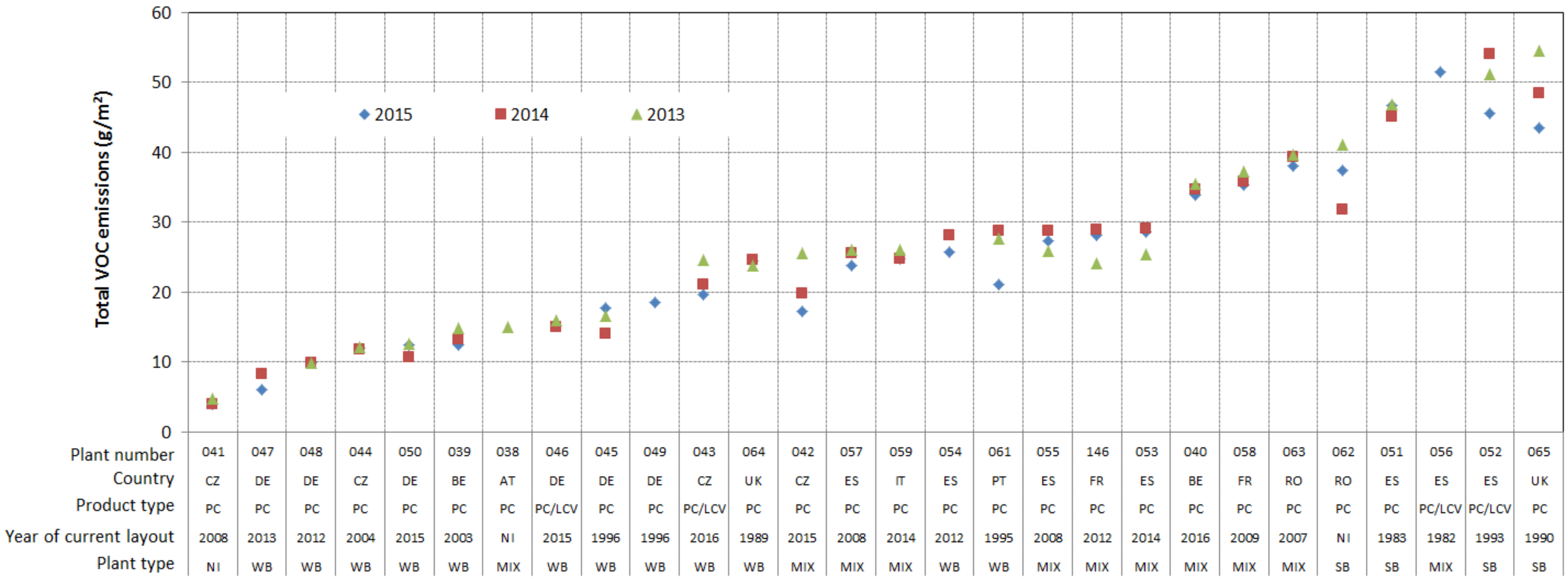
[17] TFTEI: Task Force on Technico-Economic Issues of the UNECE Convention on Long Range Transboundary Air Pollution (LRTAP).

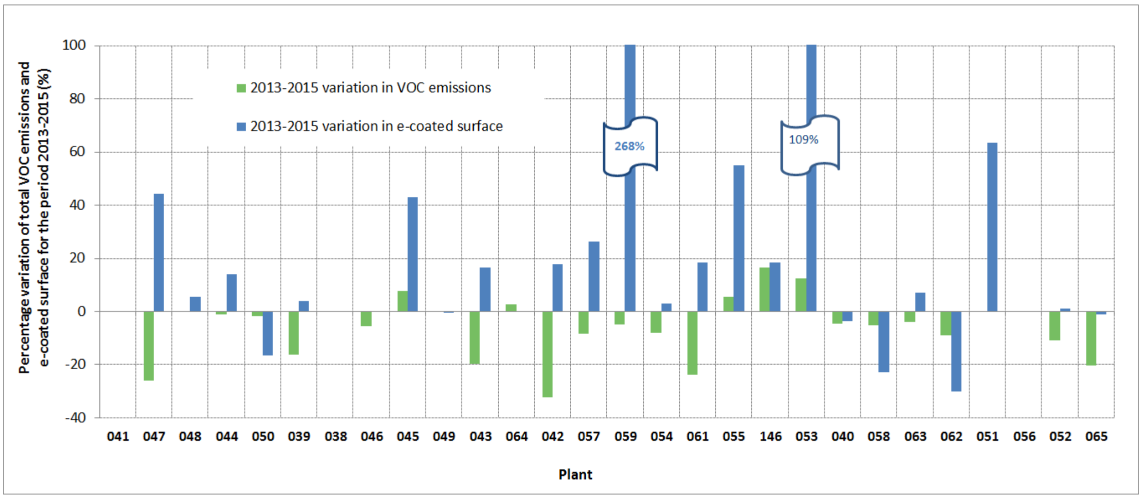
Data from the industry study show that the overall performance of European paint shops has improved over a long period (2002-2012) (see Figure 2.6) [142, ACEA 2016].



Source: [155, TWG 2016] [219, ACEA 2018]

Figure 2.20: Total emissions of VOCs (g/m^2) from the coating of passenger cars for the period 2013-2015

During the reference period (2013-2015), for most of the installations that submitted data, a decrease in total VOC emission values is observed. This, in most cases, is combined with an increase in the utilisation of the installed plant (paint shop) capacity (see Figure 2.21 below).



NB: For Plants # 047 & #054 data for the period 2014-2015.
Source: [155, TWG 2016] [219, ACEA 2018]

Figure 2.21: Percentage variation of total emissions of VOCs (g/m^2) and total e-coated surface for 2013-2015

For example, data from two installations show:

- a reduction of almost 24 % in total VOC emissions which can be correlated with the reduction of 10 % in total emitted VOC load and the increase of 18 % in coated surface for 2013-2015 *(source:* Plant #061 in [155, TWG 2016]*)*;
- a reduction of 26 % in total VOC emissions combined with an increase of about 6 % in total emitted VOC load and an increase of 40 % in coated surface between 2014 and 2015 *(source:* Plant #047 in [155, TWG 2016]).

Apart from major changes in the paint shop design and technology which are mainly associated with the installation's investment cycle, a number of other techniques can contribute to significant emission reduction. As an example, information from one installation shows that the implementation of the following –mainly managerial and not major investment– techniques had as a result the reduction of specific emissions by 34 % over a nine-year period (from 53.76 g/m^2 in 2007 to 35.41 g/m^2 in 2016) *(source:* Plant #058 in [155, TWG 2016]*)*:

- implementation of low-pressure manual paint sprayers;
- decrease in the number of paint colours;
- only one coat for three types of coat;
- increase in the number of cars in series of cars of the same colour;
- work on the transfer efficiency by optimising the application distance (base and clear coats);
- use of low-solvent products to clean the spray-painting robots which are protected by a cover;
- improving the percentage of directly well-painted cars (increased 'right first time' rate) and implementation of the localised repairing technique.

Possible impact of special paint finishes on VOC emissions.
There are various special paint finishes used in the automobile industry that have a direct impact on VOC emissions. These include, but are not limited to the following:

High-pearlescent finishes – these can be a four-coat or three-coat process depending on the ability to create that colour and the high colour shift in a given technology. The process will therefore either be:

- base coat – effect coat – clear coat – cure; or
- base coat – clear coat – cure – effect coat – clear coat – cure.

Both processes require more painting time than in the case of standard paint finishes, and in the case of a four-coat the vehicle needs to be run twice through the painting process. This impacts emissions, production capacity and scrappage rates – due to the increased overall film build-up having less scope for repairs.

At present, special paint finish application rates tend to be fairly low (~ 5 %), but even at that rate the impact on VOC emissions is estimated to ~ 1 g/m^2. If the demand for these finishes increases then a serious impact on VOC emissions would result.

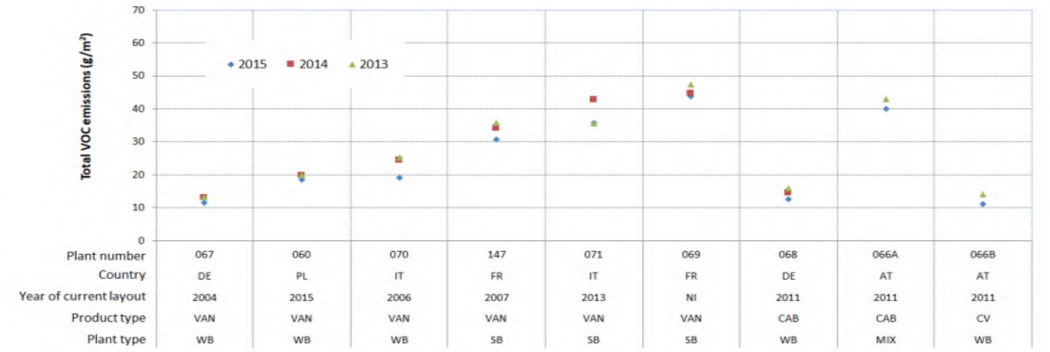
Two-tone vehicles – these vary in process, number of second colours and extent of the second colour. They can range from just a different coloured roof to the whole upper vehicle being a second colour, sometimes including the bonnet, boot or tailgate. This seems to be the latest customer trend and application rates can be 30 % or more of production. Based on an average vehicle (~ 100 m^2 electrocoat surface area) and a 30 % uptake rate, the impact on VOC emissions would be in the range of 1 g/m^2 to 5 g/m^2 depending on the extent of the second colour. If demand were to increase further with a higher uptake rate, VOC emissions would increase as a result.

Tinted clear coats – there are certain colours that are achieved by using a tinted clear coat. Sometimes two or three additional clear coats can be used in a plant. A conventional paint shop with a single clear coat will not clear or purge the automation very often. The addition of a coloured clear coat requires the automation not only to purge on a colour change but also to more frequent cleaning.

Other special finishes are available and have been used in the past, e.g. matt clear coat, matt black, liquid silver. All of these impact VOC emissions but so far they have only been applied to a fairly limited number of vehicles [ACEA comment #223 in [212, TWG 2018]].

2.3.2.1.2 Coating of vans, trucks, truck cabins and buses

Reported data from nine paint shops dedicated to van, truck and truck cabin coating are presented in Figure 2.22.



Source: [155, TWG 2016] [219, ACEA 2018]

Figure 2.22: Total emissions of VOCs (g/m^2) from the coating of vans, trucks and truck cabins for the period 2013-2015

There are data reported for only two installations for truck cabin coating, both of them below 45 g/m^2 (14.32 g/m^2 and 41.5 g/m^2 as averages for the period 2013-2015) [155, TWG 2016].

An industry report with an analysis of data from 11 truck cabin paint shops shows an average value of 21.2 g/m^2 with the 50 % mid range varying from 14.1 g/m^2 to 51.3 g/m^2 [142, ACEA 2016].

The reported data from seven paint shops for the coating of new vans and trucks show an average value of 26.3 g/m^2 with values ranging from 12.5 g/m^2 to 45.3 g/m^2 (all values are averages over the period 2013-2015) [155, TWG 2016].

An industry report analysed data from 10 paint shops for the coating of vans and 6 paint shops for the coating of trucks and derived average values of 33 g/m^2 and 50 g/m^2 respectively for the two product types [142, ACEA 2016].

The basic statistical figures from the reported data are presented in Table 2.18.

Table 2.18: Total VOC emission data for automotive paint shops

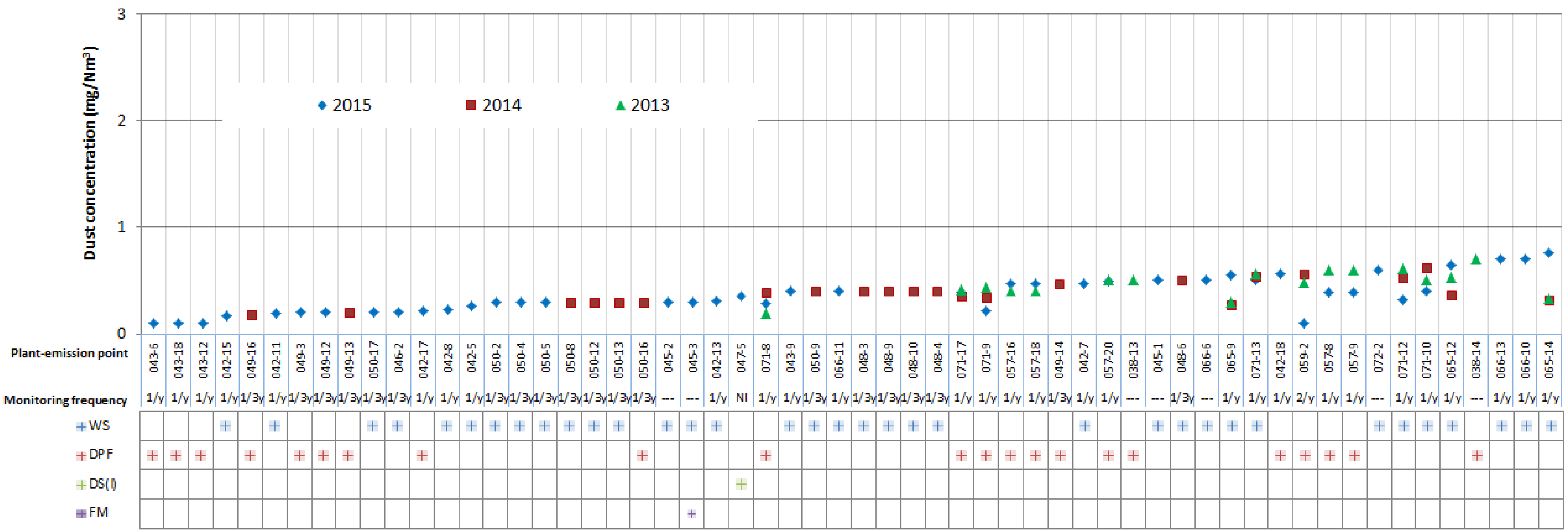
Product type	Reported data (1) 2013-2015				Industry report (2) 2012			
	No of plants	Average (g/m^2)	50 % middle range (g/m^2)	Min./ Max. (g/m^2)	No of plants	Average (g/m^2)	50 % middle range (g/m^2)	Min./ Max. (g/m^2)
PC	28	25.7	15.3-35.0	4.2/51.4	74	25.1	15.9-32.9	4.7/55.3
Van	6	28.6	20.3-36.9	12.6/45.3	10	33	24-47	16/61
CV	1	12.5	NA	NA	6	50.5	22.2-56.9	17/68.1
Cab	2	27.9	NA	14.3/41.5	11	21.2	14.1-51.3	8.3/70.6
Bus	2	138.7	NA	95.3/182	10	64.6	36.9-118	4.4/183

NB:
NA: Not applicable/available.
(1) *Source*: [155, TWG 2016] [219, ACEA 2018] [223, Spain 2018]
(2) *Source*: [142, ACEA 2016]

2.3.2.2 Dust emissions in waste gases

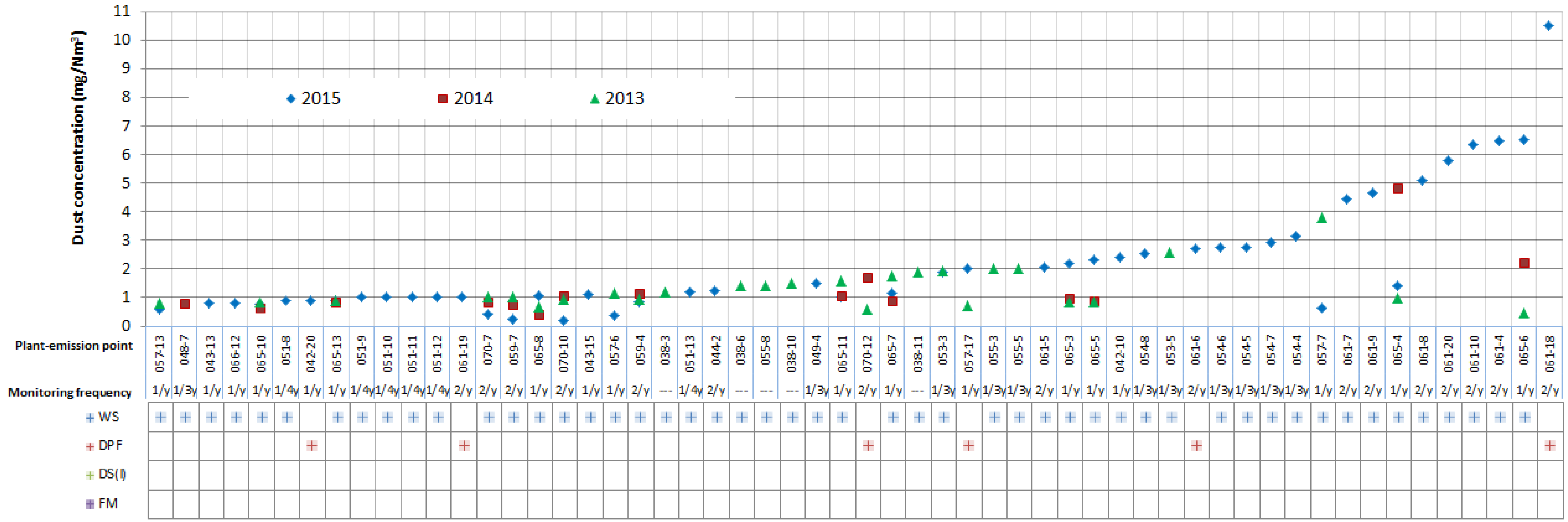
Besides VOC emissions, dust emissions resulting from paint overspray are also considered a key environmental issue for the sector. All paint shops are equipped with venturi scrubbers or dry scrubbers to reduce dust emissions arising from paint overspray.

Figure 2.23 and Figure 2.24 show the reported dust emission values from vehicle paint shops applying wet or dry dust abatement techniques. The reported concentration values are generally low.



Source: [155, TWG 2016] [219, ACEA 2018]

Figure 2.23: Dust emissions in waste gases (periodic monitoring) - Average values for the period 2013-2015 (1/2)



Source: [155, TWG 2016] [219, ACEA 2018]

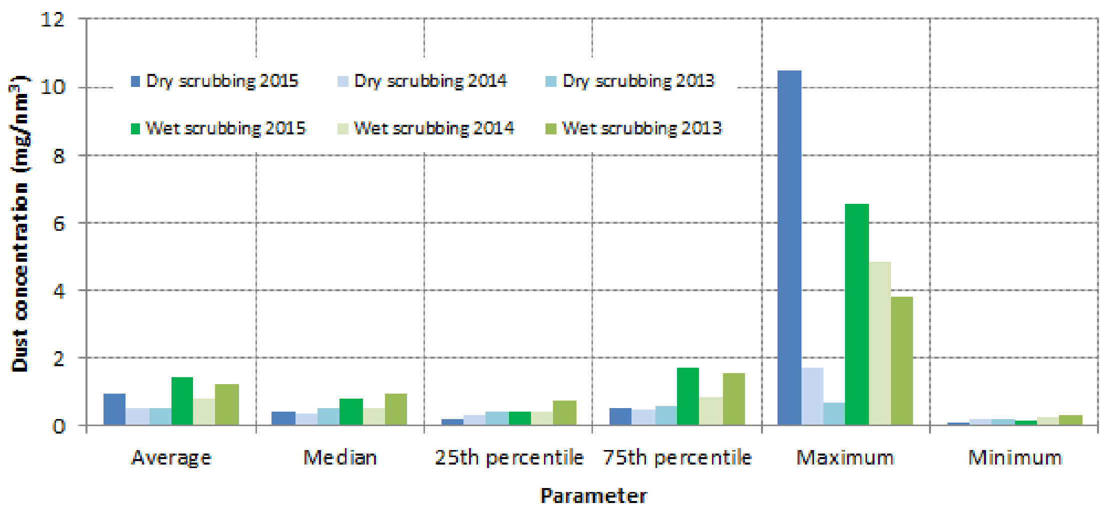
Figure 2.24: Dust emissions in waste gases (periodic monitoring) - Average values for the period 2013-2015 (2/2)

The statistical analysis of submitted dust emission data in total and by applied abatement technique is presented in Table 2.19 and Figure 2.25.

Table 2.19: Statistical data for dust emissions in waste gases for the period 2013-2015

Parameter		All data			Dry scrubbing			Wet scrubbing		
		2015	2014	2013	2015	2014	2013	2015	2014	2013
Number of measurements		90	38	44	23	9	13	67	29	31
Average	mg/Nm^3	1.3	0.7	1.0	1.0	0.5	0.5	1.4	0.8	1.2
Median		0.6	0.5	0.8	0.4	0.4	0.5	0.8	0.5	1.0
25th percentile		0.3	0.4	0.5	0.2	0.3	0.4	0.4	0.4	0.7
75th percentile		1.2	0.8	1.3	0.5	0.5	0.6	1.7	0.9	1.5
Maximum		10.5	4.8	3.8	10.5	1.7	0.7	6.5	4.8	3.8
Minimum		0.1	0.2	0.2	0.1	0.2	0.2	0.2	0.3	0.3

Source: [155, TWG 2016]



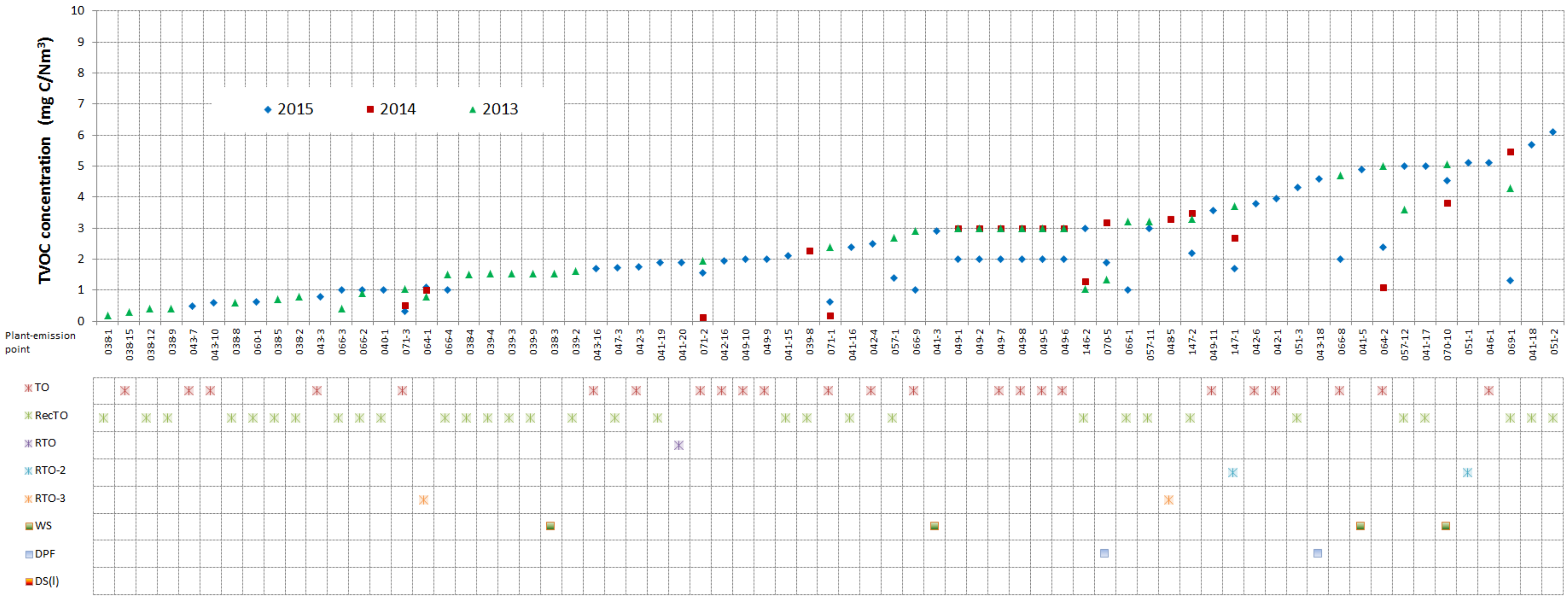
Source: [155, TWG 2016]

Figure 2.25: Statistical parameters of the reported dust emission data (periodic monitoring)

The achieved dust concentration values in waste gases are in general very low with only a few elevated values. There is no significant difference in reported values according to the dust abatement technique applied.

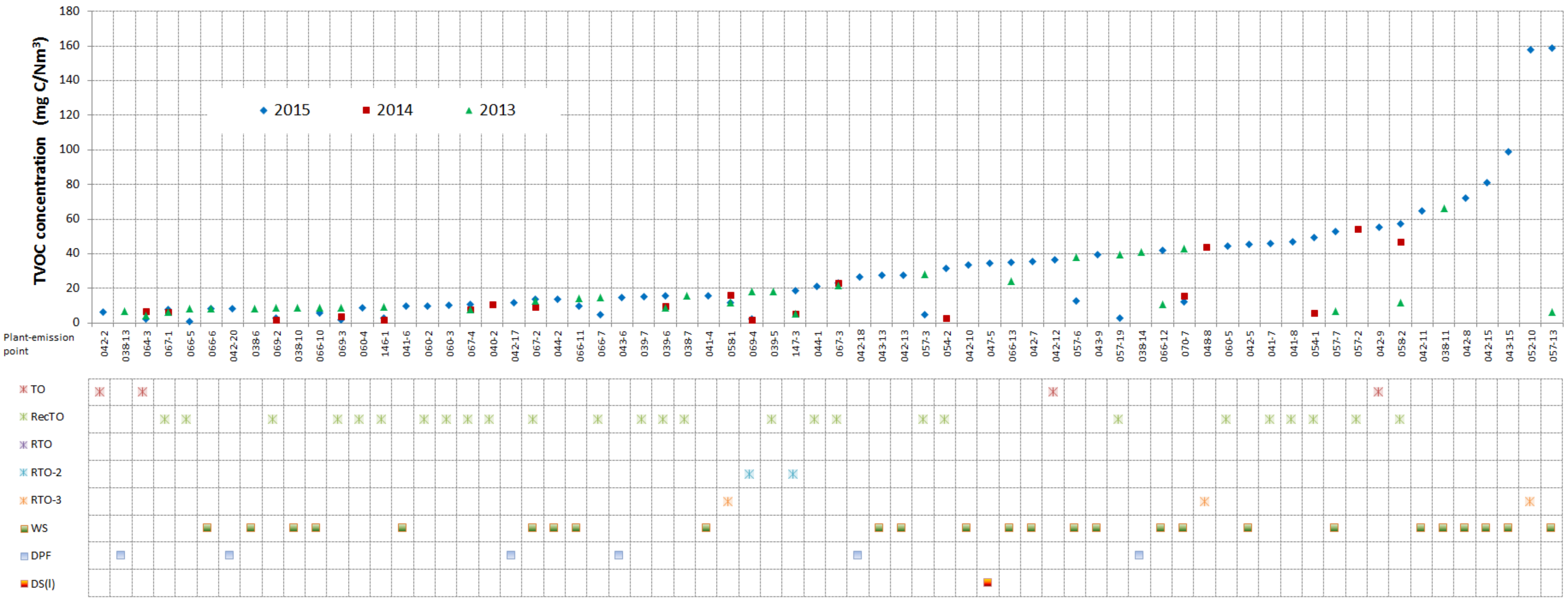
2.3.2.3 TVOC emissions in waste gases

Emissions of TVOC in waste gases occur for a significant number of emission points associated with the exhaust of spray booths or of the dryers. At the exhaust of spray booths, overspray capture techniques are applied while thermal treatment techniques are generally used for the exhaust from dryers (see also Sections 2.2.3.4, 2.2.3.5 & 2.2.3.6). In Figure 2.26 and Figure 2.27 the reported levels of TVOC emissions in waste gases are presented.



NB: Continuous monitoring for Plants #060-5, #066-6, #066-7.
Source: [155, TWG 2016] [219, ACEA 2018]

Figure 2.26: TVOC emissions in waste gases - Average values for the period 2013-2015 (1/2)



NB: Continuous monitoring for Plants #060-5, #066-6, #066-7.
Source: [155, TWG 2016] [219, ACEA 2018]

Figure 2.27: TVOC emissions in waste gases - Average values for the period 2013-2015 (2/2)

Most of the reported values are below 40 mg C/Nm^3 (a percentage of 85 % of all values) while 75 % of reported values are lower than 20 mg C/Nm^3. The higher emission levels are mainly associated with emissions from the spray booths where overspray capture techniques apply.

The basic statistical parameters of the reported data for the year 2015 are presented in Table 2.20.

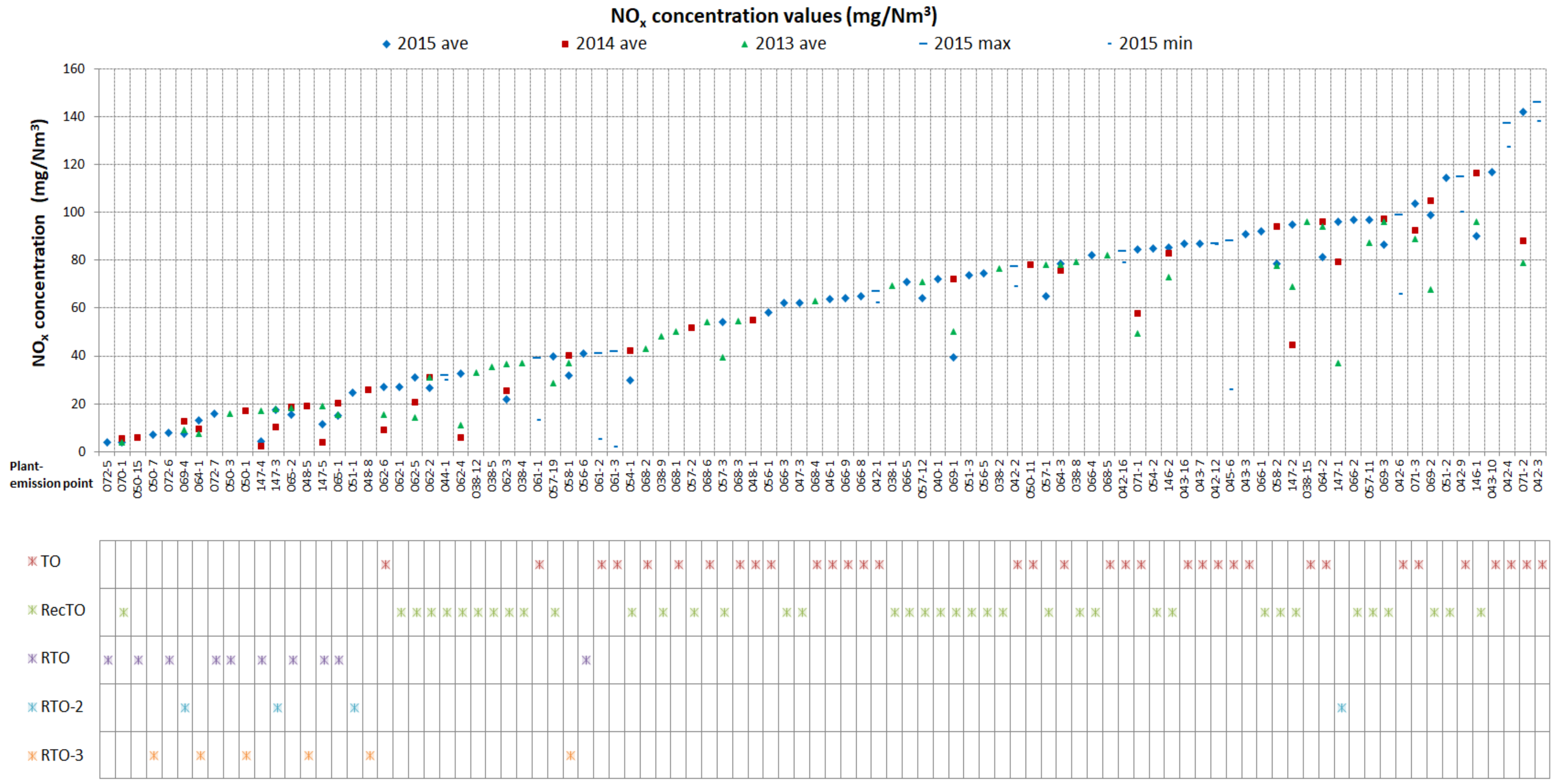
Table 2.20: Statistical parameters of the reported data for TVOC emissions in waste gases (data for 2015)

Parameter		All data	Applied abatement technique						
			TO	**CO**	**RecTO**	**RTO-3**	**RTO-2**	**DPF**	**WS**
Number of values		111	27	2	42	4	4	7	25
Average	mg C/Nm^3	16.3	5	2	10	43	7	15	37
Median		4.9	2	NA	4	7	NA	12	28
25th percentile		2	2	NA	2	2	NA	6	10
75th percentile		15.55	3	NA	11	48	NA	21	46
Maximum		159	55	2	57	158	19	35	159
Minimum		0.32	0.32	2	1	1	2	2	3

NB:
NA: Not applicable/available.
TO: Thermal oxidiser may be either recuperative (RecTO) or regenerative (RTO-2/-3)
Source: [155, TWG 2016] [219, ACEA 2018]

2.3.2.4 NO_X and CO emissions in waste gases

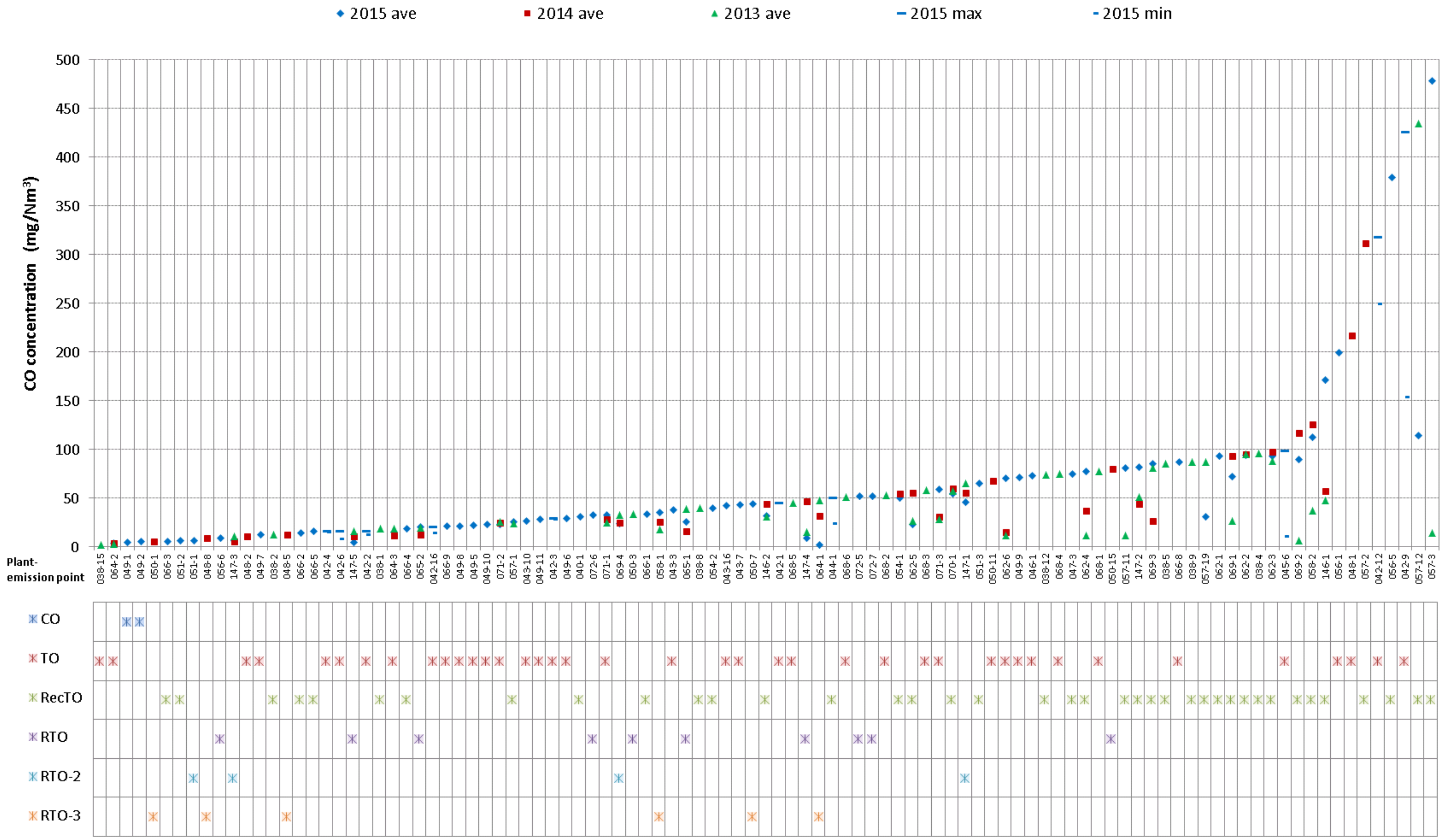
Nitrogen oxides (NO_X) and carbon monoxide (CO) emissions result from the thermal oxidation of off-gases. The reported values are presented in Figure 2.28 and Figure 2.29.



NB: Continuous monitoring for #45-6

Source: [155, TWG 2016] [219, ACEA 2018]

Figure 2.28 **NO_X emissions in waste gases for the period 2013-2015**



NB: Continuous monitoring for #45-6

Source: [155, TWG 2016] [219, ACEA 2018]

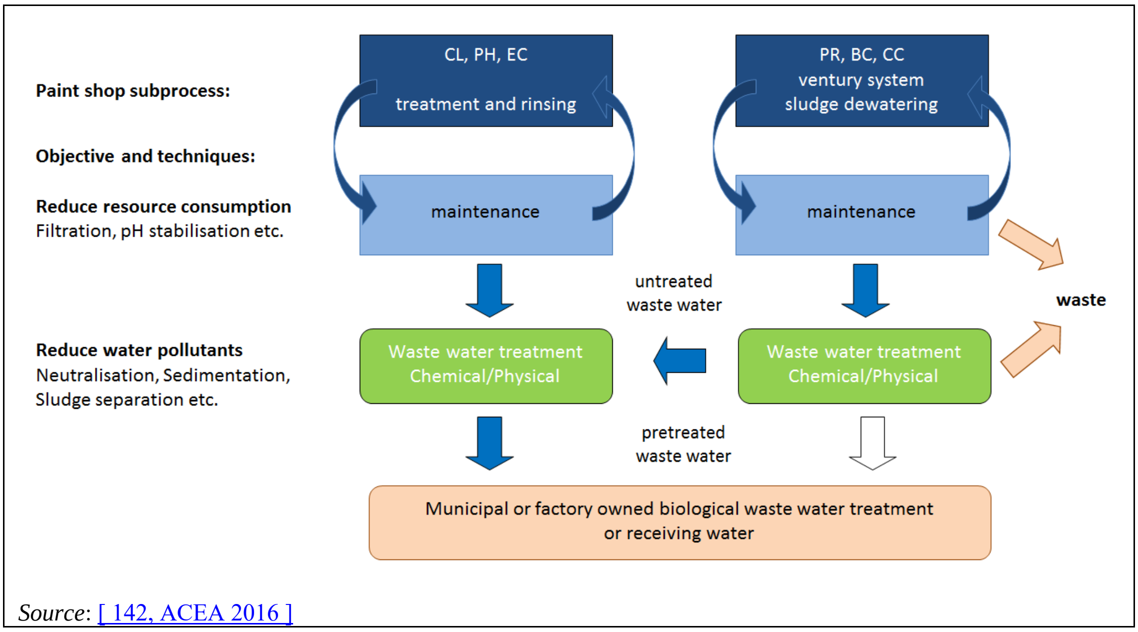
Figure 2.29 CO emissions in waste gases for the period 2013-2015

2.3.2.5 Emissions to water

Two types of waste water are generated in a paint shop:

- waste water with inorganic load (salts, heavy metals) from phosphating,
- waste water with mainly organic load (oil, detergents, paint) from cleaning, e-coat and wet scrubber systems.

A typical configuration of waste water treatment in large paint shops for vehicles is presented in Figure 2.30.



Source: [142, ACEA 2016]

Figure 2.30: Typical technical configuration of waste water treatment in large paint shops

Waste water from the pretreatment and the immersion primer coating

Most of the waste water originates from the pretreatment of the bodies by degreasing, phosphating, passivation and from the following electrocoat primer process. The waste waters are predominantly from rinsing the bodies between treatments, therefore removing the materials from the previous process. The components of pretreatment (degreasing), conversion coatings and passivation, as well as the water management and water-saving techniques applicable to all, are described in detail in the STM BREF [23, COM 2006]. These include multistage rinsing and techniques to minimise water use and recover water and raw materials, and are equally applicable to electrocoating.

Electrocoating can be operated with multiple (cascade) rinses, with separation and recovery of the paint solids and the liquid (ultrafiltrate) being returned for rinsing. Although rinses are usually carried out in a closed loop for the paint solids, some rinsing water may be lost (containing traces of paint, water-based solvents, etc.) and there is a need for periodic cleaning. Electro-immersion paint does not contain lead. Other substances in the degreasing and pretreatment waste waters are detergents, pressing oils, ferrous, manganese, nickel and zinc phosphates, fluorides and borates. Cr(VI) is no longer used as a passivation material, due to the ELV Directive strictly limiting Cr(VI) in vehicles (there are exemptions for heavy commercial vehicles). Cadmium occurs in all zinc compounds as a contaminant at 10 mg/kg[18].

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[18] For example, US and UK Pharmacopias: 10 ppm maximum permitted value in pharmaceutical zinc oxide. See also the STM BREF for zinc electroplating.

Waste water from coating processes

Other waste water is generated by the wet scrubbing of paint overspray as:

- a mix of paint, water and coagulating agent residues;
- a mix of paint, water and solvent generated by cleaning the nebuliser units and paint supply conduits;
- a mix of paint and water generated by cleaning the painting booths.

During the spraying of paint in spray booths, other waste water may be generated by the wet scrubbing of paint overspray. This is required to minimise emissions of paint as dust (particulate matter). The water for these scrubbers is recirculated in a closed loop, and the paint sludge is separated and has to be removed periodically during maintenance and continuously by desludging a bypass flow to enhance the service life of the bath. The same methods are used for the separation of both solvent-based and water-based paints.

The organic solvents contained in solvent-based paints are mostly very volatile with low solubility in water. Water-based paints have a substantially smaller solvent proportion which, however, is almost completely soluble in water. If these solvents have a very low vapour pressure, they can accumulate in the water. Solvents for water-based paints accumulate in the water circulating in the spray booth only up to the equilibrium state (usual concentrations are about 0.5 %). The rinsing water of the spray booth is held in a closed loop and is renewed periodically, i.e. twice a year or less frequently. Moreover, waste water is generated by the cleaning of the heat exchangers of the spray booth exhaust air and the heat rotors as well as by the humidification of the input air supplied to the spray booth although this constitutes very small amounts [38, TWG 2004] [212, TWG 2018].

The waste water from degreasing and pretreatments is usually treated in a waste water treatment plant (usually but not always at the same site) described in detail in the STM BREF [23, COM 2006]. The WWTP may also treat waste waters from other activities on site. The treated effluent may then be discharged directly to surface waters, to a municipal waste water treatment plant or transferred to another industrial waste water treatment plant (on or off site).

The discharge points and treatments carried out depend on the installation.

A COM study[19] identified the main parameters and other substances of interest that may be discharged in waste waters (including those mentioned above) and therefore to be considered for the data collection. These are given in Table 2.21.

Table 2.21: KEIs for waste waters from the coating of passenger cars, vans, trucks and trucks cabins and buses

Identified main parameters	Parameters of interest
TSS, TOC/COD, Ni, Zn, Cd, phenol, AOX, fluoride, phosphate Also, for trucks, truck cabins and buses: Pb, Cr(VI) (authorised restricted usage under REACH)	DEHP, NP/NPE, NMP

Data on waste water emissions from the coating of vehicles were received from 25 installations. The main techniques applied are as described in the STM BREF:

- **In-process:**
  - substitution;
  - reverse cascade rinsing.

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[19] COM working document EIPPCB 09/06/2016: Assessment of Technical Working Group (TWG) data submitted on metals and other emissions to water for their consideration as Key Environmental Issues for installations carrying out IED Annex I 6.7 activities.

- **Waste water treatment techniques:**
  - coagulation and flocculation;
  - neutralisation;
  - sedimentation (settlement);
  - filtration (using sand filters);
  - precipitation;
  - flotation
  - vacuum distillation;
  - VOC stripping;
  - physical separation;
  - biological treatment;
  - chemical reduction;
  - ion exchange.

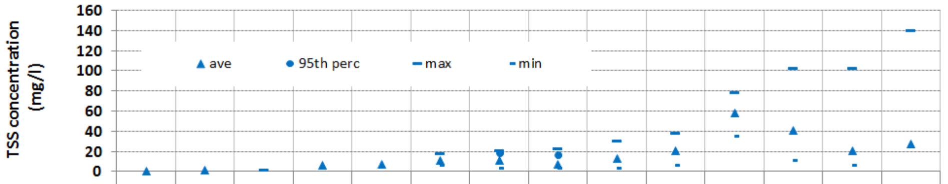
The reported concentration values for each pollutant are presented in the following sections. An explanation of abbreviations used for emissions to water data is provided in Table 2.22.

Table 2.22: Explanation of abbreviations used for emissions to water data

Type of discharge		**Type of monitoring**	
D	Direct	INT	Internal
I	Indirect	EXT	External
R	Reuse	SM	Self-monitoring
Type of sampling		**Combined or dedicated treatment**	
T	Time-proportional	CO	Combined waste water treatment facility (WWTF)
F	Flow-proportional	DE	Dedicated waste water treatment facility (WWTF) for the STS-related waste water only
S	Spot		

2.3.2.5.1 Total suspended solids (TSS)

Data for total suspended solids concentration values were reported for 13 plants and 14 discharge points. The distribution of the reported concentration values is shown in Figure 2.31.



Sampling duration	24	1.5	24	24	24	24	2	24	24	3		24	3	NI
Type of sampling	F	T	T	F	F	F	T	F	T	T	S	T	T	S
Monitoring frequency	1/y	12/y	24/y	12/y	12/y	12/y	12/y	12/y	24/y	4/y	4/y	12/y	12/y	365/y
Type of monitoring	EXT	EXT	EXT	INT	EXT	EXT	INT	EXT	EXT	EXT	EXT	EXT	EXT	INT
Type of discharge (D/I)	I	I	I	D	D	I	I	I	I	I	I	NI	NI	D
Combined / Dedicated treatment	CO	DE	DE	DE	CO	DE	DE	DE	CO	CO	DE	DE	NI	NI
Product type	PC	PC	PC	PC	PC	PC	PC	PC	PC	VANS	VANS	PC	PC	PC
Plant-discharge point	038-1	057-2	057-1	058-1	039-1	054-1	043-1	040-1	065-1	070-1	071-1	050-1	059-1	062-1

■ Neutralisation	■	■	■			■		■	■		■	■		
● Coagulation and Flocculation	●	●	●	●	●	●	●	●	●	●	●	●	●	●
◆ Sedimentation	◆	◆	◆		◆	◆	◆	◆	◆	◆		◆		
✳ Precipitation				✳		✳				✳	✳	✳		
+ Filtration	+	+	+	+	+		+	+			+	+		
○ VOC stripping														
× Biological treatment	×				×					×				×
◇ Vacuum distillation														
⋇ Physical separation		⋇	⋇											
◆ Flotation				◆										
■ Ion exchange														
▲ Chemical reduction														

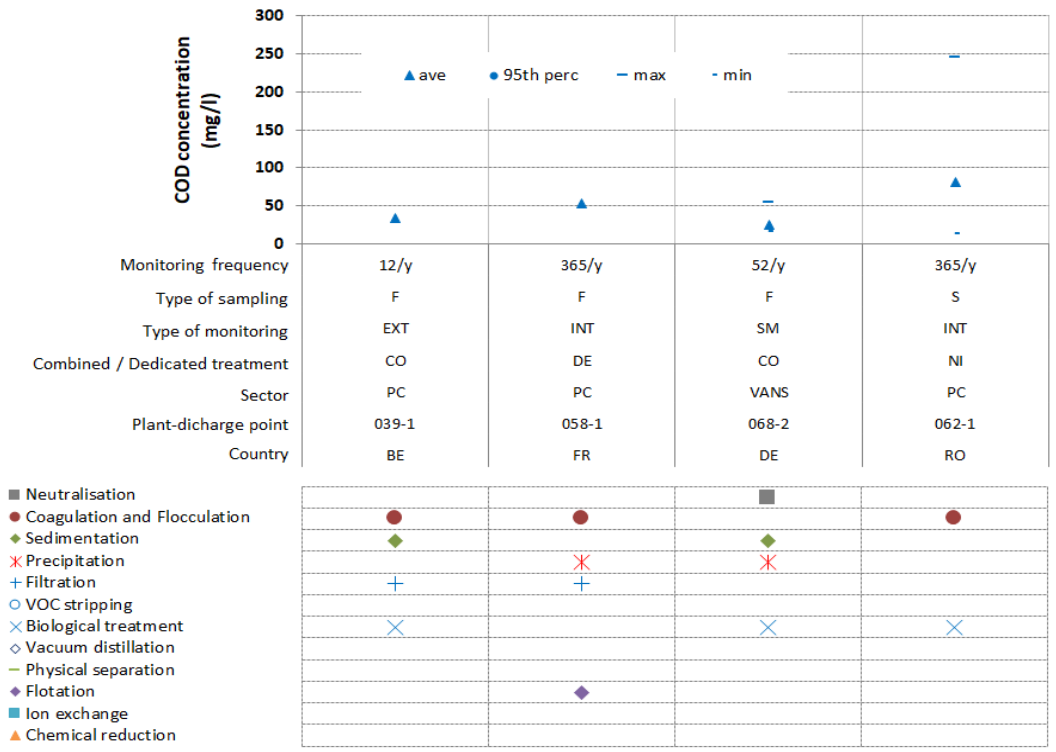
NI: No information provided
Source: [155, TWG 2016] [219, ACEA 2018]

Figure 2.31: TSS concentration values for direct and indirect discharges of waste water from vehicle coating plants (data for 2015)

Only three values are related to direct discharges to a receiving water body, with two of them lower than 6 mg/l.

2.3.2.5.2 Chemical oxygen demand (COD) and total organic carbon (TOC)

The reported concentration values of COD for direct discharges are presented in Figure 2.32. In total, data from 24 discharge points corresponding to both direct and indirect discharges were reported for COD concentration values and data from 3 plants (4 discharge points) were submitted for TOC values. The small number of reported TOC values did not allow the examination of a possible correlation between TOC and COD values.



NI: No information provided

Source: [155, TWG 2016] [219, ACEA 2018]

Figure 2.32: COD concentration values for direct discharges of waste water from vehicle coating plants (data for 2015)

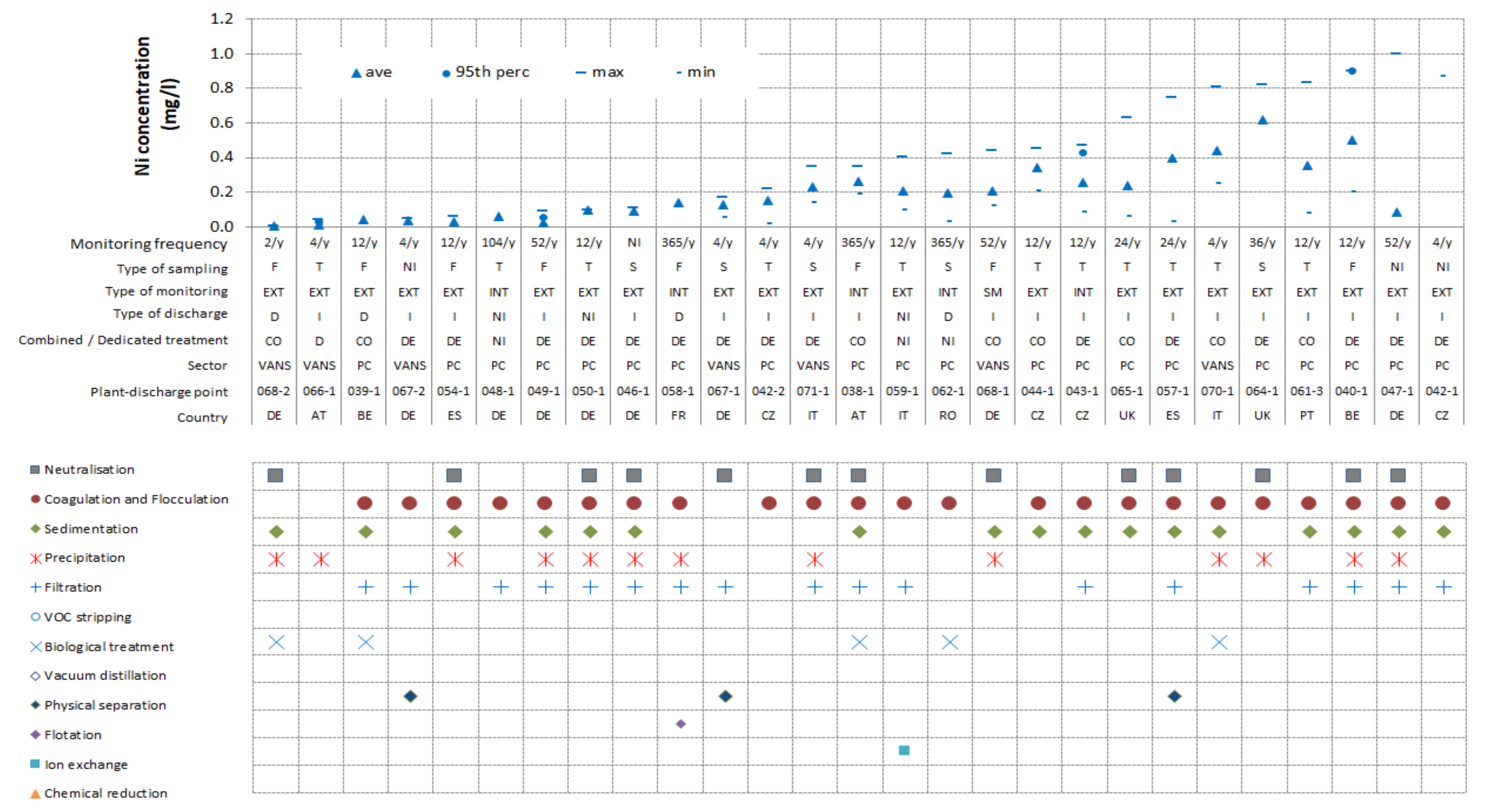
2.3.2.5.3 Nickel (Ni)

Data on nickel emissions were reported for 27 discharge points in total. The distribution of the reported concentration values is shown in Figure 2.33.

Information on the type of metal sheet that was used was not available in the collected data. In the case of using metal sheets with a higher nickel content, the emissions to waste water may be higher and the cost of waste water treatment may be higher [CZ comment #14 in [212, TWG 2018]]. Out of the 27 reported maximum values, 15 are lower than 0.4 mg/l.

2.3.2.5.4 Zinc (Zn)

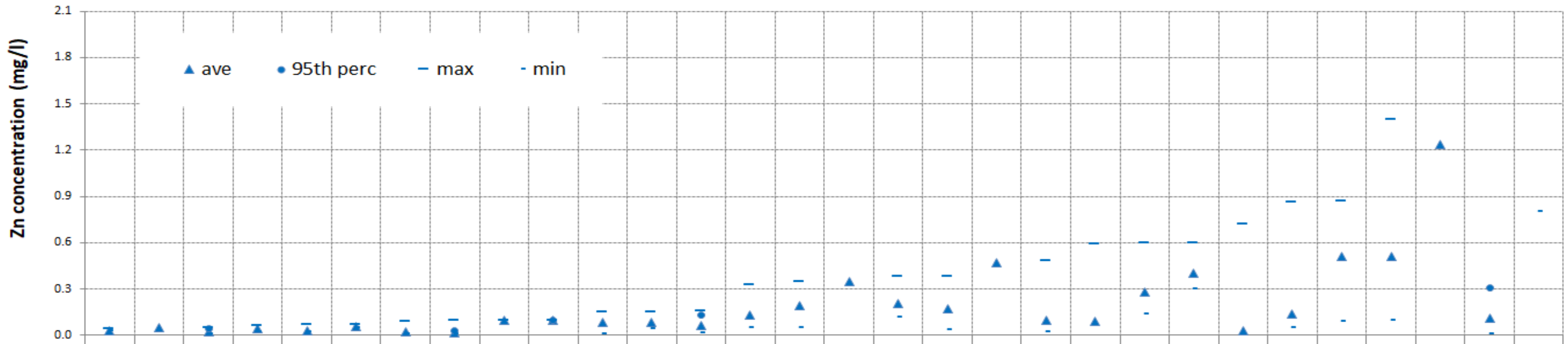
Data for zinc concentration values in waste water were received for 25 plants (in total 30 discharge points). The distribution of the reported concentration values is shown in Figure 2.34. Information on the type of metal sheet that was used was not available in the collected data. In the case of using metal sheets with a higher zinc content, the emissions to waste water may be higher and the cost of waste water treatment may be higher [CZ comment #15 in [212, TWG 2018]]. The achievable concentration levels for the majority of the reported emission points (23 out of 30) are below 0.6 mg/l (see Figure 2.34).



NB: Data not shown: #042-1, ave: 15.7 mg/l & max: 46 mg/l

Source: [155, TWG 2016] [219, ACEA 2018]

Figure 2.33: Ni concentration values for direct and indirect discharges of waste water from vehicle coating plants (data for 2015)



Monitoring frequency	NI	12/y	4/y	NI	12/y	12/y	4/y	52/y	12/y	12/y	2/y	4/y	12/y	6/y	4/y	104/y	4/y	4/y	52/y	24/y	365/y	12/y	52/y	52/y	24/y	4/y	12/y	36/y	365/y	4/y
Type of sampling	S	F	T	S	F	T	F	F	T	F	F	S	T	S	T	NI	S	S	F	T	S	T	F	NI	T	T	T	S	S	T
Type of monitoring	EXT	EXT	EXT	EXT	EXT	EXT	EXT	EXT	EXT	EXT	EXT	EXT	INT	SM	EXT	INT	EXT	EXT	INT	EXT	INT	EXT	INT	EXT	EXT	EXT	EXT	EXT	SM	EXT
Type of discharge	I	D	I	NI	I	I	I	I	NI	I	D	I	I	I	I	NI	I	I	D	I	D	NI	I	I	I	I	I	I	I	I
Combined / Dedicated treatment	DE	CO	NI	NI	DE	CO	CO	DE	DE	DE	CO	DE	DE	DE	DE	NI	DE	DE	DE	DE	NI	NI	CO	DE	CO	CO	DE	DE	DE	DE
Sector	PC	PC	VANS	PC	PC	PC	VANS	PC	PC	PC	VANS	VANS	PC	PC	PC	PC	VANS	VANS	PC	PC	PC	PC	PC	PC	PC	VANS	PC	PC	PC	PC
Plant-discharge point	046-1	039-1	066-1	046-2	054-1	061-3	068-1	049-1	050-1	040-1	068-2	067-2	043-1	045-1	042-2	048-1	071-1	067-1	058-1	057-1	062-1	059-1	038-1	047-1	065-1	070-1	057-2	064-1	056-2	042-1
Country	DE	BE	AT	DE	ES	PT	DE	DE	DE	BE	DE	DE	CZ	DE	CZ	DE	IT	DE	FR	ES	RO	IT	AT	DE	UK	IT	ES	UK	ES	CZ

■ Neutralisation	■				■		■		■	■	■						■	■		■			■	■	■		■	■		
● Coagulation and Flocculation	●	●		●	●	●		●	●	●		●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●		●
◆ Sedimentation	◆	◆		◆	◆	◆	◆	◆	◆	◆	◆		◆							◆			◆	◆	◆	◆	◆			◆
✳ Precipitation	✳		✳		✳		✳	✳	✳	✳	✳						✳		✳					✳		✳		✳		
+ Filtration	+	+				+		+	+	+		+	+			+	+	+	+	+		+	+	+			+			+
○ VOC stripping																														
× Biological treatment		×									×										×		×			×				
◇ Vacuum distillation																														
◆ Physical separation												◆						◆		◆							◆			
● Flotation																			●											
■ Ion exchange																						■								
▲ Chemical reduction																														

NB: Data not shown: #064-1, max value: 3.66 mg/l, #056-2, max value: 3.7 mg/l, #042-1, average value: 36.7 mg/l, max value: 85 mg/l

Source: [155, TWG 2016] [219, ACEA 2018]

Figure 2.34: Zn concentration values for direct and indirect discharges of waste water from vehicle coating plants (data for 2015)

2.3.2.5.5 Hexavalent chromium (Cr(VI)) and total chromium (Cr_{total})

A number of sites reported low values for Cr(VI) (see Table 2.23) and Cr_{total} (see Table 2.24). Information from industry has confirmed:

- hexavalent chromium in vehicles was generally phased out by 2003, according to the requirements of the End-of-Life Vehicles Directive[20];
- where measurements were made, this was based on outdated permit requirements;
- some values were transcription errors, omitting ‘less than’ (<) symbols;
- most values were lower than the reported LoD (which may coincide with the permit limit value).

The few trace values may be attributed to one or more of the following:

- Samples from waste water streams combined with other activities, including domestic sewage, and other unknown sources.
- Trace amounts of Cr may be caused by the etching of stainless steel surfaces (e.g. pipes, treatment tanks, car bodies, erosion of stainless steel electrodes in e-coating tanks). However, these have not been studied in detail.

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[20] Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on End-of Life Vehicles.

Table 2.23: Cr(VI) concentration values for direct and indirect discharges of waste water from vehicle coating plants (data for 2015)

Country	Plant - discharge point	Plant type	Treatment combined (CO)/ dedicated (DE)	Type of discharge	Type of monitoring	Frequency	Type of sample	Sampling duration	Number of samples	Average (mg/l)	Maximum (mg/l)	Minimum (mg/l)	Permit ELV (mg/l)
DE	050-1	PC	DE	NI	EXT	12/yr	T	24	12	0.01	0.01	0.01	0.1
DE	047-1	PC	DE	I	EXT	52/yr	NI	NI	46	0.0101	0.01	NI	0.1
AT	066-2	VANS	DE	I	EXT	1/yr	T	24	5	0.02	0.02	0.02	0.05
DE	067-1	VANS	DE	I	EXT	4/yr	S	0.16	4	0.02	0.02	0.02	0.1
PT	061-3	PC	CO	I	EXT	12/yr	T	24	12	0.018	0.062	0.01	0.2
IT	071-1	VANS	DE	I	EXT	4/yr	S	NI	4	0.1	0.1	0.1	NO
IT	059-1	PC	NI	NI	EXT	12/yr	T	3	12	0.1	0.1	0.1	0.2
IT	070-1	VANS	CO	I	EXT	4/yr	T	3	3	0.1	0.1	0.1	0.2

NB:
NI: No information provided.
Source: [155, TWG 2016] [219, ACEA 2018]

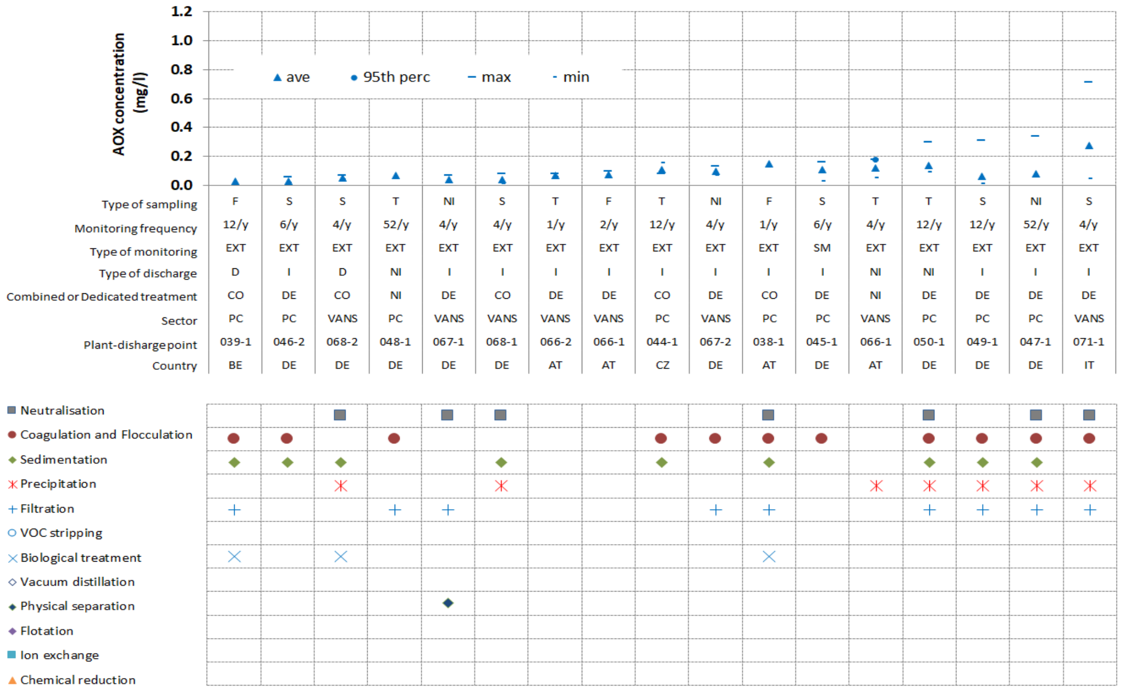
Table 2.24: Total Cr concentration values for direct and indirect discharges of waste water from vehicle coating plants (data for 2015)

Country	Plant - discharge point	Plant type	Treatment combined (CO)/ dedicated (DE)	Type of discharge	Type of monitoring	Frequency	Type of sample	Sampling duration	Number of samples	Average (mg/l)	Maximum (mg/l)	Minimum (mg/l)	Permit ELV (mg/l)
DE	068-2	VANS	CO	D	EXT	2/yr	F	2	2	0.005	0.005	0.005	0.05
DE	067-2	VANS	DE	I	EXT	4/yr	NI	0.16	4	0.004	0.006	0.003	0.5
DE	067-1	VANS	DE	I	EXT	4/yr	S	0.16	4	0.005	0.006	0.003	0.5
ES	057-1	PC	DE	I	EXT	24/yr	T	24	24	0.005	0.02	0.005	NO
DE	068-1	VANS	CO	I	EXT	4/yr	F	2	5	0.01	0.02	0.005	0.5
PT	061-3	PC	CO	I	EXT	12/yr	T	24	12	0.04	0.05	0.005	2
DE	048-1	PC	NI	NI	INT	104/yr	T	2	104	0.05	NI	NI	0.5
AT	066-2	VANS	DE	I	EXT	1/yr	T	24	5	0.05	0.05	0.05	0.5
UK	064-1	PC	DE	I	EXT	36/yr	S	24	36	0.023	0.055	NI	10
DE	050-1	PC	DE	NI	EXT	12/yr	T	24	12	0.1	0.1	0.1	0.5
IT	071-1	VANS	DE	I	EXT	4/yr	S	NI	4	0.2	0.2	0.2	NO
IT	059-1	PC	NI	NI	EXT	12/yr	T	3	12	0.2	0.2	0.2	4
IT	070-1	VANS	CO	I	EXT	4/yr	T	3	3	0.2	0.2	0.2	4
DE	047-1	PC	DE	I	EXT	52/yr	NI	NI	46	0.0148	0.24	NI	0.5
RO	062-1	PC	NI	D	INT	365/yr	S	1.15	232	0.043	0.28	0.0054	NI
ES	057-2	PC	DE	I	EXT	12/yr	T	1.5	12	< 17.44	< 50	< 0.1	NI

NB:
NI: No information provided.
Source: [155, TWG 2016] [219, ACEA 2018]

2.3.2.5.6 Adsorbable organic halogens (AOX)

Data for AOX concentration values in waste water were received for 16 plants (in total 18 discharge points). The distribution of the reported concentration values is shown in Figure 2.35.



NB: Data not shown: #058-1, average value: 5.9 mg/l

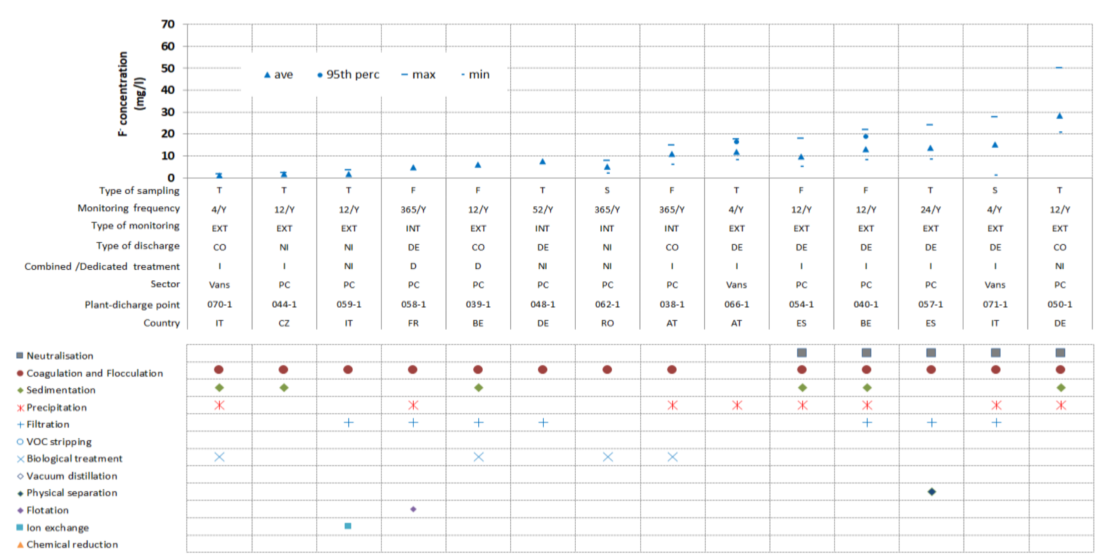
NI: No information provided.

Source: [155, TWG 2016] [219, ACEA 2018]

Figure 2.35: AOX concentration values for direct and indirect discharges of waste water from vehicle coating plants (data for 2015)

2.3.2.5.7 Fluoride (F^-)

Data for fluoride concentration values in waste water were received for 14 plants. The distribution of the reported concentration values is shown in Figure 2.36. All but one of the reported values are lower than 16 mg/l. No specific end-of-pipe techniques were identified for the removal of fluoride.

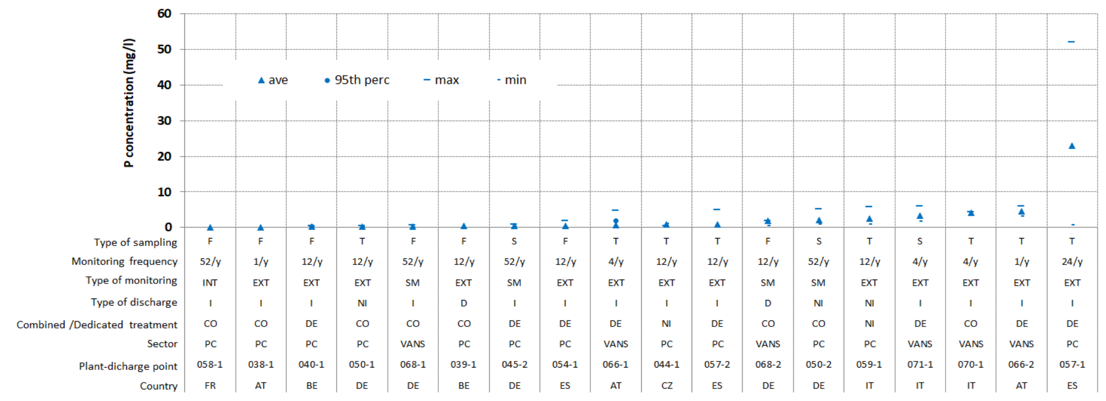


Source: [155, TWG 2016] [219, ACEA 2018]

Figure 2.36: Fluoride concentration values for direct and indirect discharges of waste water from vehicle coating plants (data for 2015)

2.3.2.5.8 Total phosphorus (TP)

Data for total phosphorus concentration values in waste water were received for 14 plants (in total 18 discharge points). The distribution of the reported concentration values is shown in Figure 2.37. For all but one of the discharge points, the reported maximum values are below 6 mg/l.

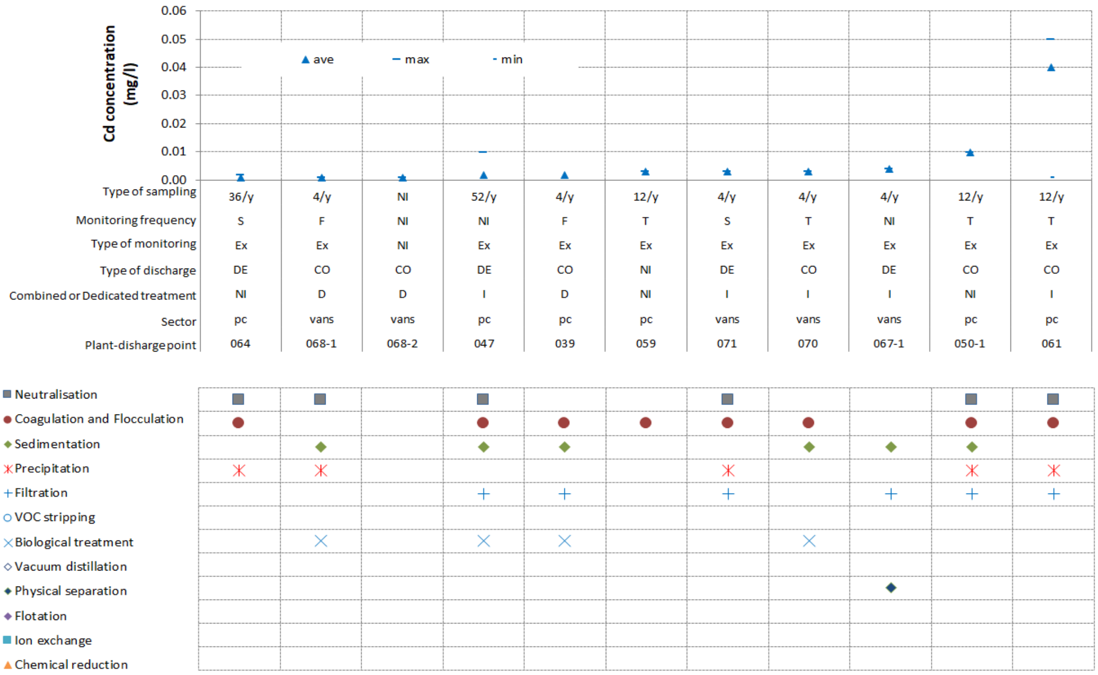


Source: [155, TWG 2016] [219, ACEA 2018]

Figure 2.37: Total phosphorus (TP) concentration values for direct and indirect discharges of waste water from vehicle coating plants (data for 2015)

2.3.2.5.9 Cadmium (Cd)

Data for cadmium concentration values in waste water were received for 11 discharge points. The distribution of the reported concentration values is shown in Figure 2.38.



Plant-dishargepoint	064	068-1	068-2	047	039	059	071	070	067-1	050-1	061
Type of sampling	36/y	4/y	NI	52/y	4/y	12/y	4/y	4/y	4/y	12/y	12/y
Monitoring frequency	S	F	NI	NI	F	T	S	T	NI	T	T
Type of monitoring	Ex	Ex	NI	Ex	Ex	Ex	Ex	Ex	Ex	Ex	Ex
Type of discharge	DE	CO	CO	DE	CO	NI	DE	CO	DE	CO	CO
Combined or Dedicated treatment	NI	D	D	I	D	NI	I	I	I	NI	I
Sector	pc	vans	vans	pc	pc	pc	vans	vans	vans	pc	pc

	064	068-1	068-2	047	039	059	071	070	067-1	050-1	061
■ Neutralisation	■	■		■			■			■	■
● Coagulation and Flocculation	●			●	●	●	●	●		●	●
◆ Sedimentation		◆		◆	◆			◆	◆	◆	
✳ Precipitation	✳	✳					✳			✳	✳
+ Filtration				+	+		+		+	+	+
○ VOC stripping											
× Biological treatment		×		×	×			×			
◇ Vacuum distillation											
◆ Physical separation									◆		
◆ Flotation											
■ Ion exchange											
▲ Chemical reduction											

Source: [155, TWG 2016]

Figure 2.38: Cadmium (Cd) concentration values for direct and indirect discharges of waste water from vehicle coating plants (data for 2015)

Almost all of the reported values are below 0.004 mg/l; only two plants reported higher values, one with a cadmium concentration value of 0.01 mg/l and the other with one of 0.05 mg/l.

Cadmium in vehicles was phased out by 2003, according to the requirements of Directive 2000/53/EC. Cadmium is a low-level contaminant of zinc compounds.

2.3.2.5.10 Phenol index

Only eight plants reported emission concentration values for phenol index, with all the values but two lower than 0.05 mg/l (one of 0.25 mg/l and another one of the order of 3.4 mg/l).

2.3.2.6 Waste generation

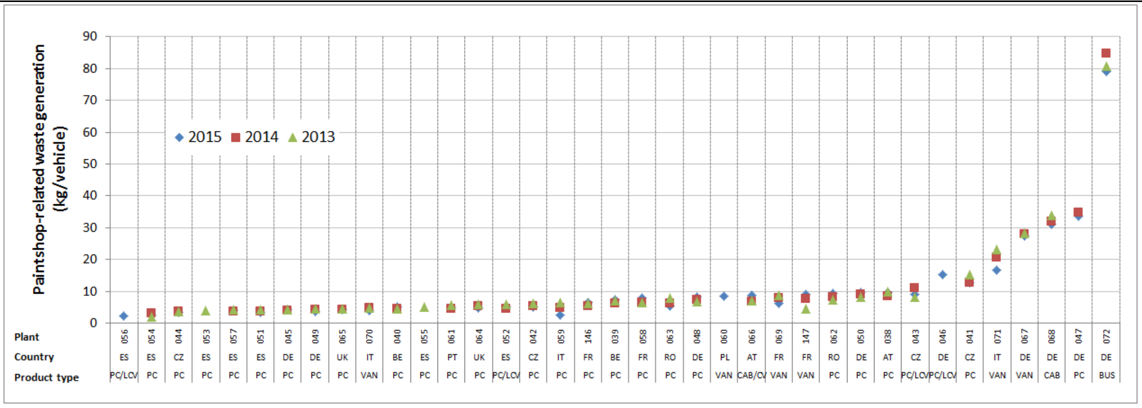
[155, TWG 2016] [142, ACEA 2016] [144, ACEA 2017] [219, ACEA 2018]

A mixture of hazardous and non-hazardous waste is generated from vehicle paint shops. An indicative list of the main types of paint-shop-specific waste reported has as follows:

- waste paint;
- plastisols, sealers, adhesives;
- used solvents;
- paint sludge;
- limestone (with paint overspray);
- filters (with paint overspray);
- other (VOCs);
- phosphate sludge;
- non-VOC sludge from the paint shop WWTP.

Further clarification on the waste types and their solvent content is provided in the following section.

Figure 2.39 shows the reported data on the paint-shop-specific waste generation (expressed in kg/vehicle) for various types of automotive paint shops.



Source: [155, TWG 2016] [144, ACEA 2017] [219, ACEA 2018]

Figure 2.39: Total waste generation values (kg/vehicle) from automotive paint shops for the period 2013-2015

The following table summarises the reported data on waste quantities generated at the automotive paint shops by vehicle type.

Table 2.25: Total waste generation data for automotive paint shops

Product type	**Reported data (1) 2015**			**Industry report (2) 2012**		
	No of plants	Average (kg/vehicle)	50 % middle range (kg/ vehicle)	No of plants	Average (kg/ vehicle)	50 % middle range (kg/ vehicle)
PC	26	7.3	4.0-8.9	59	4.59	3.16-5.91
VAN	6	12.1	6.9-14.9	8	13.4	7.9-14.0
CV/ CV-cab	2	19.9	NA	Cabs: 5	7.4	1.6-11.1
				CV: 4	7.47	NA
BUS	1	79.0	NA	6	179	70-155

NB:
NA: Not applicable/available.
(1) *Source*: [155, TWG 2016] [144, ACEA 2017] [219, ACEA 2018]
(2) *Source*: [142, ACEA 2016]

The main proposed techniques for the reduction of waste quantities sent for disposal refer to: the recovery of used solvents (one installation reported an annual recovery of 37 000 kg of solvents); the reduction of the water content of waste, e.g. by using a filter press for waste water sludge treatment; and the reduction of generated sludge and waste by reducing the number of cleaning cycles due to colour changes.

2.3.2.6.1 Solvent content of waste

[144, ACEA 2017]

The submitted data on the solvent contents of the various wastes were analysed for deriving key parameters for the relevant waste types.

The main findings are presented in Table 2.26.

Table 2.26: Solvent content of main waste types from automotive paint shops

Type	**No of samples**		**Average**	**Std. dev.**	**Min.**	**Max.**	**Median**	**> 25 %**	**< 75 %**
	All	**With solvent content in %**	**%**	**% of avg.**	**%**	**%**	**%**	**%**	**%**
Waste paint	28	18	**34.4**	66	0.4	70.0	**27.5**	12.0	50.0
Plastisols, sealers, adhesives	16	8	**3.0**	88	0.0	9.0	**2.2**	1.2	4.1
Used solvents	59	49	**61.7**	47	0.9	100.0	**65.9**	47.3	91.7
used solvents H	NA	28	**93.7**	8	75.0	100.0	**91.9**	88.3	99.8
used solvents M	NA	5	**52.8**	7	48.3	57.7	**52.6**	50.4	54.9
used solvents L	NA	16	**9.6**	78	0.0	24.0	**9.9**	3.3	16.8
Paint sludge	43	26	**4.7**	172	0.0	40.0	**2.0**	0.6	3.8
Limestone	2	1	**0.2**		0.2	0.2	**0.2**	0.2	0.2
Other (VOCs)	26	9	**10.2**	128	0.0	30.0	**1.5**	0.5	24.8
Phosphate sludge	23	2	**0.1**	NA	0.0	1.5	**0.0**	0.0	0.0
Other (non-VOCs)	59	1	**0.0**	NA	0.0	0.1	**0.0**	0.0	0.0
Not paint-shop-specific	21	2	**0.2**	NA	0.0	0.2	**0.1**	0.1	0.2

NB:
NA: Not applicable / not available

Waste paint is understood as expired paint material or paint which is to be disposed of for other reasons. Its composition resembles the composition of the new material; however, small amounts of solvents may be added on site for viscosity adjustment. In some plants, expired paints may be returned to the supplier instead of being sent to a waste disposal facility.

Plastisols, like seam-sealing materials, **adhesives** or underbody coats are usually applied after electrocoating and before spray-painting operations. Chemically, they are macromolecular materials (PVC, PU, rubber or epoxy resins, etc.) with different amounts of plasticisers, sometimes with a VOC-like volatility.

Plastisol wastes are either expired material in containers, plastic foils with droppings or stoppers with sticking sealants or underbody coats.

Used solvents are usually thinners or organic cleaning agents mixed with different amounts of paint. They are generated and collected at paint change or bell cleaning processes.

The available data show that three subtypes of used solvents with different solvent contents can be distinguished:

- ‘**H**’ high solvent concentration: median 92 %, 50 % mid range: 88 % to > 99 %;
- ‘**M**’ medium solvent concentration: median 53 %, 50 % mid range: 50 % to 55 %;
- ‘**L**’ low solvent concentration: median 10 %, 50 % mid range: 3 % to 17 %.

‘H’-type solvents are from clear coat applications or if solvent-based paints are used. ‘L’-type solvents are usually butylglycol water mixtures with water-based primer or base coat. If both types of solvents are collected in the same tank, ‘M’-type solvents are generated.

Paint overspray (paint sludge) from spray-painting operations is introduced in off-gas treatment systems for the reduction of the (paint) particle concentration in the exhaust air. Until recently, venturi scrubbers or equivalent wet scrubber systems were used in all large vehicle paint shops. In new paint shops, dry particle filters are installed and paint particles are captured either in pulverised limestone or in cardboard filter boxes.

The precipitated paint particles are removed from the water reservoir of wet scrubber systems by coagulation and sedimentation. The primary paint sludge is further dewatered using different techniques, which yield pasty (> 80 % water) or solid (< 40 % water) waste.

Solvent contents are reported to be between 1 % and 4 %, but in some cases higher concentrations are measured or calculated. In one installation (Plant #066), paint sludge with a solvent concentration of 40 % was reported, which is most probably either waste paint or a solvent paint mixture from paint change operations.

Other solvent-containing wastes

All other solvent-containing wastes fall into this group. There are solvent content data available for some of these wastes and most solvent contents are lower than 5 %, but wax residues from solvent-based cavity preservation have solvent contents between 20 % and 30 %.

2.3.2.6.2 Solvent mass flows in waste (parameter O6 of the Solvent Mass Balance)

[144, ACEA 2017]

From the submitted data, when both the amount of waste and its solvent content are reported and the total body surface of all painted vehicles is known, the waste-specific mass flow in g/m^2 is calculated. The results of this calculation are shown in Table 2.27.

Table 2.27: **Contribution of solvent-containing wastes to the solvent mass flow (parameter O6 of the solvent mass balance)**

Waste type	No of plants	Average	Min.	Max.	Median	> 25 %	< 75 %
		g/m^2					
Other (VOCs)	6	0.18	0.00	0.68	0.0	0.0	0.3
Paint sludge	23	0.91	0.00	8.68	0.3	0.1	0.6
Plastisols, sealers, adhesives	8	0.13	0.00	0.33	0.1	0.0	0.3
Waste paint	11	0.70	0.00	4.31	0.3	0.2	0.6
Used solvents	24	8.87	0.10	26.74	5.7	2.8	11.6

The data above indicate the major contribution of used solvents to the parameter O6 (solvents in waste), with mass flows between 3 g/m^2 and 15 g/m^2 for most of the cases. For most of the reported plants, used solvents carry more than 80 % of all the solvent content in the waste.

2.4 Techniques to consider in the determination of BAT for the coating of cars

In Chapter 17, general techniques (i.e. those used that are commonly used) are discussed which might also be applicable to the automotive industry. In Table 2.28, the general techniques relevant for vehicle coating that are described in Chapter 17 are shown. These techniques are not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 17.1.

The TFTEI synopsis sheet for the coating of passenger cars [147, TFTEI 2016] provides important data on the costs and benefits at the European level of primary and secondary techniques for the reduction of VOC emissions. However, the TFTEI approach necessarily has to limit its complexity and only key techniques are given without consideration of the other BAT factors, such as compatibility and cross-media effects or of the technical characteristics of individual installations and products [84, EGTEI 2005] [147, TFTEI 2016]. As an example, a retrofit of brownfield paint shops from wet to dry scrubbing - if technically achievable - would cost approximately EUR 10-20 million/line [ACEA comment #194 in [212, TWG 2018]].

Table 2.28: Reference to techniques generally applicable to the sector

Technique	Section number
Environmental management techniques	17.1
Storage and handling of raw materials	17.2
Monitoring	17.3
Water use and waste water generation	17.4
Energy management and energy efficiency	17.5
Raw material management (including substitution)	17.6
Coating processes and equipment	17.7
Drying and/or curing techniques	17.8
Cleaning techniques	17.9
Off-gas extraction and treatment	17.10
Waste water treatment techniques	17.11
Waste management techniques	17.12
Odour emissions	17.13

Unless otherwise stated, figures (e.g. g VOCs/m^2, cost, emissions, energy consumption) given in this chapter are for passenger vehicles.

A study to establish the costs and benefits of different approaches to VOC abatement in the coating of passenger cars considered the four paint shop families which covered 70 out of 74 existing high-volume car paint shops: SB, SB-MIX, WB and integrated (there are two options in SB-MIX paint shops, see Section 2.4.2.1) [147, TFTEI 2016].

Solvent emissions can be reduced by applying in-process (primary) and end-of-pipe (secondary) measures.

Possible primary measures are as follows [147, TFTEI 2016]:

- improved solvent management (for example collection of solvent);
- optimisation of cleaning cycles;
- improvement of transfer efficiency and application technology.

Various single techniques can be used in several or all steps of the coating process and usually a combination of techniques is used.

An evaluation of the emission reduction of possible primary measures is presented in Table 2.29 (with the range in square brackets).

Table 2.29: VOC emission reduction - primary measures (case studies)

Primary measures	Reduction of VOC emissions (g/m^2)	Number of sites for data collection
Collection of solvents	2.4 [0.5-4.5]	5
Optimisation of cleaning cycles	0.6 [0.05-1.8]	6
100 % automation of primer, base coat, clear coat	1.2 [1.1-1.2]	2
Optimisation of colour change technology (base coat)	0.5 [0.07-1.1]	4
Innovative application technology (e.g. bell-bell)	0.8 [0.6-1]	2
100 % automation of interior coating, with rotational bell atomisation and low-loss colour changers (base coat, clear coat)	2.6 [0.8-6]	2
Replacement of pneumatic guns application with robots by electrostatic bells (base coat)	0.23	1

Source: [147, TFTEI 2016]

It is noted that it may not be possible to deduce the maximum achievable VOC emission reduction by summing up all possible different primary measures for two reasons:

- The specific emissions reduction effect of each single measure is different for each process step and paint system used.
- Not all primary measures can be combined; some measures are mutually exclusive.

Secondary measures considered in [147, TFTEI 2016] for vehicle paint shops are:

- thermal oxidation of VOCs in off-gases from ovens and/or spray booths without pre-concentration of VOCs;
- pre-concentration of VOCs with an adsorption technique followed by thermal oxidation of VOCs.

The estimated potential emission reduction as well as the calculated total VOC emissions from the application of secondary measures are presented in Table 2.30 (with the range in square brackets).

Table 2.30: Estimated VOC emission reduction and calculated total emissions (g/m^2) for the application of secondary measures (case studies)

Reference installations	1 *SB*	2 *SB-MIX*	3 *WB*	4 *Integrated process*
VOC emission (g/m^2) without air treatment (I1-O6-O8)	59.3 [42.9-95.2]	38.7 [35.0-44.0]	32.5 [25.0-42.3]	23.5 [17.9-31.9]
Potential VOC emission reduction with implementation of air treatment in ovens/dryers (g/m^2) O5 air treatment on dryers/ovens	11.2 [9.0-16.6]	5.8 [1.5-8.0]	9.7 [6.1-15.3]	7.1 [4.1-12.5]
VOC emission with air treatment (ovens/dryers) (g/m^2) (I1-O5-O6-O8)	55.3 [38.0-78.6]	32.9 [27.0-36.0]	22.8 [18.9-28.5]	16.4 [13.0-25.3]
Potential VOC emission reduction with implementation of air treatment in ovens/dryers and spray booths (g/m^2) O5 air treatment in dryers/ovens and spray booths	14.6 [10.0-19.2]	14.0	11.6	1.5
VOC emission with air treatment (ovens/dryers + spray booths) (g/m^2) (I1-O5-O6-O8)	30.3 [23.7-37.0]	17.0 [12.5-23.5]	8.8 [6.0-11.8]	19.3 [12.4-26.1]

Source: [147, TFTEI 2016]

2.4.1 Solvent mass balance of motor vehicle paint shops

[143, ACEA 2017]

Description
For a general description, see Section 17.3.1.

Solvent mass balances (SMBs) are a tool to calculate total emissions of organic solvents from industrial installations. The results are expressed - in general - as total emissions of x kg organic solvents from the whole installation (E) and - in the case of coating of new motor vehicles - as relative total emissions (Er) in g per m^2 surface area of the products which are painted in this installation. The reporting and averaging period is 12 months for demonstration of compliance with emission limit values (ELV). SMBs may be calculated for shorter intervals, e.g. as an internal management tool to identify process deviations that may lead to a violation of the ELV.

A detailed description can be found in Annex 21.5.1.

2.4.2 Selection of coating system (paint shop type, 'paint shop family')

[143, ACEA 2017] [155, TWG 2016] [212, TWG 2018]

The basis for the types of paint shop families is explained in Sections 2.2.3.8 and 2.2.3.9.

The technical differences between SB and WB paint shops are indicated in Section 2.2.3.8, which demonstrates that changing from SB to WB is far more complex and costly than a simple substitution.

A classical high-solvent-content SB paint shop system can be regarded as the 'conventional' case, as it is unlikely that a new paint shop being built, or an existing paint shop being rebuilt, would be a high-solvent-content SB system. SB paint shops are to be considered only in combination with high-solids SB paint/coating systems (see Section 2.4.3.3). Reported data and information from SB paint shops for the coating of passenger vehicles show an average value of 45.5 g VOCs/m^2 with a total emission range from 36.8 g VOCs/m^2 to 50.2 g VOCs/m^2; all values are averages over the three-year reference period (2013-2015) [155, TWG 2016].

2.4.2.1 Solvent-water mix (SB-MIX) coating system

Description
Coating system where one coating layer (primer or base coat) is water-based.

Technical description
Where these changes are implemented, they are most frequently restricted to only one subprocess (primer or base coat). This type of paint shop is then called a SB-MIX paint shop.

Achieved environmental benefits
Reduction of VOC emissions.

Environmental performance and operational data
An average value of 29.9 g VOCs/m^2 is reported from SB-MIX paint shops for the coating of passenger vehicles. The reported range is 15-39 g VOCs/m^2; all values are averages over the three-year reference period (2013-2015) [155, TWG 2016].

Solvent emissions can be reduced by applying in-process (primary) and end-of-pipe (secondary) measures.

Technical considerations relevant to applicability
Only applicable to new plants or major plant upgrades. It is not possible to change from solvent-based to water-based technology on existing paint shop lines unless a new paint shop is built or a paint shop line for one coating layer is upgraded. In the case of an existing plant, there would need to be enough room to build a second paint shop (or paint shop line) in parallel without interrupting the existing one.

Example plants
More than 25 % of all paint shops in the EU are WB paint shops (see Table 2.7, Section 2.2.3.8).

Reference literature
[147, TFTEI 2016] [155, TWG 2016] [201, ACEA 2016]

2.4.2.2 Water-based (WB) coating system

Description
Coating system where the primer and base coat layers are water-based.

Achieved environmental benefits
Reduction in solvent usage and emissions from the process.

Environmental performance and operational data
An average value of 16.9 g VOCs/m^2 is reported for 12 WB paint shops for the coating of passenger vehicles. The reported range is 7.1-25.8 g VOCs/m^2; all values are averages over the three-year reference period (2013-2015), however the basis for the lowest figure is not clear [155, TWG 2016].

Solvent emissions can be reduced further by applying in-process (primary) and end-of-pipe (secondary) measures.

Cross-media effects

Some technical arguments (paint application window, longer dryer ovens, see Section 2.2) suggest that the use of water-based coats will result in higher energy consumption. At locations with high humidity and high values for cooling degree days (CDD), stricter paint cabin conditions for WB paints may lead to a higher energy demand compared to SB paint shops. However, available data from paint shops operated in the EU do not show significant differences between SB and WB paint shops.

There are increased space requirements for longer spray booths, which results in larger air volumes that need to be conditioned.

Technical considerations relevant to applicability

Only applicable to new plants or major plant upgrades. It is not possible to change from solvent-based technology to water-based technology on existing sites unless a new paint shop is built. There would need to be enough room to build a second paint shop (or paint shop line) in parallel without interrupting the existing one.

Economics

Switching the primer and the base coat from solvent-based (SB) to water-based (WB) coating (data from one plant) implies the following costs:

- investment cost: EUR 128 million;
- annual cost: EUR 11.5 million/year;
- cost per unit: EUR 0.593/year/m^2;
  EUR 57.9/year/car body,

assuming 97 m^2/car body and 200 000 cars/year [210, TFTEI 2017].

Example plants

More than 50 % of all paint shops in the EU are WB paint shops (see Table 2.7, Section 2.2.3.8).

Reference literature

[147, TFTEI 2016] [155, TWG 2016] [201, ACEA 2016] [210, TFTEI 2017] [212, TWG 2018]

2.4.2.3 Integrated paint shop (IP) coating system

Description

A coating system which combines the functionalities of primer and base coat and applies them by spray coating in two steps.

Technical description

Sometimes these coating concepts are called ‘compact process’, because no primer dryer is required.

Some installations utilise a functional base coat first layer. A functional base coat layer combines the functional properties of a primer layer but has the appearance properties of the base coat layer which will be applied over it.

Achieved environmental benefits

Significant savings in space and energy consumption.

Environmental performance and operational data

Without additional VOC emission reduction measures, the VOC value is 20.5 g/m^2. The range given is 8.9-32.1 g VOCs/m^2 (see also Table 2.17), however the basis for the lowest figure is not clear [147, TFTEI 2016].

Cross-media effects

None

Technical considerations relevant to applicability

Only applicable to new plants or major plant upgrades. Due to multiple technical constraints, these integrated processes are difficult to install in existing installations.

Economics

The costs for changing a new paint shop (SB) to the integrated process (data from two plants), i.e. switching the base coat from solvent-based to water-based and removing the primer, are:

• investment cost:	EUR 52.7 million;
• annual cost:	EUR 4.7 million/year;
• cost per unit:	EUR 0.244/year/m^2; EUR 23.7/year/car body,

assuming 97 m^2/car body and 200 000 cars/year [210, TFTEI 2017].

Driving force for implementation

Energy and space savings.

Example plants

Approximately 17 paint shops in the EU (2014).

Solvent-based high-solids: CNHI (commercial vehicles and vans); Daimler: Abrantes/Tramagal (truck cabins); PSA Hordain (passenger cars/LCV).

Water-based: BMW: Dingolfing, Cowley/Oxford; Daimler: Rastatt, Kecskemet, Hambach; FCA: Atessa; PSA: Trnava, Sochaux; VW: Bratislava(H2a), Pamplona.

Reference literature

[147, TFTEI 2016] [210, TFTEI 2017] [265, TWG 2019]

2.4.2.4 Wet-on-wet-on-wet coating (three-wet)

Description

Wet-on-wet-on-wet coating replaces a conventional three-coat (primer, base coat, clear coat) two-bake (primer, topcoat) process with a process where materials are applied wet on wet onto the previous layer with one final bake at the end.

Technical description

In conventional two-coat topcoating, a primer coat is applied and then baked in an oven, before a colouring base coat is applied then subsequently covered with clear coat and baked again.

Three-wet processes can be operated with solvent-based or water-based coats. Some installations utilise a conventional primer-type first layer.

Achieved environmental benefits

- Less energy consumption compared to processes with a primer oven.
- Smaller factory footprint (smaller paint shop).

The environmental benefits vary depending on the process and materials used prior to any conversion.

The primer oven is no longer required to bake the primer layer. However, in a wet-on-wet process, any body sealer, wet-applied NVH (noise, vibration, harshness) material or anti-stone-chip material should be fully cured prior to entering the wet-on-wet application. Therefore, during some conversions to wet-on-wet application, where only a sealer gel oven is used, a sealer bake oven is required to fully cure these materials before the wet-on-wet application.

Environmental performance and operational data

Solvent-based three-wet processes require less space than water-based ones, as no forced flash-off is required. Compared to a conventional water-based paint shop, the overall booth length can be reduced by 30-40 % in a solvent-based three-wet plant.

Due to the smaller footprint of the operation, a smaller air volume needs to be moved and conditioned, resulting in reduced energy consumption. Further energy savings for air conditioning can be achieved in solvent-based three-wet operations, where no forced water flash-off zone is needed and a wider range of climatic conditions are tolerated. The less strict temperature and humidity requirements for solvent-based three-wet processes are especially important in countries with extremely low or high ambient temperatures.

The higher VOC concentration in the oven exhaust air and booth exhaust air of solvent-based systems has a beneficial effect on the energy consumption of the abatement system. The higher VOC concentration supports the combustion in the oxidiser and depending on the concentration may sustain combustion (‘fumes to fuel’). The heat is usually recovered and used for heating the dryers.

The increased line speed results in a reduced production time of 20 % per vehicle.

Cross-media effects

None.

Technical considerations relevant to applicability

Only applicable to new plants or major plant upgrades.

There are numerous space constraints on existing automotive sites. Three-wet solvent-based technology has a small footprint and can therefore be established on existing sites more easily than other modifications or such drastic changes as a material type change. In an operational plant, modifications can only be made during the short 2- to 3-week shutdown periods in summer or winter. This limits the extent of changes that are possible.

Economics

A solvent-based three-wet process has the potential to be retrofitted into existing installations, although for some sites the benefits of the reduced plant footprint do not outweigh the cost of conversion. For an example plant, the total investment for a new paint shop line with a three-wet process was estimated at more than EUR 85 million [256, COM 2018].

Driving force for implementation

See Achieved environmental benefits above.

Example plants

Solvent-based high-solids: Ford, Craiova.

Water-based: Nissan, Sunderland (new line); Renault, Valladolid.

Reference literature

[183, ACEA 2017] [256, COM 2018] [265, TWG 2019]

2.4.3 Material-based techniques

2.4.3.1 Water-based paint systems

Description
Water-based paints have a low content of VOCs. They are used as electrocoat, primer and base coat.

Technical description
For automobile volume paint shops, water-based paints are used as an electrocoat, primer and base coat.

In electrocoating, the application of water-dilutable or water-dispersible paints uses materials with a solvent content of 2-4 %. Electrocoating materials are delivered in a closed system and applied using dipping techniques.

Conventional water-based systems contain the following solvent contents: 5-12 % in the primer and 12-17 % in the base coat. Primer and base coat materials are delivered in a closed system and applied using spraying techniques.

Water-based paints contain water as the main solvent plus organic co-solvents. Binder systems used are polyurethanes, polyesters, acrylates and melamine resins. The organic co-solvents are necessary for achieving qualities such as optimum spread properties, dissolving capacity and adherence of different substrates as well as a sufficient application window.

Achieved environmental benefits
The main advantage of water-based paints is the reduction of VOC emissions.

Typical VOC emission factors for the water-based phases of the paint shop include 0.6-1 g/m^2 for the electrocoat, 0.5-2 g/m^2 for the primer and 3-7 g/m^2 for the base coat with no emission controls.

Cleaning of spraying devices and other tools can be carried out with water/solvent mixtures with a solvent proportion of about 5-20 %. In some cases, the cleaning material can be solvent-free.

Another advantage is that there are no flashpoint hazards associated with this paint, minimising the risks of combustion and explosion[21].

Environmental performance and operational data
The average energy consumption in water-based paint shops that participated in the data collection exercise is 0.96 MWh/vehicle (average from nine paint shops for the period 2013-2015 with 50 % mid-range: 0.7-1 MWh/vehicle). For data on specific processes, see Section 2.3.1.1. Influences on operations include production volume, local climatic conditions, abatement techniques used, air volume requirements, length of booths, and booth operating criteria such as temperature and paint application techniques.

Cross-media effects
Compared to organic solvents, water has higher evaporation energy. Therefore, the energy demand for the drying of water-based paints may be expected to be higher if the same drying rate as for solvent-based paints has to be achieved. However, compared to atomisation,

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[21] Pidioll, U.; Ignitability of Spray Clouds of Organic Solvents, Solvent/Water Mixtures, and Water-Based Paints by Electric Sparks, Arcs, and Open Flames; IEEE Transactions on Industry Applications (Volume: 44, Issue: 1, 2008, p. 15-19) DOI: 10.1109/TIA.2007.912764.

acclimatisation of spray booths, heating of substrates, oven losses, etc., the energy demand for evaporation of volatile compounds is only in the range of 1-2 % for many industrial processes. Water, instead of organic solvents, has a minor impact on total process energy. The additional energy requirement is only significant for drying in ambient conditions.

There is higher energy consumption in the booth, due to the assisted flash-off, and the increased space and associated air volume that needs to be handled. Also, stricter cabin conditions with regard to humidity and temperature control may result in additional energy demand depending on the local climatic situation.

Technical considerations relevant to applicability
Water-based materials can be used as the electrocoat, primer and base coat and in some repair operations. They can be used on metals and plastic materials and are widely used. Due to the continuous development of these materials, their range of application is steadily increasing.

Water-based clear coats are not used for cars due to their poor appearance and quality.

Due to considerable differences in paint shop design, a change from solvent-based to water-based spray coats cannot be made without radical modification of the paint shop. In existing sites, changing from a solvent-based to a water-based system can be done only if there is room to build a second paint shop (or paint shop line) in parallel without interrupting the production in the existing one, and where the new paint shop can be linked to the body shop and to the assembly shop. Due to these constraints, such a transformation is very expensive and is rarely made.

There are difficulties in retrofitting water-based systems into conventional solvent-based paint shops due to cost and physical constraints, e.g. assisted flash-off zones or stainless steel pipes (see Economics below). Water-based booths have to operate under tighter temperature and humidity controls. Because water must be completely evaporated before the substrate temperature reaches 100 °C, the heating curve is flatter for water-based paints compared to solvent-based paints. Therefore the dryer oven must be longer or the line speed is reduced.

Economics
Costs for changing existing automated painting lines may be very high in some cases. The need for extended ovens with intercoat flash-off zones to meet additional curing requirements means that paint shops designed and installed for solvent-based systems may not have the space to accommodate a water-based system. Other requirements are that the paint supply pipes and systems are made of stainless steel. Retrofitting is usually done at the end of the technical lifespan of the existing installation. Additional costs associated with the operational requirements, materials and equipment installation mean that water-based systems are often restricted to new paint shops or those already equipped with the necessary systems.

Due to the increased volumes used, water-based paints have become cheaper than solvent-based paints.

Driving force for implementation
Possible reduction of off-gas treatment.

Example plants
More than 50 % of all paint shops in the EU are WB paint shops (see Table 2.7, Section 2.2.3.8).

Reference literature
[5, DFIU et al. 2002] [78, TWG 2005] [183, ACEA 2017] [201, ACEA 2016]

2.4.3.2 Powder coating – conventionally cured

Description

Solvent-free coatings consisting of powder with a particle size in the range of 25-60 µm. Powder coatings are cured in conventional (convection) high-temperature ovens.

Technical description

Powder coatings are solvent-free systems that require electrostatic application procedures and are, therefore, primarily suitable for metal bodies. Powder coatings are typically based on acrylic resins with either an acid or an anhydride. They can be used in primer or clear coat applications. Powder application takes place in a purpose-built spray booth with downdraft and exhaust ventilation and can be by automatic electrostatically assisted spraying or manual spraying applications. See also Section 17.7.2.6.

Achieved environmental benefits

- Almost free of solvent emission.
- Low waste generation.
- Application of electrostatically assisted spraying reduces recapture of overspray paint particles by water.
- Simplification of cleaning of tools and booths (vacuum cleaning, compressed air).
- High application efficiency.

Environmental performance and operational data

Powder coat technology has zero VOC emissions and does not require water use for dust abatement. The use of reclaimed powder enables material reuse of up to 97 %.

Cross-media effects

- Loss of energy generation due to solvent oxidation. High curing temperatures are required.
- There are possible health risks due to the use of some mutagenic substances.

Technical considerations relevant to applicability

Only one plant was in operation in Europe in 2007. In general, the colour and finish achieved with this technique do not meet most European manufacturers’ quality standards.

The powder paint technique allows reduced reprocessing of the spray booth air compared to conventional installations. There have been problems with a yellowish colouration of the clear coat application in the final product. The main problem is that control of the film thickness is difficult: a greater layer thickness will be created than is necessary (approximately 65 µm), which results in higher paint consumption; however, increasingly nowadays, thinner layers (approximately 55 µm) are also achievable.

Experience from the PSA Mulhouse plant shows that, after many years of testing, quality levels did not reach the quality standards expected by European customers. The price of powders never falls because of lack of deployment (only a few production lines in Europe). The viability of installations remains below the conventional levels of other painting production lines.

It has also been found that lines without the primer coat step (integrated process) give better results than the powder production line, in terms of economics and/or quality level. The overall VOC emissions of the two technologies are within a similar range.

Economics

When changing from existing solvent technology to retrofitting powder technology, high capital costs are involved, because powder technology is a completely different technology and requires a total refit of facilities, equipment and materials. However, a reduction of operating costs can be observed; present estimations describe a reduction of at least 12 % in energy costs over either water-based or solvent-based systems with abatement costs.

Driving force for implementation

- Reduction in costs due to reduced VOCs and waste water treatment.
- Reduced waste treatment costs.

Example plants

The technique is not currently applied in European plants for the coating of passenger cars or vans. It is used in some installations for the coating of trucks and truck cabins. It was used in the past in BMW AG in Dingolfing, Germany and the PSA Mulhouse plant but now it is no longer in use (see also Section 17.7.2.6) [ACEA comment #215 in [212, TWG 2018]].

Reference literature

[5, DFIU et al. 2002] [27, VITO 2003] [38, TWG 2004] [78, TWG 2005] [212, TWG 2018]

2.4.3.3 High-solids solvent-based paints

Description

For a general description, see Section 17.7.2.1. This technique refers to high-solids solvent-based paint applied as base coat and topcoat.

Technical description

With modern solvent-based very-high-solids paints, the same VOC to solids ratio as with water-based paints can be achieved. High-solids solvent-based paints typically have double the solids content of medium-solids (MS) solvent-based or standard water-based (WB) paints (HS base coat: 35-45 % solids, MS SB or standard WB: 18-22 % solids) [219, ACEA 2018]. The solids in the paint make up the final paint layer, hence one litre of high-solids paint can replace two litres of standard paint. High-solids solvent-based paints typically contain 20-35 % less VOCs than conventional solvent-based paints (HS 55-65 % VOCs vs MS 78-82 % VOCs), which means that for each litre of paint used less VOCs are released compared to a medium-solids paint.

For more information on the various types of high-solids coatings, e.g. medium-solids (MS), high-solids (HS) ultra-high-solids (UHS) and their use in vehicle coating, see Section 2.2.3.8 and Table 2.5.

Achieved environmental benefits

- The use of high-solids paints reduces solvent use compared with conventional, solvent-based paints, while still applying the requisite amount of coating.
- Reduction of solvent consumption and emissions.
- Less energy consumption compared to water-based paints.

Environmental performance and operational data

With the utilisation of high-solids solvent-based paints, the same coating effect as with conventional solvent-based paints can be achieved but with less paint volume and therefore less VOC release. Water-based paints usually also have a lower solids concentration, so the difference in VOC load emissions is less than the difference in VOC concentration between the two paint types, as more WB paint needs to be applied to achieve the same coating.

Stainless steel equipment in paint supply equipment and application is not required unlike in the case of WB paints.

Solvent-based systems achieve high-quality outputs in a wider range of climatic operational conditions compared to water-based paint systems. Therefore, less energy is needed to heat or cool the booth air, and to adjust the humidity. This is especially important in countries with extremely high or low temperatures.

Solvent-based materials do not require a forced flash-off before the oven. This saves space and therefore air volume to be conditioned plus the energy required for the forced flash-off. In a solvent-based paint shop, the flash-off between base coat and clear coat takes only 90 seconds. In a water-based paint shop, the flash-off takes 10 minutes and the vehicle needs to be brought from ambient temperatures to about 60-80 °C and then cooled again to ambient temperature. In the enamel zone, 36 % more air needs to be moved in a WB paint shop. As a result, the direct energy requirements for each vehicle body are lower for solvent-based systems.
The higher VOC concentration in the oven exhaust air and booth exhaust air of solvent-based systems has a beneficial effect on the energy consumption of the abatement system. The VOCs support the combustion in the oxidiser, and depending on the concentration may sustain combustion (‘fumes to fuel’). The heat is usually recovered and used for heating the dryers.

Cross-media effects
Solvent-based paints are more likely to require off-gas treatment system compared to water-based paints. However, water-based paints still contain VOC solvents and the clear coat is usually solvent-based, so water-based systems will also require energy-intensive abatement.

VOC abatement is usually done with oxidisers which generate secondary emissions of carbon monoxide and nitrogen oxides.

Technical considerations relevant to applicability
Solvent-based paints can be used in all phases of the painting operation (primer, base coat, clear coat and repair), and can be used on metals and plastics. They can be applied in new and existing paint shops where space is limited and where changes in the paint materials may not be technically possible.

Economics
Conversion to high-solids solvent-based paints can be achieved without loss of production in existing sites, as it can usually fit into the same plant footprint. Investment costs for a solvent-based plant are significantly lower compared to water-based systems. The plant footprint is smaller, air conditioning can be sized to allow for a wider range of climatic conditions, mild steel can be used and the vehicle throughput is high.

High-solids solvent-based paints are cheaper than water-based paints on a per solids basis; however, this is strongly dependent on the market conditions.

The solvent-based technology can also be applied globally due to its reliability, which is an important factor for international companies. Commonality of processes and materials is an important factor to achieve economies of scale and reduced product development testing.

Driving force for implementation
Automotive manufacturers in the EU operate on sites that have been established sometimes up to 100 years ago. There are numerous space constraints, inside and outside the paint shop. Approximately 35 % of all passenger car paint shops and 65 % of commercial vehicle paint shops (vans, trucks, truck cabins and buses) in the EU currently use solvent-based primer and/or base coat. High-solids solvent-based paints can be retrofitted into an operational plant, where modifications can only be made during the short 2- to 3-week shutdown period in summer or winter.

Example plants
Ford, Europe, see Section 2.2.

Reference literature

[142, ACEA 2016] [212, TWG 2018] [219, ACEA 2018]

2.4.3.4 Cavity preservation with flood wax

Description

Additional corrosion protection of inner surfaces of cavities is achieved with thin films of hot wax or cold wax in a flooding process.

Technical description

Hot wax

This consists of solid paraffin wax, which is liquefied by heating to 120 °C. The typical chemical composition is 80 % paraffin wax, 0 % additives, 13 % mineral oil (with high boiling points). The solid wax is heated and kept in a storage tank at 120 °C.

The car body is positioned on a flood frame which is equipped with a series of connecting tubes, one for each cavity. The tubes are tightly pressed on the body's cavity bores and a measured amount of hot wax is pumped into the cavities until they are completely flooded. When the flooding is completed, the excess wax is allowed to flow back on a collecting tray and is reintroduced into the process. The body is preheated to 50-80 °C to avoid rapid cooling and solidification of the wax which would lead to unnecessarily thick wax layers.

Cold wax

Composition: No information provided.
The application is carried out at room temperature, and solidification of the liquid film is achieved by oxidation with ambient air.

Achieved environmental benefits

- Prevention of VOC emissions.
- Energy savings (cold wax).

Environmental performance and operational data

- Material consumption (kg/unit): No information provided.
- Energy consumption for heating (wax and car body) (kg/unit): No information provided.
- Adverse effects due to wax aerosols (closed cabins, ventilation necessary).

Cross-media effects

Energy demand for liquefying the wax and body preheating.

Technical considerations relevant for applicability

- Only applied for car plants with a high production volume as the construction of flood frames is very expensive.
- Bodies must be designed for spray flooding.
- Not applied for coating of trucks, truck cabins and buses.

Driving force for implementation

Quality improvement compared to manual spray application.

Example plants

Hot wax: Volkswagen, Audi, Seat, Skoda, Porsche plants in Europe.

Reference literature

[ACEA comment #388 in [212, TWG 2018]]

2.4.3.5 Cavity preservation with water-based wax emulsion

Description

Additional corrosion protection of inner surfaces of cavities is achieved using solvent-free wax formulations other than hot wax.

Technical description

Materials

- Low-tech water-based wax.
- High-tech water-based wax.

Application method

For every cavity there is at least one application hole for introducing the wax material by nozzles (40-50 such holes in a body). The material is applied with spray nozzles which are adapted to each cavity in order to achieve a complete spray film without spray shadows. Application can be done manually or automatically (see Section 2.4.4.3).

To remove water or for cross-linking of the wax components, the bodies are transferred in ovens.

Achieved environmental benefits

Reduction of consumption and emission of VOCs.

Environmental performance and operational data

- Material consumption (kg/unit): No information provided.
- Energy consumption for heating (and/or other processes like ventilation) in MWh/unit: No information provided.

Cross-media effects

Higher energy consumption compared to solvent-based cavity wax.

Technical considerations relevant for applicability

- Flexible; can be applied even at multi-model lines and in low-volume paint shops.
- Not applied for coating of trucks, truck cabins and buses.

Driving force for implementation

Quality improvement.

Reference literature

[ACEA comment #388 in [212, TWG 2018]]

2.4.4 Techniques and equipment for the application of paint and other coating materials

The following paint application techniques and equipment are commercially applied:

- electrocoating, see Section 17.7.3.6 and Section 2.2.3.2.1;
- high-volume low-pressure (HVLP) spraying, see Section 17.7.3.10;
- electrostatically assisted high-rotation discs and bells, see Section 17.7.3.11;
- electrostatically assisted compressed air, airless and air-assisted spraying, see Section 17.7.3.12;
- automated spray application of cavity wax, see Section 2.4.4.3.

2.4.4.1 Automated coating spray application using painting machines

Description
Several spray heads (atomisers) are mounted on a beam construction that is mounted laterally (left and right) and/or above the floor. The spray heads can be moved along the beams to a limited extent.

Technical description
Painting machines are side and roof machines (roof machines in the shape of gantry machines). They have one or more freely programmable arms with application devices that can be moved transversely to the conveyance direction and follow the contours of the bodyshell.

Usually, pneumatic atomisers or high-rotation bells with electrostatic charge are used as atomisers.

For painting, the body passes slowly through this beam construction and is successively painted from front to back. Alternatively, the three beams can also be moved along the stationary body.

Source: [169, VDI 2013]

Figure 2.40: Automated paint application using painting machines

Achieved environmental benefits
Compared to the manual spray application, the main advantages are:

- reproducible painting process;
- no restrictions with regard to maximum workplace concentrations of VOCs.

Environmental performance and operational data
Disadvantages compared to manual application and robot application are:

- only the outer contour of the body can be painted;
- a group of 9-12 individual atomisers is required for the application of the paint, which increases the consumption of paint and rinse thinner.

Technical considerations relevant for applicability
Applicable to existing plants for the coating of passenger cars, vans and truck cabins. Paint machines cannot be used for interior coating.

Driving force for implementation
Reduction of labour costs and better quality.

Example plants
Widely used especially in old existing plants across Europe.

Reference literature
[169, VDI 2013] [212, TWG 2018]

2.4.4.2 Automated coating application using robots

Description
For spray application, a single atomiser is attached to a multi-axis robot. Robots are also used for the application of sealants.

Technical description
Usually, pneumatic atomisers or high-rotation bells with electrostatic charging are used as atomisers. For each working sequence three or four robots are used, which work simultaneously.

In modern robots, the device for changing the colour or for rinsing is integrated in one of the robot axes. Alternatively, the respective paint can also be prepared as required in cartridge filling stations next to the robot. To change colours, the robot approaches this station and replaces the empty one with a full cartridge.

Achieved environmental benefits
Automated operation of robots ensures a paint layer application with optimal coating thickness and reduced overspray that does not need any reworking.

Compared to the machine spray application (see Section 2.4.4.1), the main advantages are:

- interior painting is also possible;
- the atomisers can be guided very precisely along the bodywork, thus achieving a high degree of application efficiency;
- fewer atomisers are required for painting (reduction of paint and rinse thinner quantities when changing colour or cleaning).

When robots are used in the application of sealing and damping materials, the tolerance of the required coating thickness can be reduced, resulting in a material saving of about 5-10 %

compared to manual application. In addition, process reliability is typically higher which considerably reduces rework [169, VDI 2013].

Environmental performance and operational data
The use of robots is necessary for the use of atomisers with high transfer efficiency, like rotating bells with electrostatic charging.

Technical considerations relevant for applicability
Applicable to new and existing plants for the coating of passenger cars, vans and truck cabins.

Economics

- Higher investment costs compared to coating machines.
- Not profitable with low quantities or very strongly varying geometries.

Driving force for implementation
Reduction of labour costs and better quality.

Example plants
Robot spraying systems are considered standard in systems for painting passenger cars, vans and truck cabs. They are also applied in the coating of other metal and plastic surfaces.

a) *Source*: [169, VDI 2013]

b) *Source*: Renault Douai, FR [169, VDI 2013] [181, COM 2017]

Figure 2.41: a) Automated paint application using robots and b) automated sealant application using robots

Reference literature
[169, VDI 2013] [212, TWG 2018]

2.4.4.3 Automated spray application with cavity wax

Description
Corrosion protection wax is applied to the inner surfaces of car body cavities with automated spray processes with control of wax consumption.

Technical description
The liquid material is sprayed (airless at 100-130 bar, or airmix with a lower pressure), into the bores of the body cavity. For each cavity there is at least one application hole for introducing the nozzles (typically 40-50 such holes in a body). The nozzle-holders and the arrangement of the different nozzles at the nozzle head are adapted to each cavity in order to achieve a complete and even spray film without spray shadows. Reproducible dosing is achieved by preprogramming the volume applied (‘time spray’).

Two types of automated application systems may be used [169, VDI 2013]:

- Nozzles mounted on a multiple-nozzle carrier. The carrier is moved to the bores and spraying is carried out simultaneously. With this method a high production rate can be achieved, provided all bores can be reached simultaneously with one or several nozzle carriers.
- Several pneumatic fold-out nozzles are arranged in a nozzle-exchange head. A robot retrieves the required nozzle head, applies it to the corresponding cavity and replaces it, if the specific cavity requires another nozzle type. At least one robot per side is required.

Spraying is at room temperature. Depending on the material type applied, film building and drying is enhanced by heating the bodies in convection or IR dryers.

In a new process, the material is nebulised in very fine particles (< 15 µm) at moderate speed which fill the cavity volume by turbulent and diffuse propagation.

Achieved environmental benefits
Lower material consumption and waste generation compared to manual application.

Environmental performance and operational data
Can be used with several material types.

Cross-media effects
None.

Technical considerations relevant for applicability
The technique is applicable to passenger car paint shops. Depending on body type, application with robots offers higher flexibility with regard to multi-model processing, whereas nozzle carriers have advantages if high production rates are demanded.

Driving force for implementation
Product quality.

Reference literature
[169, VDI 2013] [ACEA comment #390 in [212, TWG 2018]]

2.4.5 Minimisation of raw material consumption

The following techniques are commonly applied:

- batch painting/colour grouping, see Section 17.6.2.1;
- pig cleaning systems, see Section 17.2.4.2;
- low-loss paint changers, see Section 2.4.5.1;
- robot application of coatings and sealants, see Sections 2.2, 2.4.4.2 and 17.2.5,

and other solvent management and reduction methods.

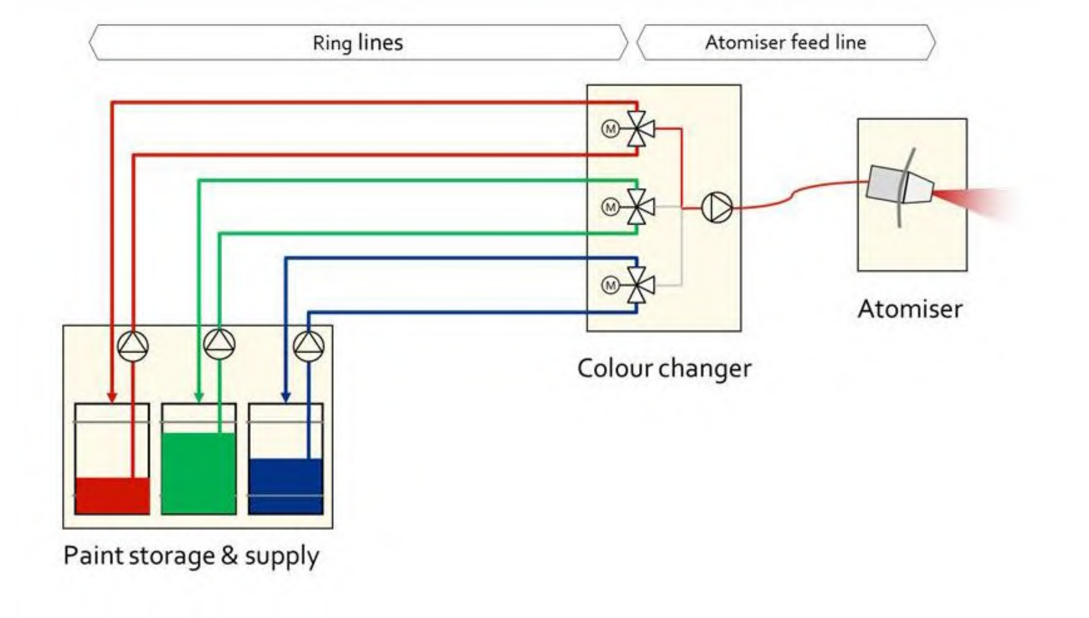
2.4.5.1 Low-loss paint change and purge systems

Description
Paint is pumped from the paint supply centre to the spray booths by steel ring lines, where each line is dedicated to one paint type.

Technical description
Coloured coats (mainly base coats) require colour changes. Colour blocks are often less than two cars on average. Even when the best techniques for recovery are in place, purging/rinsing of bells and guns contributes significantly to emissions when solvent-based paints are used. For water-based coats, purge liquids usually comprise 90 % water [38, TWG 2004].

The use of paint cartridge systems substantially reduces the purging requirements, and therefore can lower emissions and wastage rates.

In mass-volume vehicle paint shops, paint is generally stored in a paint supply centre and pumped to the spray booths by steel ring lines, where each line is dedicated to one paint type (see Figure 2.42). Low-use colours are very often supplied from small paint distribution systems close to the booth. For base coat and primer (if more than one primer colour is used in the paint shop), these ring lines are connected to colour change devices for each single application unit (robot with one atomiser or paint machine with several atomisers). The colour changer switches between the linked paint pipes and the selected colour flows to the spray gun or bell. Alternatively, separate paint cartridges are filled with paint (0.5-1.0 l) in a docking station and automatically docked to the application robot on demand. This method can also be used in the case of manual application. Several other systems are used.



Source: [142, ACEA 2016]

Figure 2.42: Schematic diagram of the different parts of a paint supply system with ring lines

Achieved environmental benefits
Reduction in solvent consumption, purging requirements and VOC emissions.

Environmental performance and operational data
If electrostatic spray application with internal charging is used, paint supply systems with water-based paints need special electrical potential decoupling arrangements.

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation
Savings in raw material consumption and reduction of waste generation.

Example plants
Widely used.

Reference literature
[142, ACEA 2016] [ACEA comment #507 in [212, TWG 2018]]

2.4.5.2 Recovery of used solvents

Description
See Section 17.12.3. Modern paint supply equipment including recovery of the purge solvents is commonly applied. Recovery is by piping the cleaning agents from the application equipment to the storage tanks.

Achieved environmental benefits
Typically 80-90 % of cleaning and purge solvents can be recovered, either on or off site, for reuse.

Environmental performance and operational data
In the cleaning process there is also paint residue in the cleaning agent which may result in clogging of the pipes and containers because of hardening of the paint itself. Therefore continuous washing may be needed, resulting in an increase in the usage of cleaning agents.

Economics
The installation of a typical solvent recovery system costs EUR 0.4 million per spray booth (2006 data) but costs also depend on what is included in the system.

A potential saving will be achieved because of a reduced consumption of solvents and reduced amounts of hazardous waste. In large plants, the savings will approximately outweigh the investment.

Example plants
Ford, Europe.

Reference literature
[1, INTERGRAF and EGF 1999] [5, DFIU et al. 2002] [26, CITEPA 2003] [38, TWG 2004] [142, ACEA 2016] [212, TWG 2018]

2.4.6 Drying techniques

The following techniques are commonly applied:

- drying via circulating air with or without dehumidified air;
- infrared radiation curing, see Section 17.8.5.1.

2.4.7 Off-gas extraction and treatment

The following techniques are commonly applied:

- wet separation spray booth (flushed impact panel), see Section 17.10.4.1;
- absorption using a suitable liquid (wet scrubbing), see Sections 17.10.4.2 and 17.10.6.3;
- dry overspray separation with pre-coated material, see Section 17.10.4.3;
- dry overspray separation using filters, see Section 17.10.4.4;
- electrostatic filter, see Section 17.10.4.5;
- techniques for maintaining VOC concentration prior to treatment, see Section 17.10.3;
- adsorption: fixed-bed adsorption, fluidised bed adsorption and rotor adsorption, see Section 17.10.6.2;
- oxidation: recuperative, catalytic and regenerative oxidation, see Section 17.10.5.

2.4.7.1 Cabin air recirculation combined with overspray separation

In paint shops for the coating of passenger cars, vans and truck cabins, cabin air is recirculated after intense overspray separation, with dry overspray separation for new or completely refurbished paint shops or less frequently with wet scrubbing for existing plants. See also Section 17.10.3.2.

2.4.7.2 Enclosed application zones

Description

Coatings with solvents are applied in enclosed application zones with dedicated ventilation and waste air collection systems.

Technical description

A tunnel paint booth consists of the following sections:

- plenum chamber;
- spray cabin up to grate level;
- air conditioning system.

The separation system for the paint overspray is located below the cabin grating.

In the walkable plenum chamber, the conditioned air from the HVAC systems is distributed evenly over the entire zone. The system is structured as follows:

- air distribution duct;
- filter plenum.

From the air distribution duct, the supply air passes through perforated plates into the filter plenum, which is separated from the cabin zone by the filter cover. The ceiling filters present in the filter cover are primarily used for uniform air distribution in this zone. In addition, the air is once again ‘finely filtered’ through the filter mats before entering the cabin, in order to prevent the penetration of dust and fibre particles into the airway.

Spray cabin

The spray cabin consists of self-supporting frame elements with planking. The inner side walls are equipped with windows to the control areas and are even to avoid deposition of paint on landings and in dead zones. Access from the control areas arranged on the long side is possible via doors with safety interlocks. The control areas can only be entered via airlocks.
The car bodies are mounted on transport skids and are automatically transported to the various painting stations. They are dedusted using different techniques before entering the painting zones. In a painting booth, 10 to 20 vehicles are machined simultaneously.

After completion of the coating process, the car bodies are transferred into a dryer.

Ventilation system

The conditioning of the air to the required parameters is achieved using ventilators with heaters (direct or indirect heating), coolers, humidifiers, filters and fans. The air is supplied to the cabin via a plenum chamber over the whole cabin area. The exhaust air is withdrawn from the cabin via fans. The cabins are operated with a low vacuum to prevent leakage of solvents. The paint overspray deposition can be carried out with different systems. During wet washout, the humidity increases to over 90 %. Therefore, use of circulating air is only possible with high energy expenditure for dehumidification.

In the case of the dry deposition of the lacquer dispersion, recirculating air operation is useful since the parameters of the air, in particular the humidity, are not significantly changed.

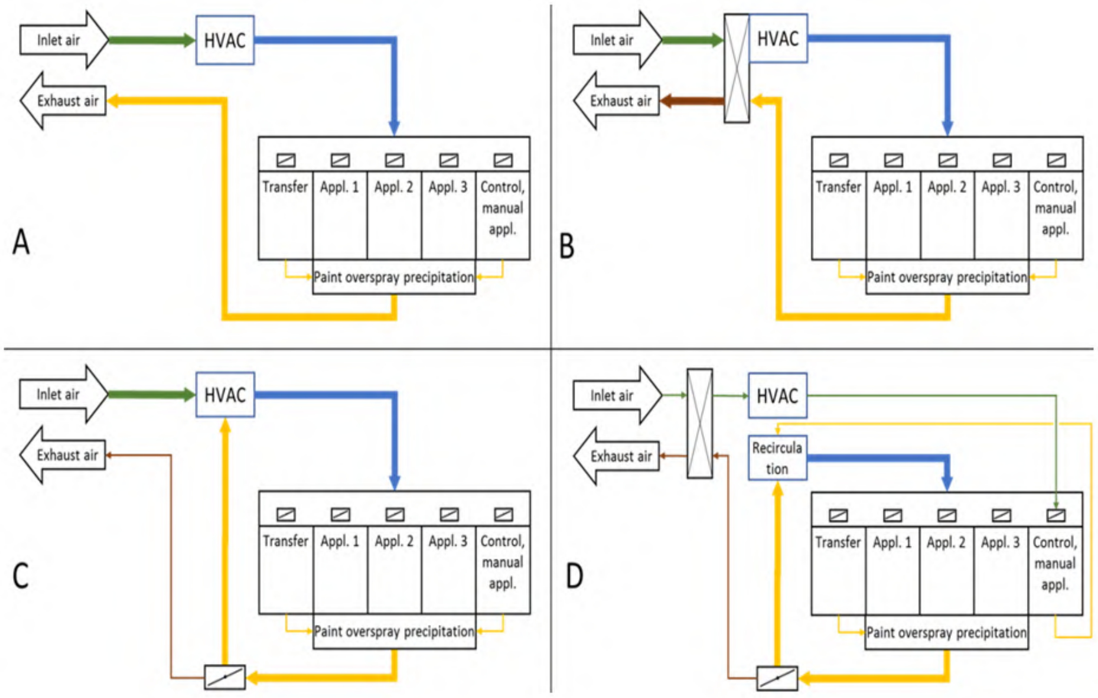
Heat recovery is possible and efficient in wet washing through heat wheels. In the case of dry deposition with recirculating air guidance, the solvents are concentrated. These are often treated in a thermal off-gas treatment system with heat recovery.

Various variants of air routing and energy recovery are shown in Figure 2.43 and Figure 2.44.

1 Inlet/outlet air heat exchanger.
2 Inlet air conditioning.
3 Plenum chamber and inlet air distribution.
4 Application zone with robots and body conveyance system.
5 Control room.
6 Paint overspray separation (example: cross venturi scrubber).
7 Reservoir for scrubber water circulation system.
8 Exhaust air ventilator.

Source: [183, ACEA 2017]

Figure 2.43: Structure and air conduction of a spray booth



A: No cabin air recirculation, no energy recovery.
B: No cabin air recirculation, energy recovery.
C: Cabin air recirculation, no energy recovery from exhaust air.
D: Cabin air recirculation, energy recovery from exhaust air.
Source: [183, ACEA 2017]

Figure 2.44: Different variants of air routing and energy recovery

Paint boxes

In contrast to large pass-through cabins with simultaneous coating of many bodies in different painting stations, in a paint box a single body is coated. This type is used for:

- small-scale passenger car production;
- truck chassis painting;
- bus painting;
- paint repair operations.

All necessary working steps for coating a vehicle are carried out successively at the same workstation. Paint overspray is collected in dust filters. For drying, either IR radiators are used, hot circulating air is introduced into the painting booth or the body is transferred into an adjacent single body dryer oven[22].

Dip tanks

The pretreatment and electrocoating zones are also equipped with housings. These are kept under low negative pressure (1 mbar) to avoid fugitive emissions to the nearby workplaces.

Achieved environmental benefits

- Elimination of fugitive emissions.
- Reduction of solvent consumption and emission.

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[22] Dürr-Krouzilek, Ralf (2011): Ressourcen-Effizienz auf hohem Niveau. Reinigungs- und Lackierlinie für Nutzfahrzeuge. In: JOT 51 (3), S. 42–45. DOI: 10.1365/s35144-011-0042-5.

Environmental performance and operational data

The requirements to be met in the air conditioning of spray booths are presented in Table 2.31.

Table 2.31: Requirements for air conditioning in pass-through paint booths

	Relative humidity (%)	Temperature (°C)	Downdraft velocity (m/s)
Solvent-based paint	40-85	20-30	0.3-0.5
Water-based paint	60-70	20-26	0.3-0.5
Water-based one-layer topcoat	55-75	20-26	0.3-0.5

Cross-media effects

High energy demand for air conditioning:

- When using wet scrubbing, as a rule, a 100 % fresh air fraction is necessary since the very moist exhaust air can only be reused with high energy consumption for dehumidification.
- When dry deposition is used, a circulating air volume flow of up to 90 % is possible. However, the recirculation rate is limited by the fresh air demand of the control zone, by manual workstations, or by the need to not exceed 25 % of the lower explosive limit. Usually 75-80 % recirculation rates are observed.

Technical considerations relevant for applicability

Pass-through paint booths are generally used in the paint shops for serial coating of passenger cars, vans and trucks. Enclosed cabins are standard in electrocoating and pretreatment.

Driving force for implementation

- Product quality.
- Workplace health and safety.

Example plants

- Tunnel spray booths and housing for pretreatment and electrocoating are found in all high-volume vehicle paint shops.
- Single cabins (paint boxes) are standard for low-volume production (e.g. sports car, truck and bus paint shops).

Reference literature

[169, VDI 2013] [183, ACEA 2017]

2.4.7.3 Rinsed electrofilter (overspray separator)

Description

System to separate overspray particles from the process air using electrostatic filters (for a general description, see Section 17.10.4.5).

Technical description

A rinsed electrofilter is an overspray separation system located below the grid level of the spray booth. The loaded air will be treated in electrostatic filters.

Exhaust air with overspray flows through the intake area to the separation module. As the air passes through the module, overspray particles are removed. As the system achieves a very high degree of separation, the spray booth can be operated with recirculated air. A large proportion of the scrubbed air is sucked in by a recirculation fan and returned to the booth. Depending on the exhaust air's solvent load, a portion of it is removed from circulation and replaced with fresh air. Separation modules comprise an alternating arrangement of active and passive elements. In the active elements, a corona cloud formed under a high voltage, charging all paint particles. These particles are then attracted by the passive grounded separating plate. This is covered with a thin layer of separating agent by a coating system installed above it. The paint particles are bonded to the separating plate and detackified by the separating agent. The agent containing overspray flows into the collection tank below the electrofilter system. From there it is returned to the coating system via the system tank. Part of the agent is scrubbed of overspray by a discharge system and returned to the separating agent cycle.

Achieved environmental benefits

In an electrofilter system the paint particles are separated > 99 %, with a remaining particle content of 0.3-0.8 mg/m^3.

Environmental performance and operational data

The separating agent is circulated in the system. Only a small stream of separating agent will be removed and disposed of with the overspray.

The operation and maintenance areas of the electrostatic filter are separated. The contact between the electrostatic filter and the generators is automatically activated when the module is inserted or removed. The handling is done in the operation area.

The electrostatic filters and the separating agent supply will work largely in automatic mode. The system function will be monitored by the programmable logic controller (PLC).

Cross-media effects

None.

Technical considerations relevant to applicability

The rinsed electrofilter system is suitable for systems of all sizes.

Driving force for implementation

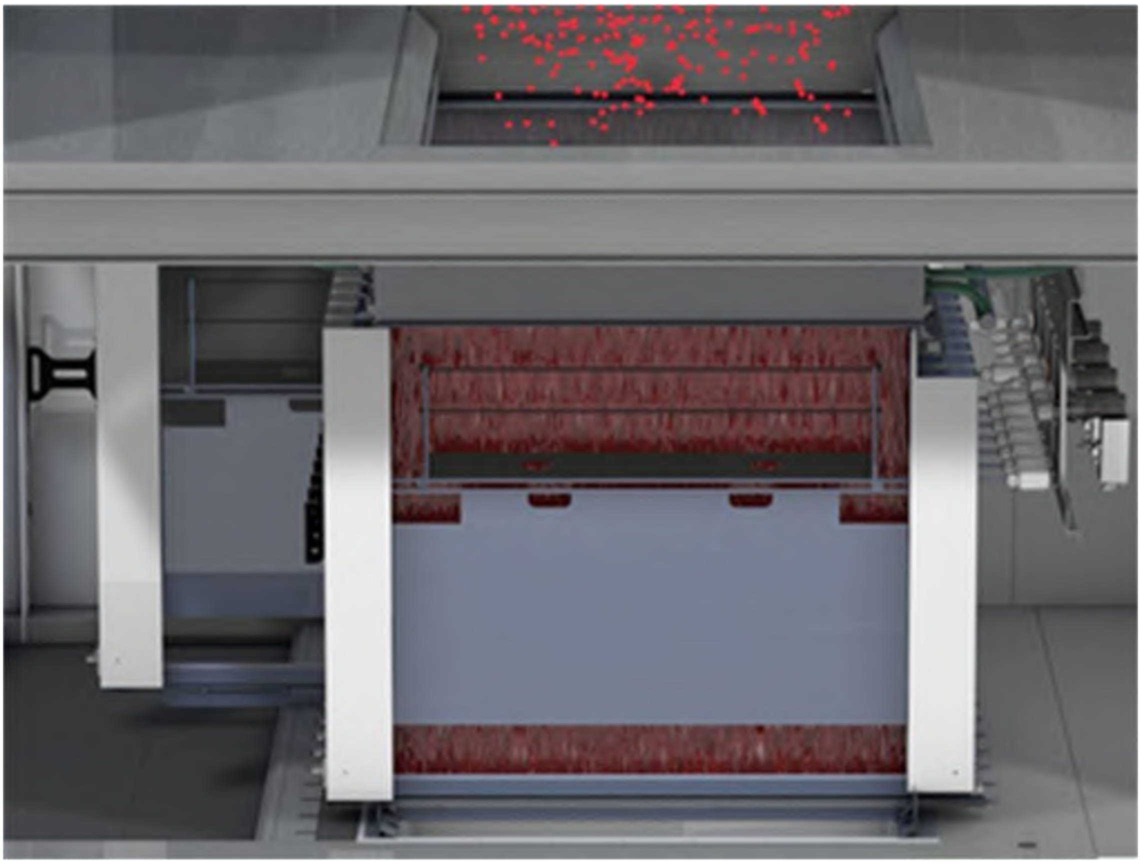
The particle content of the exhaust air is low enough that the air can be recirculated. This reduces the cost and energy consumption for conditioning the cabin air.

Example plants

Several paint shops in Europe, the US and China.

Source: [183, ACEA 2017]

Figure 2.45: Rinsed electrofilter system



Electrostatic filters (silver plate in front).
Separating agent (red area behind the silver plate).

Source: [183, ACEA 2017]

Figure 2.46: Detail of electrostatic filters and application of separating agent

Reference literature

[183, ACEA 2017]

2.4.8 Water management and waste water treatment

The commonly applied techniques are described in Section 17.11 and Section 17.4.

3 COATING OF OTHER METAL AND PLASTIC SURFACES

3.1 General information on the coating of other metal and plastic surfaces

[155, TWG 2016] [212, TWG 2018]

In this chapter, the processes related to coating of other metal and plastic surfaces are discussed. These include the metal and plastic components of the following types of products as well as the products themselves: fabricated metal products, moulded plastic parts, small and large agricultural and construction equipment, commercial and industrial machinery and equipment, interior or exterior automotive parts (such as bumpers, wheel covers, steering wheels, truck cab roof tops / aero aids and other plastic parts), motor vehicle accessories, trains, bicycles and sporting goods, toys, etc.

A small number of installations submitted data and additional information [155, TWG 2016]. According to data submitted in the frame of the call for initial positions, the total number of installations in EU Member States is significantly higher [161, TWG 2015]. The number of installations that participated in the data collection and the reported total number of installations are presented in Table 3.1.

Table 3.1: Estimated total number of installations in the EU and number of installations that submitted data for the coating of other metal and plastic surfaces

Activity	**Reported number of installations at the submission of initial positions (2015) (1)**	**Number of installations that submitted data (2)**
Coating of plastic workpieces	36	7
Coating of metal surfaces not described in other sections	32	4
Coating of trains	2	0
Coating of agricultural and construction equipment	4	1
Source: (1) [161, TWG 2015], (2) [155, TWG 2016]		

The coating of plastic and other metal surfaces serves decorative, protective and functional purposes. Coating protects metal parts from corrosion by providing resistance to moisture, heat and other factors. Plastic parts may be coated to provide colour, texture or protection, improving appearance and durability, and can also function to attenuate electromagnetic interference / radio frequency interference signals, and to conceal mould lines and flaws in the substrate surface.

In respect of vehicle parts painting, parts integrated into vehicle bodies have the same quality requirements as the body itself, and hence require multiple coatings. Fashions in colour design (e.g. the use of specialist or contrasting colours) can increase the solvent emissions per unit due to additional coating requirements, or additional cleaning between colours.

These coating processes for metal products and plastic parts may be divided into three main unit operations: (1) surface preparation, (2) coating application operations, and (3) cleaning activities. All three types of activities use VOC-containing compounds (i.e. coatings, thinners, and/or cleaning materials).

The three main process steps are briefly described below [160, USEPA 2008].

Surface preparation
Surface preparation is performed for two main reasons: to correct any flaws in the part prior to coating and to prepare the part to receive the coating. The amount of surface preparation a part requires or the types of surface preparation processes employed can vary greatly between metal and plastic part substrates.

Before a metal product can be coated, its surface must be thoroughly cleaned. The cleaning operation consists of the following basic processing steps: alkaline or acid cleaning, water rinse, phosphate treatment (typically iron phosphate), water rinse, and pretreatment and/or water rinse. The last step can involve drying the parts in an oven. In general, the cleaning chemicals used in this cleaning operation contain only a small amount of VOCs and therefore generate negligible emissions.

Coating application
Surface coating is accomplished by applying a coating to the metal or plastic surface, followed by curing or drying the coating. The coating itself may be in the form of a liquid or powder. Several different types of application technology are used to apply liquid coatings, and the selection of the application technology can have a significant effect on the amount of coating used and the resulting VOC emissions from the operation. The most common types of liquid coating applicators include air-atomised spray coating, electrostatic spray coating, high-volume low-pressure (HVLP) spray coating, dip coating, flow coating, roll coating, electrocoating, and autodeposition coating. Powder coatings can be applied through electrostatic spraying or dipping.

Cleaning activities
Cleaning activities other than surface preparation also occur at metal or plastic surface coating installations. Cleaning materials are used to remove coating residue or dirt from coating equipment (e.g. spray guns, transfer lines), tanks, and the interior of spray booths. These cleaning materials are typically mixtures of VOC-containing solvents but low-solvent or solvent-free cleaning techniques and materials are available.

3.1.1 Coating of other metal surfaces

A wide range of metal surfaces are coated for corrosion prevention and/or decoration. They may be for finished products (such as cleaning machines) or in sub-assemblies that are a part of other products, such as engine blocks for vehicles. They are not dealt with individually in detail, but example data are given. Some examples are:

- steel furniture, e.g.:
  - furniture and fittings for commercial use, hospitals, etc.;
- household appliances, e.g.:
  - white goods: fridges, washing machines, etc.;
- mechanical engineering, components, cabinets:
  - e.g. for high-voltage switch gear;
- automotive sub-assemblies, e.g.:
  - engine blocks,
  - windscreen wiper assemblies,
  - radiators,
  - brake discs,
  - aluminium rims;
- construction, e.g.:
  - facade panels,
  - door and window frames,
  - heating panels, radiators;

- components for windmills, e.g.:
    - windmill tower,
    - windmill hub, nacelle and wing.

3.1.2 General information on the coating of agricultural and construction equipment

[5, DFIU et al. 2002] [41, ISACOAT 2004] [78, TWG 2005]

The machinery produced in this industry are vehicles (e.g. tractors, earth movers), or equipment used for specific purposes, which may or may not be mobile (e.g. screens or sieves). To cover the whole range of activities, the term agricultural and construction equipment is used here. Most companies manufacture their machines over the whole year but sell them mainly in spring. Due to the heavy seasonal fluctuations of the business, machines are placed outdoors with the impact of UV radiation, rain, marine atmosphere, sometimes for almost a year between manufacturing and vending, so gloss and colour retention, adhesion and corrosion protection are critical issues. However, the main task is corrosion prevention. In use, the coating has to sustain heavy mechanical and chemical stress. Chemical corrosion occurs due to aggressive liquids arising from the materials handled (e.g. potatoes, manure) and moisture. The coating does not generally last as long as the vehicle. The optical qualities of the surface are less critical than for cars.

Large enterprises are typically those manufacturing self-driving machines. Due to relatively high technological and optical demands, pretreatment and coating processes are sophisticated. Paint consumption is above 50 tonnes per year, associated with a solvent consumption of between 5 tonnes and 50 tonnes per year.

3.1.3 General information on the coating of plastic surfaces

[5, DFIU et al. 2002] [38, TWG 2004] [119, May et al. 2006]

A wide variety of modern products incorporate plastic parts, although many are used with the appropriate finish achieved in the moulding process and do not require coating. In general, around 75 % of the paints supplied to this industry are applied to plastic parts of vehicles. This is predominantly for bumpers, wheel covers and steering wheels. The remaining 25 % of the paints are for coating of televisions, sound systems and computer housings.

The plastic parts coated for the vehicle industry include parts that are coated by the vehicle producer (in-line vehicle production or in separate coating lines), as well as parts that are coated by component suppliers. Plastic parts integrated in the car body often have to achieve a matching colour. Nowadays colour design is increasingly seen in the automotive sector, including the interior decoration, for example, colour-matching the steering wheel to the dashboard or to the interior. In many cases, the car bodies and the components may be coated in different installations using different application devices and/or coating materials and good colour matching is of major importance.

Due to the increase in the use of recyclable plastics in the vehicle component supplier industry in recent years, the use of polyolefins has also greatly increased. These materials are non-polar and need surface preparation to guarantee the necessary adhesion for the coating.

Plastics typically display certain basic characteristics, and these affect the type of surface preparation which can be applied, the type of coating which can be used, and the process used to apply it. Some basic characteristics of plastics are as follows:

- resistant to mechanical or thermal stress;
- chemically resistant;
- electrically non-conducting;
- additional wetting and adhesion properties compared to metal surfaces;
- possibility of leakage or migration of the plastic ingredients.

Coating systems need to be chosen carefully with respect to the solvent they contain, as some aggressive solvents may cause swellings and embrittlement, may create cracks in the plastic or reduce the adhesive strength of the coating system. Also, the coating needs to be more elastic than the substrate in order to resist deformations.

3.1.4 General information on the coating of trains

[5, DFIU et al. 2002] [38, TWG 2004]

Besides high optical qualities of the paint, good corrosion protection is also required for rail vehicles. The applied coating system must resist climatic impacts, aggressive cleaning agents (used for the removal of graffiti) as well as abrasion from sliding contacts.

3.2 Applied processes and techniques

3.2.1 Applied processes and techniques in the coating of other metal surfaces

[155, TWG 2016]

Any of the relevant techniques in Chapter 17 may be applied.

The applied coating techniques reported in the data collection are:

- spray application in an enclosed coating cabin;
- spray application in enclosed cabins with clean room conditions;
- airless spraying.

The paint supply systems applied are similar to those in vehicle coating, e.g. paint container directly connected to robot/workplace, without a pigging or flushing technique.

3.2.2 Applied processes and techniques in the coating of agricultural and construction equipment

[5, DFIU et al. 2002] [41, ISACOAT 2004] [78, TWG 2005]

Common issues for all kinds of coating of agricultural and other machinery are:

- complex and large three-dimensional objects;
- relatively thick metal sheets which are processed by laser-cutting, welding, etc.;
- necessity of pretreatment due to processing rough edges, residues, rust and oil on metal surfaces;
- multiple substrates (steel, cast metal, wood, thermoplastics, duroplastics, fibre-enforced plastics, pre-assembled parts);
- pneumatic, airmix and airless application, electrostatically assisted application, dipping, or/and electrocoating are possible;
- limited baking conditions due to mass or pre-assembled thermosensitive parts;
- one main solid topcoat colour (typical for the brand) and a few additional colours (design);
- single or dual layer system (primer plus topcoat on visible external surfaces, or single layer topcoat);
- high quality of finish with regard to corrosion protection (edges), gloss and colour retention, chemical resistance, adhesion, etc.

The typical process in central Europe for large self-driving machines (combine harvesters, potato seeders/harvesters) includes electrocoating (anodic single layer or cathodic primer) and topcoat application over primer (two-component high-solid solvent-based, sprayed on partial surface areas, or water-based topcoat, applied by dipping). However, traditional technologies are still widely spread, especially for smaller machines.

Primers and single layer topcoats have to reach all parts of the machines. Due to the complex structure of objects, dipping of components before assembly is therefore the preferred process option and can be automated. If installations are not available because low capacity cannot justify the investment, spray application is feasible with some drawbacks on quality issues. In order to reach the internal surfaces of machines, airmix application is preferred. For external surfaces, electrostatic support of the application is feasible and widely used.

Traditional technologies
Primers: polyvinyl butyrate (PVB)-based, or acid-hardened alkyd (phosphoric acid), for spray operations; or dipping with solvent-based materials (organic solvents or chlorinated hydrocarbons, based on alkyd resins).
Single layer topcoat: dipping with solvent-based materials is widely used; alkyd coatings contain organic solvents, even chlorinated hydrocarbons are still used.

Topcoat: traditionally solvent-based polyester/alkyd.

New technologies
Primer: two-component epoxy-based, solvent-based or water-based, for spraying; or water-based coatings for conventional and electrocoating; resins are mainly polybutadiene (anodic electrocoat) or epoxy.

Single-layer topcoat: water-based coatings are available for conventional and electrocoating; resins are mainly acrylic due to demands for UV stability.

Topcoats: isocyanate-hardened acrylate/polyester (medium-solids, high-solids, or water-based), or one-component acrylic (water-based, high bake), for spraying; or polyester or acrylic coatings (water-based) for conventional dipping. Powder coat has been used successfully.

Usually, there is only one colour primer and a maximum of four colours for liquid topcoats. So for epoxy primer and for isocyanate-hardened topcoats, two-component mixing machines are technically and economically feasible.

3.2.3 Applied processes and techniques in the coating of plastic surfaces

[5, DFIU et al. 2002] [38, TWG 2004] [119, May et al. 2006]

Generally in the serial coating of plastic parts, three issues need to be addressed:

- surface preparation;
- structure of the coating;
- coating system and application technique applied.

Surface preparation
Surface pretreatment may be applied to prepare the surface for the coating, e.g. to increase the adhesive properties of the surface (especially for applications of water-based coating systems), to activate the surface, to increase the electrical conductivity of the surface (e.g. for use with electrostatically supported application devices) or to reduce faults in the surface, e.g. created by the leakage of ingredients. Typical pretreatments include chemical pretreatments in baths; flame treatment; plasma processes; the corona technique; and fluoridation, which offers the advantages of one-layer coating and enabling the parts to be stored for longer periods before being supplied for a subsequent coating process.

Structure of the coating system
Depending on specific requirements, two, three or four layers of paint may be necessary. In relation to vehicle parts like for the main vehicle body, numerous layers of paint are required to coat bumpers and other parts. This ensures a quality consistent with the main body and the durability of the part. A ground coat may also be applied first depending on the composite. On the surface of especially difficult surfaces such as polypropylene, an additional primer may be necessary. For soft PVC or PUR soft foam, an isolating or inhibiting ground coat is needed to avoid migration of the softener. In order to smooth surface roughness, an elastic filling is applied. The topcoating may be either one or two layers, and is also elastic.

Coating system and application technique applied

The choice of coating system and application technique depends on the end-product needs. In Germany, predominantly solvent-based one- and two-component systems based on PUR and one-component paints based on acryl melamine are used, although water-based systems, UV cross-linking systems and powder coatings are also used.

Typically, high-pressure air spraying is used for wet paints. Depending on the workpiece's geometry, the application efficiency is between 20 % and 40 %. The high-volume low-pressure (HVLP) paint application method is also common for some applications, with achievable application efficiency factors varying between 25 % and 50 %. There is an increasing use of robots, as they allow a more homogeneous layer thickness to be achieved compared to manual painting. However, manual painting may still be employed where the painting of many different or complex parts requires frequent change and adaptation. This will result in a potentially higher emission of solvents through increased overspray.

Electrostatic application techniques are also available but up to now have only been used for multilayer superstructures. Here, an electrically conducting ground coat is first applied with conventional spray guns, often followed by a base coat, also applied with conventional guns. The application of the clear coat layer can then be carried out electrostatically (e.g. by high-rotating bells). Application efficiency factors can be greatly increased by using electrostatic techniques, e.g. if high-rotating bells are used, application efficiency factors of up to 85 % can be achieved. In some cases, a maximum level of only 50–65 % transfer efficiency can be obtained (e.g. in the case of the complex parts of some processes in the automotive industry, for example the low conductivity of substrates in the case of plastic parts). However, the electrostatic coating technique cannot be used for single layer coatings, as it needs an electrically conducting pre-coat.

In general, drying and curing are carried out at a maximum temperature of 80 °C, due to the heat-sensitiveness of the substrate. However, in certain cases, heat-up zones of up to 135 °C and hold zones of up to 110 °C can be reached. For some plastics, UV and electron beam curing may cause a yellowing of pale colourings.

The following spray booths and techniques are applied:

- simple spray booth;
- spray booth and dryer;
- wet separation spray booth;
- dry-separation spray booth;
- water emulsion techniques in a spray booth;
- paint-in-paint spray booth;
- combined systems (wet and dry separation).

3.2.3.1 Coating of bumpers

An example of a simplified water-based bumper coating process is shown in Figure 3.1.

The workpieces being coated consist of polyurethane moulded pulps and thermoplastic plastics.

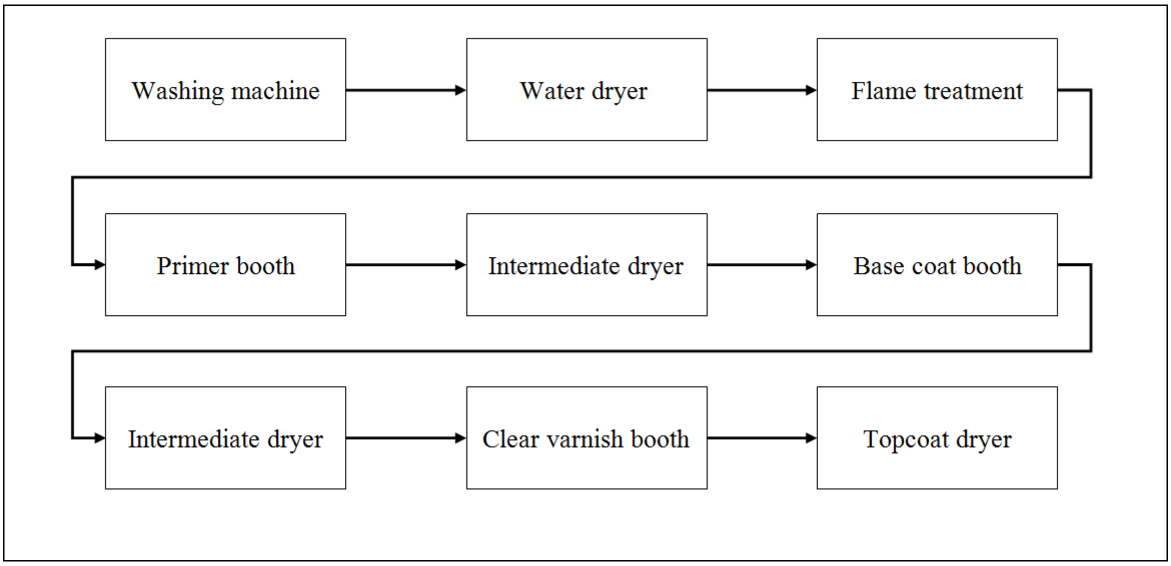


Figure 3.1: Water-based bumper coating process

Surface preparation

Different techniques can be used for the surface preparation. Often spray cleaning with water is carried out by automation, with the parts progressively passing through different zones, e.g.:

- first degreasing with an aqueous-alkaline cleaning agent;
- rinsing with water;
- second degreasing with an aqueous-alkaline cleaning agent;
- rinsing with water;
- final rinsing with deionised water.

Spray cleaning with water and chemicals can be avoided for polypropylene bumpers by manually wiping the bumper with solvent-impregnated wipes. In one example installation, the bumpers are cleaned manually with a water-isopropanol mixture (the proportion of isopropanol is 5 wt-%) and afterwards dried in convection dryers.

Cascade rinsing is usually used, in order to reduce water consumption. The water discharging from the parts can be used for substitution of evaporation losses of the degreasing step. Also, the deionised water can be recycled. After the cleaning process, the parts are transported through a blowing, drying and cooling unit. If a condensation dryer is used, the cooling unit is not necessary.

After drying, the workpiece's surfaces are often activated by flame treatment or plasma ionisation. Polyurethane parts do not need any further preparation.

Application of the coating

In general, bumpers are coated with a three-layer coating consisting of a ground coat, a base coat and a clear coat. The paint is applied by robots or manually by using electrostatically assisted spraying or by spraying with HVLP guns. First, a primer is applied to the plastic parts. Primer can be either solvent-based (e.g. solvent-based two-component ground coating) or water-based. The primer may need to be dried (e.g. within a circulating airflow at 80 ºC) prior to the application of subsequent layers. Application of the base coat is carried out with the same technique as the ground coat. Where the base coat uses medium-solids paint, the solvent proportion can be up to 70 %. Base coats may be one- or multiple-component paint systems and can be either water-based or solvent-based. After the paint application, a conventional solvent-based two-component clear coat is applied and evaporated. Additionally, wet-on-wet application can also be used, eliminating the need for intermediary drying zones.

After evaporation, the paint layers are dried in the dryer. Solvent-loaded exhaust air originating from the flash-off areas and dryers are captured and passed to a thermal treatment unit. The achieved efficiency factor may be 95-99 % (depending on the load to the combustion unit). For example, a concentration of 277 mg C/m^3 in the raw exhaust gas is reduced to 25 mg C/m^3 in the cleaned gas. Cleaning of the overspray is carried out via wet deposition. Table 3.2 below shows the proportions of solvents in different coating systems.

Table 3.2: Proportions of solvents in different coating systems used for the coating of bumpers

Coating structure and systems	Solvent proportion (wt-%)
Ground coat • solvent-based • water-based	40-55 15
Base coat • solvent-based • water-based	50 15
Clear coat • solvent-based • water-based	50 30

3.2.3.2 Coating of wheel covers

The coating system for wheel covers is characterised by two layers. First a conventional or water-based metallic base coat and subsequently a conventional solvent-based two-component clear coat or a UV clear coat are applied. The requirements for the coating include scratch resistance, water resistance and resistance against stone-chips, as well as a high surface quality. The coating is carried out by automation.

Figure 3.2 below illustrates the production procedure of wheel covers with solvent-based paints.

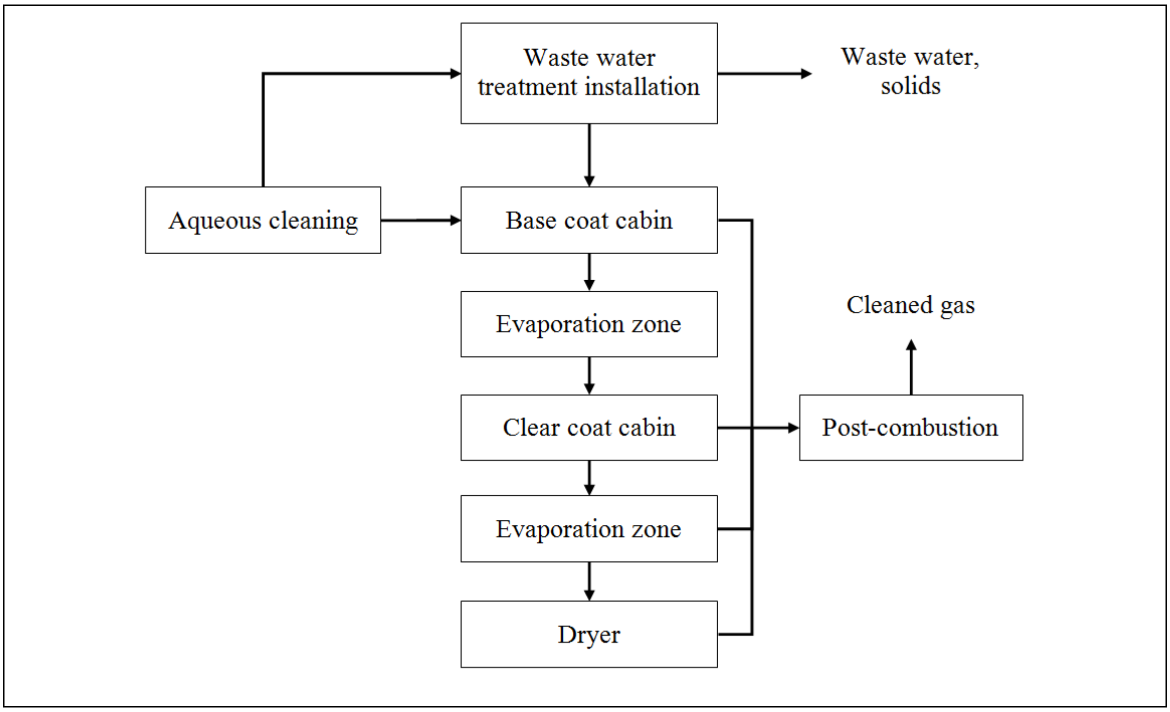


Figure 3.2: Process flow for the coating of wheel covers with a conventional coating system

Table 3.3 below compares some different systems in use.

Table 3.3: Comparison of the proportions of solvent in coating systems applied for the coating of wheel covers

Coating structure and systems	Solvent proportion (wt-%)
Base coat	
• solvent-based • water-dilutable	75 10
Clear coat	
• solvent-based • UV cured • water-dilutable	50 10 16

3.2.3.3 Coating of steering wheels

For steering wheels, properties such as resistance against sun radiation, cleaning agents or sweat from hands have to be guaranteed by the coating. At present, steering wheels are typically coated by the in-mould technique. For this technique, a release agent is applied onto the heated mould and the in-mould coating is sprayed onto the release agent. In this way, the proportion of overspray and therefore the material loss is comparably low, approximately 20 %. After a short evaporation time, the mixed PUR components are poured in. During the foaming process within the closed mould, the material creates a strong connection with the coating. The applied coating has to be compatible with the mould release agent and with the polyurethane system used. Up to now, solvent-based one- and two-component coating systems have been in use.

3.2.3.4 Coating of reflectors

Reflectors require an extremely smooth and homogeneous surface. The coating structure is a one-layer type.

3.2.3.5 Coating in the production of televisions, sound systems and computer housings

Nowadays, there is a trend in the audiovisual sector for more colourful products and even individual customer requests regarding the colour design. The quality requirements for the coating of the housings include resistance against alcohols, skin fat, etc., scratch and abrasion resistance, and good optical surface properties. State-of-the-art is the serial use of water-based coatings, although solvent-based coating systems are still widely used. An application efficiency of 45 % can be achieved in the coating of television housings, with the coating being carried out by automation.

3.2.4 Applied processes and techniques in the coating of trains

[5, DFIU et al. 2002] [38, TWG 2004]

The selection of the coating system, materials, colour and layer thickness is determined by the customer. Because of large volume flows and discontinuous operations, off-gas treatment is not used in small installations. However, in some large installations, the treatment of the off-gases from the dryers is common practice.

The coating processes of rail vehicles can be divided into the coating of new vehicles and maintenance operations. The coating systems are identical for both processes. Both activities usually take place where the rail vehicles are manufactured. The characteristics of the maintenance operations with environmental impacts are outlined in the following paragraphs and are also valid for new constructions:

- Reparation of the paintwork in the finishing department or during maintenance operations: The paintwork is partly sanded and renewed.
- Complete lacquer finish of old rail vehicles: As a function of the lacquer condition, the paint is sanded down to the ground coat or completely removed by blasting.
- Paint removal and new paint finish: After the reconstruction of rail vehicles, old paint is removed via blasting or sanded down to the ground coat layer. Then, a new coating is applied. In general, paint removal is done manually via grit blasting. For paint removal from aluminium and stainless steel (e.g. superstructures), corundum is used as the blasting shot. For normal steel, steel itself is utilised as the blasting agent. After blasting, the dust is removed from the surface by blowing with compressed air. Usually, all blasting materials are recycled.

The process of constructing and painting new rail vehicles is described in more detail in the following paragraphs. As the applied painting processes of construction and maintenance operations are identical, this is also valid for maintenance processes.

Table 3.4 shows the coating systems used for rail vehicle bodies according to the regulations of the Deutsche Bahn AG as an example for a possible layer construction.

Table 3.4: Layer construction for rail vehicles according to the regulations of the Deutsche Bahn AG

Area	Layer construction	Material (1)	Layer thickness of dried material (µm)
Complete rail vehicle body	Pretreatment	Blasting	-
Outside surfaces: Front and side wall including door and window housing, roof and also head areas made of glass-fibre-reinforced plastic	Ground coat	EP, WB	60
	Knifing filler	SB	60
	Primer	PUR or EP primer, WB	60
		PUR primer, SB (alternative)	40
	Topcoat	PUR, SB	40
		PUR, WB	20-30
		Base coat, WB	40
		PUR, SB and anti-graffiti paint, SB	40 40
Roof	Primary coat	EP, WB	80
	Topcoat	EP, WB, thick film	140
		EP, SB, thick film (alternative)	140
Base frame, floor, underbody	Primary coat	EP, WB	60
	Topcoat	EP, WB, thick film	140
		EP, SB, thick film or one-component underbody protection (alternative)	140-200
Bogie frame	Primary coat	EP, WB	60
		EP, SB (alternative)	60
	Topcoat	EP, WB, thick layer	140
		EP, SB, thick layer (alternative)	140
	DIN component parts	Anti-corrosion wax	NI
Interior surfaces: Floor, roof, side and front wall	Primary coat	EP, WB	NI
	Topcoat	EP, WB, thick layer	NI
		EP, SB, thick layer (alternative)	NI
	Seam sealant	Sealing agent	NI
	Acoustic insulation	Artificial resins, WB	NI

(1) SB: solvent-based; WB: water-based; EP: epoxy; PUR: polyurethane.
Source: [5, DFIU et al. 2002]

Pretreatment of the wagon bodies

Optional degreasing via aqueous-alkaline cleaning agents is carried out after assembly (especially for aluminium). Subsequently, the interior and the exterior surfaces are cleaned by blasting. The blasting agent is partially recycled.

Ground coat application (onto exterior areas and interior surfaces)

A ground coat is applied onto the entire wagon. Paint is applied manually via an airless spray application. Besides conventional paints, water-based, two-component, chromate-free paints, based on epoxy resins are also available. The solvent content of these materials varies from 3 % to 5 %. A layer approximately 60-100 µm thick is applied onto the roof and approximately 200 µm thick on the side walls. Component parts such as luggage racks are coated with solvent-based paints or powder coatings.

Filling

After the ground coat is dried, a filler is manually applied via palette knives. The material has a solvent content of about 16 % (of which 8 % is reactive and not relevant for emission). After curing the material, sanding of the side walls takes place. Grinding dust is removed by blowing with compressed air and by using cleaning agents. Usually, the filler material is only applied onto welding seams (minimum filler application).

Primer application (generally only onto exterior surfaces)

The primer is applied onto the side walls via an airmix spray application. As a primer, either a two-component, amine-hardening, water-based epoxy material (containing 3 % organic solvents) or a solvent-based polyurethane (containing 35 % organic solvents) is used. The layer thickness amounts to about 60 µm. The drying time is about 2 to 3 hours. If a dryer is used (80 °C), the drying takes about 45 minutes. The temperature of the substrate may not exceed 45 °C for completed wagons due to the electronic equipment.

Topcoat application (generally only onto exterior surfaces)

Depending upon the kind of track, several layers of topcoat are applied. For the Deutsche Bahn AG, six different colours are used for city rail vehicles. Among these, three colours are utilised for coating the side walls, one for the roof, one for the underbody and one for the bogie frames. The lacquer is applied via airmix spray applications. In between the paint applications, evaporation takes place (1 hour). After the last layer is applied, the paint is dried at temperatures of 50-60 °C. After 2 hours, the finished surfaces are masked and the next paint layer is applied. The layer thickness of the paint that is applied onto the side walls amounts to 40 µm. It can be up to 120 µm depending on the number of paint layers. About 120 µm is applied onto the roof.

Predominantly, solvent-based topcoats and clear coats are processed. Good performance is needed from coating systems. This is especially important for high-speed trains (300 km/h), for regular cleaning and removal of graffiti. Although water-based materials are already available, solvent-based topcoats are still preferred for the reasons mentioned earlier and are sometimes prescribed by specifications.

Underbody protection

The underbody is coated with water-based underbody protection via an airless spray application. A minimum layer thickness of 120-200 µm is applied.

3.3 Current consumption and emission levels in the coating of plastic and other metal surfaces

The reported data refer to plants for the coating of other metal and plastic surfaces and agricultural and construction equipment (ACE). No data were received from train coating plants.

3.3.1 Consumption

3.3.1.1 Material consumption

3.3.1.1.1 Coating of trains

[5, DFIU et al. 2002]

In Table 3.5 the material consumption for specific paint layers is listed. The total solvent input (from thinners, cleaning agents and paints) of the inspected installation (Deutsche Bahn) was 187.6 tonnes in 1999. Data for individual films of paint could not be determined.

Table 3.5: Material consumption per coated wagon

Paint/substrate	Consumption (kg)
Ground coat	200
Primer	35-40
Topcoat:	
Roofs	35
Windows	35
Braids, decor strips	5
Side wall underneath windows	15
Underbody protection	150-200
Source: [5, DFIU et al. 2002]	

Mass balances
No data submitted.

3.3.1.1.2 Coating of plastic surfaces

[155, TWG 2016]

The consumption of raw materials in this sector depends on:

- the type of processes applied;
- product-specific substrate and geometry;
- volume of production.

Reported data from installations for the coating of plastic surfaces indicate a specific solvent consumption in the range of 0.15–1.02 kg solvent per m^2 of coated surface. The large deviation in this range is related to the differences in the product types and their geometries.

Only three installations reported detailed information on the process steps and the use of materials for the different coating layers.

Of these installations, two are using solvent-based (SB) material for the three coating layers (primer, base coat, clear coat) while the third is using both SB and water-based (WB) coats, WB for the base coat and SB for the clear coat.

Coating of bumpers

For one example site in Germany (Volkswagen, Wolfsburg), in 2002 [119, May et al. 2006]:

- about 1 million bumpers were painted;
- surface area (external side only): between 0.9 m^2 and 1.5 m^2;
- substrate: polypropylene with EPDM modification;
- three-layer coating system with primer, base coat and clear coat;
- pneumatic atomisation of coating materials by spray-guns mounted on robots;
- drying oven after primer and clear coat, wet-on-wet process for base coat and clear coat.

Solvent consumption figures in Table 3.6 refer to a mixed coating system with solvent-based primer, water-based base coat and solvent-based clear coat. The solvent used may increase by 20 % when medium-solids paint is used. If a complete solvent-based system was applied, the solvent consumption would amount to 550 t/yr. Consumption of paint solids would be 207 t/yr. VOC emissions according to EVABAT (Economically Viable Application of Best Available Techniques) range between 51.75 t/yr and 72.45 t/yr. Emissions were estimated to be 0.25–0.35 kg VOCs/kg of paint solids (2002 data).

Table 3.6: VOC use for bumper coating (2000 data)

Coating system	Solvent used (1) (t/y)
Ground coat (solvent-based)	125
Base coat (water-based)	31
Clear coat (solvent-based)	84
Total solvent in paint	**240**
Rinsing diluent ground coat	61
Rinsing diluent base coat	9
Rinsing diluent clear coat	41
Total rinsing diluent	**111**
Total solvent used	**351**

(1) It has been reported that the solvent used may increase by 20 % when medium-solids paint is used.
If a complete solvent-based system was applied, the solvent consumption would amount to 550 t/yr.
Source: [38, TWG 2004]

Coating of truck cab roof tops and other plastic parts for commercial vehicles

A jobbing coating shop in Germany reports the following data [119, May et al. 2006]:

- coating of about 30 000 truck cab roof tops and complete plastic part sets per year;
- surface area (external side only) between 6 m^2 and 11 m^2 per rooftop;
- substrate mostly fibre-reinforced SMC (sheet moulding compound) polyester.
-
- The combination of techniques used is:
- predominantly two-layer coating systems with primer surfacer and solid colour topcoat;
- atomisation of coating materials by high-rotation bells mounted on robots, assisted by shaping air, but without electrostatic charging;
- drying oven after topcoat, wet-on-wet process for solvent-based primer surfacer and topcoat.

In the case of the conventional medium-solids system, solvent consumption was about 400 t/yr, and consumption of paint solids was (in 2005) 253 t/yr.

Due to specific technological requirements (i.e. covering of substrate defects, customer specification, wet-on-wet process), the jobcoater for plastic workpieces prefers to continue the use of solvent-based coating materials. In the area of trucks and commercial vehicles, more than 95 % of objects are coated with single-layer topcoats instead of base coat/clear coat. The colour range is typically above 600, due to matching fleet colour schemes. This leads to a very high number of colour changes, including the purging of 5-7 m supply hoses for robots. As a consequence, large quantities of purging liquids are used (and recovered).

Table 3.7: Breakdown of conventional VOC materials

Paint	Consumption (kg/yr)	VOCs (%)	VOCs (kg/yr)	Non-volatiles (%)	Non-volatiles (kg/yr)
Putty	1 000	8.5	85	91.5	915
Sanding primer	3 900	29.5	1 150	70.5	2 750
Primer surfacer	88 000	32.4	28 512	67.6	59 488
Topcoat	133 000	42.2	56 126	57.8	76 874
Elastic additive	4 100	22.3	914	77.7	3 186
Base coat	5 050	77.3	3 904	22.7	1 146
Clear coat	10 400	54.0	5 616	46.0	4 784
Hardener	66 300	54.5	36 134	45.5	30 166
Diluent	28 600	100	28 600	0	0
Special products	275	46.3	127	53.7	148
Purge solvent	137 000	100	137 000	0	0
Structure topcoat	22 000	42.0	9 240	58.0	12 760
Powder	2 000	0	0	100	2 000
Total	**501 625**		**307 408**		**194 217**
Source: [119, May et al. 2006]					

The option to achieve low VOC emissions would be the introduction of high-solids and very-high-solids coating material and adapted purging liquid (see Table 3.8). This would give an emission value of 0.29 kg VOCs/kg of paint solids.

Low-emission materials include:

- very-high-solids wet-on-wet primer surfacer;
- high-solids topcoats;
- low-VOC purging liquid (70 % organic materials not classified as VOCs);
- additional low-emission products (see Table 3.8).

Table 3.8: Breakdown of low-VOC materials to achieve low VOC emissions

Coating material	Consumption (kg)	Solvent content (%)	Solvent content (kg)	Solid content (%)	Solid content (kg)
Putty	600	8.5	51	91.5	549
Wet-on-wet primer	98 985	15	15 343	84.5	83 642
Sanding primer	4 260	29.5	1 257	70.5	3 003
Primer surfacer	140	56.7	79	43.3	61
Topcoat	150 955	28.4	42 871	71.6	108 084
Hardener	49 507	25	12 376	75	37 130
Additive	624	22.3	139	77.7	485
Clear coat	11 027	37	4 080	63	6 947
Base coat	5 226	9.5	496	23.7	1 239
Diluent	27 618	100	27 618	0	0
Structured coat	17 022	8	27 618	54	9 192
Hardener	2 635	5	133	95	2 505
Special products	255	46.3	118	53.7	137
Purging liquid	106 311	30	31 893	0	0
Total	475 165		137 815		252 974
Recovery	197 185	33	65 071		
Total VOC emission			72 744		
Source: [119, May et al. 2006]					

3.3.1.1.3 Coating of other metal surfaces (OMS)

[155, TWG 2016]

Reported data from installations for the coating of other metal surfaces (OMS) indicate a specific solvent consumption range from 0.01 kg up to 0.5 kg solvent per m^2 of coated surface.

3.3.1.1.4 Coating of agricultural and construction equipment (ACE)

[155, TWG 2016]

Data for only one installation were submitted. The main characteristics of the process stages are presented in Table 3.9.

Table 3.9: **Main characteristics of process stages for an ACE coating plant**

Stage	Pretreatment	Layer 1	Layer 2	Layer 3	Cavity preservation
Process	Cleaning, degreasing	Primer coating	Gloss	Lubricant and rust inhibitor	Cavity preservation
Material (VOC content)	Aqueous detergent emulsion	SB (305 g/l)	SB (425 g/l)	NI	Wax coat with solvents
Application method	High-pressure spray cleaner, automatic	Spray application in enclosed cabins with clean room conditions	Spray application in enclosed cabins with clean room conditions	NI	NI
Paint supply	NA	Circulation lines fed from central mixing chamber, without pigging or flushing technique	Circulation lines fed from central mixing chamber, without pigging or flushing technique	NI	NI
Colour change, system purging	NA	Batch painting/colour grouping	NI	NI	NI
Dryer type	Convection drying	Convection drying	NI	NI	NI

NB:
NI: No information provided.
NA: Not applicable.
Source: Plant #073 in [155, TWG 2016]

3.3.1.2 Energy consumption

Reported data show that the specific energy consumption values vary from 7 kWh/m^2 up to 35 kWh/m^2 of coated substrate surface. The specific energy consumption depends on the type of process, the substrate and specific aspects of the process. Given the significant share of energy consumed in off-gas thermal treatment in relation to the total energy consumption, it is worth noting that energetically efficient techniques have a major positive effect on energy consumption. As an example, at one reference installation, the replacement of thermal oxidation by a regenerative thermal oxidiser (RTO) resulted in a reduction of the total energy consumption of 66 % (Plant # 080 in [155, TWG 2016]).

3.3.1.3 Water consumption

[155, TWG 2016]

Reported values from installations for the coating of plastic surfaces show that the specific water consumption varies from 5 l/m^2 up to 30 l/m^2 of coated surface.
For the coating of agricultural and construction equipment, the reported specific water consumption value was 0.26 m^3 per tonne of product.

3.3.2 Emissions

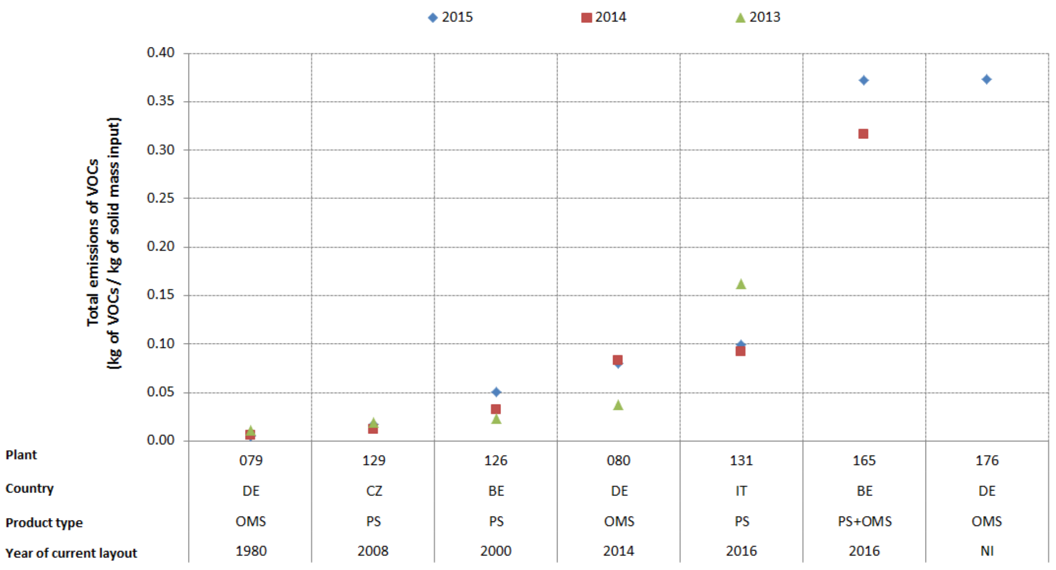
[155, TWG 2016]

3.3.2.1 Total and fugitive emissions of VOCs

This industry group covers a wide range of activities with significant differences in:

- the type of processes applied;
- the end-of-pipe techniques applied;
- the products;
- the production volume.

The reported VOC emission values, expressed as kg VOCs emitted per kg of solid mass input (kg VOCs/kg solids), are presented in Figure 3.3.



Source: [155, TWG 2016]

Figure 3.3: Total emissions of VOCs expressed in kg VOCs per kg of solid mass input for the period 2013-2015

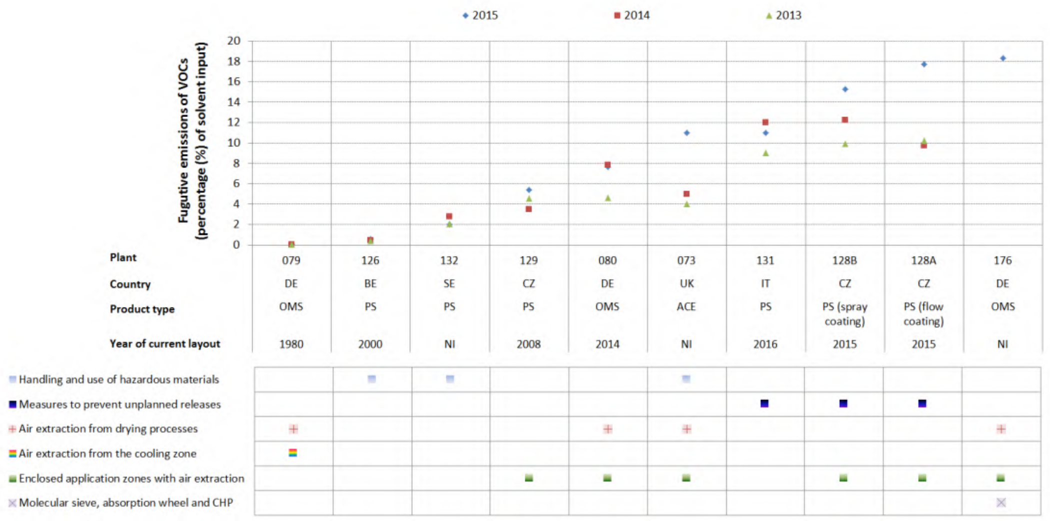
Contextual information related to the material and processes applied for the installations presented above is given in Table 3.10.

Table 3.10: Information on coating materials and techniques applied at installations for the coating of plastic and other metal surfaces

Plant	Coating materials (VOC content)	Thinner/cleaning materials (VOC content)	Application and enclosure	Colour change
079	SB (33-73 %)	SB (100 %)	Spray application in enclosed coating cabin	Batch painting/ colour grouping
126	Primer: SB (80 %) Base coat: SB (75 %) Clear coat: SB (55 %)	Primer: SF Base coat: SF Clear coat: SF	Primer: HRB Base coat: HRB Clear coat: HRB	First-generation colour changers – high paint loss
132	Primer: SB (80 %) Base coat: SB (75 %) Clear coat: SB (55 %)	Primer: SF Base coat: SF Clear coat: SF	Primer: HRB Base coat: HRB Clear coat: HRB	First-generation colour changers – high paint loss
129	Primer: SB-WB Base coat: WB Clear coat: SB	NI	NI	NI
165*	Primer: SB (40 %) Base coat: SB (40 %) Clear coat: SB (60 %)	Primer: SB (90%) Base coat: SB (90%) Clear coat: SB (90%)	Closed cabins with dedicated ventilation	NI
080	SB (72 %)	No thinner necessary	Airless application, paint container directly connected to robot, enclosed cabin	NI
176**	SB	NI	Pneumatic atomisation Enclosed cabins with extraction	NI

* One dryer (out of three) not connected to abatement system. Plant applies Reduction Scheme (RS).
** Reported emissions include methane emissions from the CHP units.
NB:
SB: Solvent-based; SF: Solvent-free; WB: Water-based; HRB: High-rotation bells.
NI: No information provided
Source: [155, TWG 2016]

The reported values of fugitive emissions of VOCs as a percentage of the solvent input are presented in Figure 3.4.



NB: For Plant #176, F value includes methane emissions from electricity production of CHP plant.
Source: [155, TWG 2016]

Figure 3.4: Fugitive emissions of VOCs expressed as percentage of the solvent input for the period 2013-2015

The comparison of the reported values for total and fugitive emissions of VOCs expressed as a percentage of the solvent input shows the dominant role of fugitive emissions in the overall emissions pattern, with contributions that in most cases are of the order of 90 % to 99 %. That emphasises the necessity to control fugitive emissions.

The following have been identified as major sources of fugitive emissions:

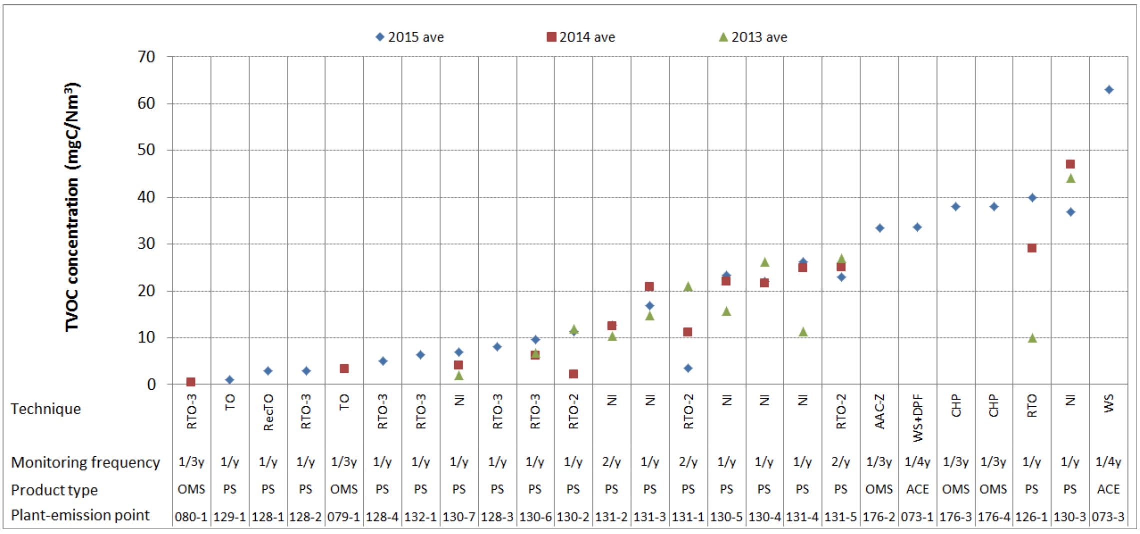
- paint storage;
- paint preparation - mixing area (area where the mixing of the different paints and addition of additives and thinners take place), including the paint sampling which is usually done in the absence of the vacuum system;
- coating processes;
- drying processes.

The following main techniques have been identified for the minimisation of fugitive emissions:

- Safe storage and handling of hazardous substances and measures to prevent unplanned releases.
- Enclosed application zones with air extraction.
- Thermal treatment of extracted air.
- Air extraction from drying processes. The drying ovens are operated with subatmospheric pressure to avoid fugitive emissions. The extracted air is treated.

3.3.2.2 TVOC emissions in waste gases

The reported values for periodic monitoring of VOC emissions in waste gases are presented in Figure 3.5.



Source: [155, TWG 2016]

Figure 3.5: TVOC emissions in waste gases (periodic monitoring) - Average values for the period 2013-2015

The basic statistical parameters of the submitted data for TVOC emissions in waste gases from plants for the coating of plastic surfaces, other metal surfaces and ACE are presented in Table 3.11.

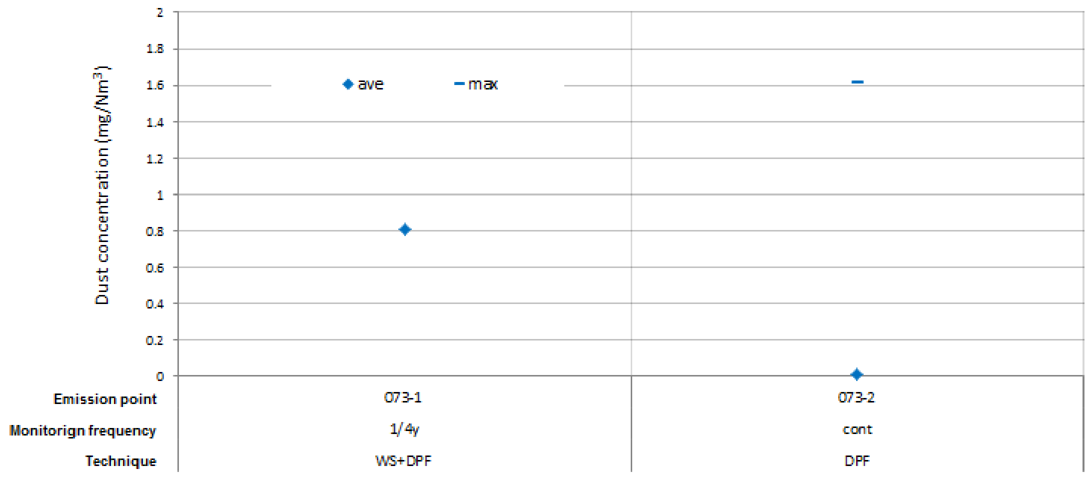
Table 3.11: Statistical parameters of reported data for periodic monitoring of TVOC emissions in waste gases for the period 2013-2015

Applied technique	2015				2014				2013			
	No of values	Ave-rage	Max.	Min.	No of values	Ave-rage	Max.	Min.	No of values	Ave-rage	Max.	Min.
		mg C/Nm^3				mg C/Nm^3				mg C/Nm^3		
AAC-Z	1	34	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TO	1	1	NA	NA	1	3.4	NA	NA	NA	NA	NA	NA
RecTO	1	3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
RTO-2	1	11.3	NA	NA	1	2.2	NA	NA	1	12	NA	NA
RTO-3	5	6.4	9.6	3	2	3.3	6.2	0.4	1	6.8	NA	NA
RTO	3	22.1	40	3.5	3	21.7	29	11.1	3	19.3	27	10
CHP	2	38	38	38	NA	NA	NA	NA	NA	NA	NA	NA
WS	1	63	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WS+DPF	1	34	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NB
NA: Not applicable/available.
Source: [155, TWG 2016]

3.3.2.3 Dust emissions in waste gases

Dust emission data associated with dust abatement techniques were reported only for one installation (two monitoring points). The reported values for monitoring of dust emissions in waste gases are shown in Figure 3.6.



Source: [155, TWG 2016]

Figure 3.6: Dust emissions in waste gases (data for 2015)

For the majority of reporting installations, dust abatement is not the top priority. Nevertheless, the use of dust abatement techniques (e.g. dry particle filter, wet scrubber) results in low dust emission values.

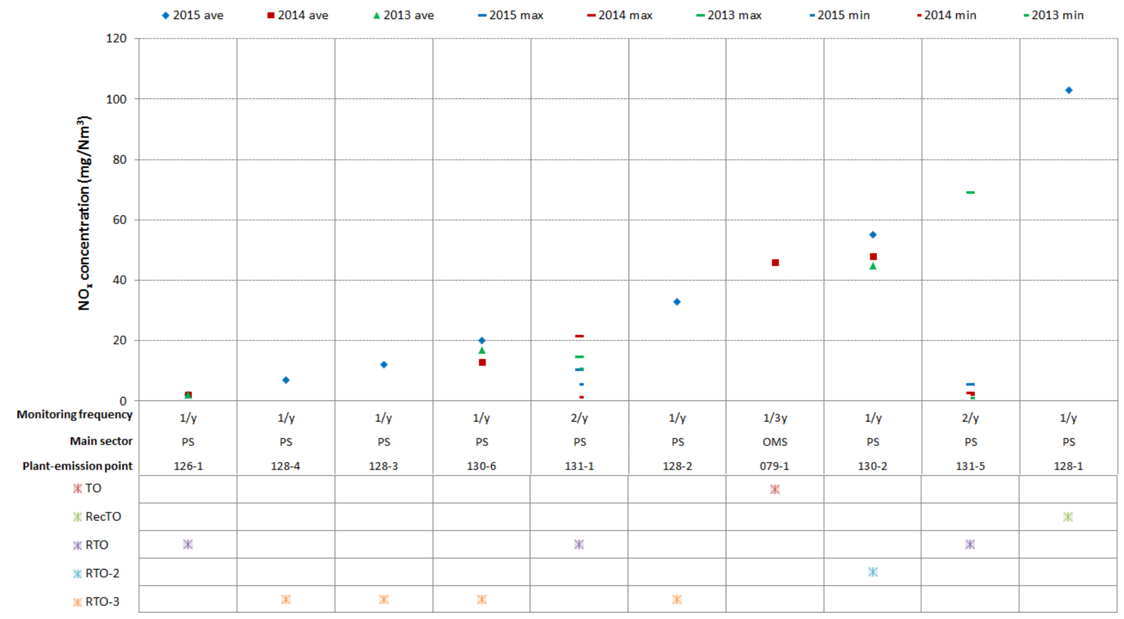
3.3.2.4 NO_X and CO emissions in waste gases

Nitrogen oxides (NO_X) and carbon monoxide (CO) emissions result from the thermal oxidation of off-gases. The reported values are presented in the following figures.

Nitrogen oxides

Data for 10 monitoring points (from five plants) were reported for NO_X emissions in waste gases with a yearly monitoring frequency in most cases. All of the reported values are lower than 105 mg/Nm^3.

The reported values for periodic monitoring of NO_X emissions in waste gases are shown in Figure 3.7.



Source: [155, TWG 2016]

Figure 3.7: NO_X emissions in waste gases for the period 2013-2015

Carbon monoxide

Data for eight monitoring points (from four plants) were reported for CO emissions in waste gases. The monitoring frequency varies between once a year and once every three years. Values for all emission points but one are lower than 45 mg/Nm^3.

The reported values for periodic monitoring of CO emissions in waste gases are shown in Figure 3.8.

Source: [155, TWG 2016]

Figure 3.8: CO emissions in waste gases for the period 2013-2015

3.3.2.5 Emissions to air from the coating of trains

[5, DFIU et al. 2002] [38, TWG 2004]

Only dust from overspray and blasting is deposited. Emission values of less than 3 mg/m^3 are achieved. VOCs from coating processes are emitted to the air as channelled or fugitive emissions. In some installations, thermal oxidation units are already used for treating the off-gases from the dryers. Emission values of less than 50 mg/m^3 are achieved.

However, as spray booths are extremely large and exhaust air volumes are around 200 000 m^3/h, dry filtering systems are preferred.

If a standard, solvent-based paint system without off-gas cleaning, about 326 g VOCs/m^2 are emitted. From the total solvent input of 187.6 tonnes into the inspected plant (Deutsche Bahn), 134.08 tonnes were emitted and 53.52 tonnes was disposed of as waste (a thermal combustion unit is not installed).

By the implementation of the following measures, emission values of < 110 g VOCs/m^2 are achieved:

- Material-specific techniques:
  - Application of water-based ground coats, primers and topcoats.
  - Only for two-layer lacquer finishes, an application of a conventional clear coat.
  - Water-based primers and underbody protection in combination with thick layer materials.
  - Water-based primers and fillers.
  - Minimum use of knifing fillers and use of low-styrene-content filler.
  - Processing of pre-coated (coil-coated) materials for new construction of rail vehicles. This technique minimises the emissions of the train coating installation but emissions occur at the coil coating plant.

- Process-specific techniques:

- Reduction of painted surfaces, for example, by the use of adhesive foils for decorative designs or as graffiti protection.
- Efficient application devices: HVLP, airless and air assisted airless spraying.
- Recycling of cleaning agents via distillation of solvent-containing paint wastes and paint sludge.
- Use of automated supply of coagulant for wet precipitation for increased service life of the water.

3.3.2.6 Emissions to water from the coating of trains

[5, DFIU et al. 2002] [38, TWG 2004]

Waste water is generated by the wet precipitation of overspray and the cleaning of application devices. More detailed data could not be determined.

3.3.2.7 Emissions to water from the coating of ACE

[5, DFIU et al. 2002] [78, TWG 2005] [41, ISACOAT 2004]

The rinsing tanks used for the pretreatment of workpieces generate waste water. In an installation, about 18-20 m^3 per day of waste water is generated. This amount can be halved by the implementation of the cascade technique. Due to the ultrafiltration unit, the dip coating installation does not generate waste water.

3.3.2.8 Waste generation

[155, TWG 2016]

The following table summarises the reported data on the main types of waste generated in the coating of plastic surfaces, other metal surfaces (OMS) and agricultural and construction equipment (ACE).

Table 3.12: Waste generation data

Waste type	Source	Quantity range (t/yr)	Solvent content (%)	Destination
Paint sludge	Production processes	50-400	0-2	Delivered off site
Phosphate sludge	Production processes	NI	NI	Delivered off site
Waste from coating removals	Production processes	3-4	2	Delivered off site
Water sludge	Waste water (pre)treatment	50-80	1-2	Delivered off site
Waste paint & varnish	Production processes	80-120	2	Delivered or sold off site
Waste solvents	Cleaning processes	50-170	5-95	Delivered off site
Sludge containing dust	Air emission abatement	35-80	1	Delivered off site
Used paint containers	Production processes	100-160	1	Delivered off site
Other contaminated packaging	Production processes	5-6	1	Delivered off site
Contaminated absorbents	Cleaning processes	1.5-3	2	Delivered off site
Solid waste from distiller	Distillation	1.5	38-75	Delivered off site
Liquid waste from distiller	Distillation	< 1	75	Delivered off site
Paint filters	Production processes	1-2	15	Delivered off site
Paint residues	Production processes	60-80	40-50	Delivered off site

NB: NI: No information provided.
Source: [155, TWG 2016]

The main identified techniques for the minimisation of waste generation are:

- use of reusable containers;
- distillation of used solvents;
- filter press for waste water sludge treatment and reduction of waste water volume;
- less colour changes in the process, resulting in lower solvent and cleaning material consumption.

3.4 Techniques to consider in the determination of BAT

In Chapter 17, techniques are discussed which might also be applicable to the serial painting of plastic and metal surfaces. In Table 3.13, the general techniques relevant for the serial painting of plastic and metal surfaces that are described in Chapter 17 are shown. These techniques are not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 17.1.

The EGTEI background document for the industrial application of paints (see Annex 21.3.1) gives some data on the costs and benefits at the European level of some techniques to reduce VOC emissions. However, the EGTEI approach necessarily has to limit its complexity, and only key techniques are given without consideration of the other BAT factors, such as cross-media effects, or of the technical characteristics of individual installations or products [92, EGTEI 2005].

Table 3.13: Reference to techniques generally applicable to the sector

Technique	Section number
Environmental management techniques	17.1
Storage and handling of raw materials	17.2
Monitoring	17.3
Water use and waste water generation	17.4
Energy management and energy efficiency	17.5
Raw material management (including substitution)	17.6
Coating processes and equipment	17.7
Drying and/or curing techniques	17.8
Cleaning techniques	17.9
Off-gas extraction and treatment	17.10
Waste water treatment techniques	17.11
Waste management techniques	17.12
Odour emissions	17.13

3.4.1 Minimisation of raw material consumption

Description
Some techniques to increase the resource efficiency and to reduce the amount of waste generated in the painting process are:

- optimisation of the painting process (see Sections 17.7.3 and 17.6.2), including automation (see Section 17.2.5);
- dewatering of paint sludge (see Section 17.12.4.1);
- recycling of paint sludge or the water emulsion.

Achieved environmental benefits
Reduction of the amount of waste (e.g. paint overspray) produced by the process.

Technical considerations relevant to applicability
These techniques are commonly applied in the coating of bumpers.

Example plants
Volkswagen, Wolfsburg, Germany.

Reference literature
[56, ACEA 2005]

3.4.1.1 Batch painting/colour grouping

For a general description, see Section 17.6.2.1. This technique is commonly applied in the coating of bumpers.

Colour block building can reduce the consumption of coating material and rinsing diluents. Furthermore, the rinsing thinner can be captured and reused. About 66 tonnes of rinsing diluent can thus be saved per year, for a recapture proportion of 90 %.
[5, DFIU et al. 2002]

3.4.2 Material-based techniques (substitution)

3.4.2.1 Water-based paints

Description
For a general description, see Section 17.7.2.2. Water-based coating systems can be applied for the ground coat, base coat and sometimes the clear coat. The following water-based paint systems are commonly applied:

- one-component acrylate dispersion: 5 wt-% organic solvent;
- two-component PUR system: 10-15 wt-% organic solvent;
- two-component epoxy resin: 5 wt-% organic solvent.

Achieved environmental benefits
The amount of solvents used can be reduced by up to 48 % by the use of water-based ground coats, and consequently solvent emissions can also be reduced accordingly in the case of coating of bumpers.

Technical considerations relevant to applicability
In the vehicle component supplier industry, water-based paints are already in use as fillers and base coats on, for example, bumpers and wheel covers. Water-based paints can lead to mechanical constraints on the physical characteristics of the plastic. In the painting of television, sound systems and computer housings, the serial use of water-based coatings is commonly applied.

Example plants
Plants #129 and #131 in [155, TWG 2016].

Reference literature
[5, DFIU et al. 2002] [38, TWG 2004] [119, May et al. 2006] [155, TWG 2016]

3.4.2.2 High-solids paints

Description
For a general description, see Section 17.7.2.1.

3.4.2.3 Powder coating – conventionally dried

Description
See Section 17.7.2.6. Powder coatings with conventional convection drying are not broadly applied due to the lack of electrical conductivity and the temperature sensitivity of plastics. They are only applied in small batches in the coating of small parts, such as composite parts of metal and plastics for car radiators.

Environmental performance and operational data
Developments in thermal curing low-temperature powder coatings look promising.

Reference literature
[5, DFIU et al. 2002]

3.4.2.4 Radiation cured paints

Description
See Section 17.7.2.3. UV-cured coatings are applied to clear coats, e.g. on wheel covers, and contain 10 wt-% organic solvent. A progressive technique is the automated application of UV-cured coatings during coating on reflectors; the coating system contains about 5-10 wt-% organic solvent. Another industrial application of UV-cured powder is for the coating of PVC floor tiles.

Achieved environmental benefits
Water-based and solvent-free radiation curing paints do not generate VOC emissions.

Environmental performance and operational data
UV-cured paints can be applied by several different techniques, such as brushing, rolling, casting, spraying and vacuum coating.

Cross-media effects
None.

Technical considerations relevant to applicability
These paints can be applied for all paint layers.

Example plants
Plant #128A in [155, TWG 2016].

Reference literature
[5, DFIU et al. 2002] [155, TWG 2016]

3.4.2.5 One-layer coating after fluoridation

Description
If pretreatment of the plastic surface is done by using the fluor preparation, the filling layer is partially not necessary because this technique already creates a homogeneous surface independent of the geometry of the workpiece.

Another advantage of fluoridation is that the fluoridated parts can be stored for a long time before being supplied subsequently for a following painting process.

Achieved environmental benefits
Reduction in VOC emissions and in coating materials.

Cross-media effects
None.

Reference literature
[5, DFIU et al. 2002]

3.4.3 Paint/coating application techniques and equipment

- Pretreatment (prior to coating) techniques are discussed in Section 17.7.1.
- Paint/coating application techniques are discussed in Section 17.7.3.
- Electrocoating for metal substrate is discussed in Section 17.7.3.6.
- Techniques for the minimisation of raw material consumption are discussed in 17.2.4.
- Automation of equipment is discussed in Section 17.2.5.

3.4.4 Off-gas extraction and treatment

Techniques for the extraction of off-gases and minimisation of fugitive emissions are discussed in Section 17.10.2.

A general description of external concentration of solvents in off-gases (as a pretreatment stage) is given in Section 17.10.3.3. Identified applied techniques are the molecular sieve buffer technique for elimination of VOC peaks (see Section 17.10.3.3.1) and adsorption to activated carbon or zeolites (see Section 17.10.3.3). See also Section 3.4.4.1.

Information on internal concentration of solvents in off-gases is provided in Section 17.10.3.2. See also Section 3.4.4.1.

The following off-gas treatment techniques are commonly applied:

- oxidation: recuperative and regenerative oxidation, see Sections 17.10.5.3 & 17.10.5.4;
- sending off-gases to a combustion plant (including CHP plants), see Section 17.10.5.1;
- adsorption using activated carbon or zeolites, see Section 17.10.6.2;
- absorption using a suitable liquid (wet scrubbing), see Sections 17.10.4.2 and 17.10.6.3;
- dry scrubbing, see Section 17.10.4.4;

3.4.4.1 Concentration and recirculation of waste gases from the painting booths

Technical description
Some manufacturers of plastic workpieces prefer to continue the use of solvent-based coating materials. This is because of the specific technical requirements (i.e. characteristics of plastic substrates, customer specifications, flexibility in use, ability to use wet-on-wet processes).

To assist in achieving low solvent emissions, the plastic coating industry concentrates the off-gas streams externally by means of rotating adsorbers (see Section 17.10.3.3). They also use internal recirculation (see Section 17.10.3.2) in spray booths with automatic application of the paint.

The exhaust air of a spray booth (typically 40 000–80 000 m^3/h) is recirculated after intense filtration (typically a venturi wet scrubber plus an additional filtering step) which achieves particle concentrations below 0.1 mg/m^3 in order to avoid optical surface defects on the workpieces. By reheating the exhaust after the wet scrubber, stable climatic conditions (about 70 % relative humidity) can be achieved. By achieving 90-95 % recirculation of air volumes, the solvent concentration in spray booths is multiplied by 10 or 20 (typically from 250 mg/m^3 to 2.5 g/m^3). The solvent concentration then has to be controlled for safety reasons (to remain sufficiently below lower explosive limits) and for technical reasons (the influence on the evaporation of solvents from workpieces). Between 5 % and 10 % of air volumes are sent to abatement. The low air volume and high solvent concentration are good preconditions for thermal oxidation.

Achieved environmental benefits
Reduction of VOC emissions and reduction of energy consumption for thermal treatment of off-gases.

Technical considerations relevant to applicability
Recirculation of air streams with increased solvent concentration is only suitable for installations which allow effective enclosure of spray booths (small inlet and outlet openings), where application is performed by automatic devices, and for workpieces without internal space volumes.

Economics
Reduced cost of thermal treatment, due to lower volumes, and a higher VOC concentration that can achieve autothermal conditions.

Driving force for implementation
See Economics above.

Example plants
Volkswagen, Wolfsburg, Germany.
Plant #176 in [155, TWG 2016] where a molecular sieve is used for smoothing of the peaks before adsorption wheel which then increases the VOC concentration for subsequent treatment in the CHP plant.

Reference literature
[119, May et al. 2006] [155, TWG 2016]

3.4.5 Water management

Description
See Section 17.4. One of the techniques to consider is the minimisation of dumping of the tanks from the spray booths to reduce water consumption and effluent discharges by minimising the build-up of paint sludge. Optimising the paint transfer efficiency also reduces the need to change the water.

Reference literature
[56, ACEA 2005]

4 COATING OF SHIPS AND YACHTS

[5, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005] [202, SEA SMRC 2017]

4.1 General information on the coating of ships and yachts

Ships are largely constructed from shipbuilding steel, and yachts are constructed from shipbuilding steel and aluminium, as well as FRP (fibre-reinforced plastics). These materials corrode or deteriorate if unprotected and must therefore be preserved by means of corrosion protection systems. The required costs in the case of ship construction amount to about 3-7 % of the total construction costs. Corrosion protection enhances ship safety during passage, maintains the ship's value and reduces maintenance costs. Different parts of a ship, e.g. the hull (above and below water), outside decks, hold and tanks, are exposed to a varying degree of corrosion so different corrosion protection systems are applied. Fouling prevention by the application of antifoulings is also important. Resistance to mechanical action on surface areas and decks and visual quality in various areas are also key factors in the specification of coatings.

The requirements for the coating of ships and yachts are different. For the coating of merchant ships, adhesion, corrosion protection and prevention of fouling are the key issues. For the coating of yachts, appearance also plays a crucial role; therefore, the coating of merchant ships and yachts are described separately. Due to different construction, coating and pretreatment processes, the coating of new ships and the repair and maintenance are also considered separately. No information on the coating of warships has been submitted.

In 2015, European shipyards, constructed, maintained and repaired ships with a value of more than EUR 33 billion. The maritime equipment manufacturers, who highly depend on building, maintaining and repairing ships in Europe, contribute to another EUR 47 billion of turnover. European ship repair activities amounted to a total turnover of EUR 3 billion in 2015. All combined, this results in the direct employment of about 450 000 people in more than 22 000 companies.

The EU's recreational boating industry comprises 32 000 directly involved companies, 280 000 direct employees, and more than EUR 20 billion in annual manufacturing turnover. Of the 32 000 companies, approximately 90 % of these businesses are SMEs. This figure includes repair and maintenance of superyachts, marine engine manufacturers, marine and yacht coat manufacturers and applicators, high-technology electronics companies and equipment manufacturers. However, it excludes the superyacht new-build sector which for 2016 had an order book of 424 orders with an average length of 48 metres.

4.2 Applied processes and techniques in the coating of ships and yachts

Coating systems consist of one or more layers of solvent-based, low-solvent or solvent-free coatings. The bonding agent bases are predominantly epoxy resin (usually two-component), polyurethane, acrylates, polysiloxanes and alkyds. The total layer thickness is 100 µm or higher for ship internal areas and up to 1 000 µm for outside areas. A thicker layer of special top coatings are usually applied to ramps and working areas and fillers can be applied at around 2 500 µm. Coating materials are usually applied by means of airless spraying processes, which enable the processing of low-solvent and solvent-free products. Application by conventional spray, rollers and brushes is widely used in coating yachts, and rollers are used for pre-delivery coating of passenger ships. They are not widely used in other parts of the industry (with the exception of small areas). Rollers and brushes are used for repair, maintenance and so-called stripe coating.

For new construction, repair and maintenance of ships and yachts, both the surface preparation and coatings are defined by shipowner specifications. The specifications will consider the required corrosion and physical protection, appearance and antifouling, and also the warranty requirements. In repair and maintenance yards, the customer purchases the coatings directly for shipyard application.

4.2.1 New construction

The coating of ships is mainly carried out by contractors that specialise in corrosion protection for shipbuilding. In modern shipbuilding, sheet metal is made into sections or block stages. These are large sub-assemblies which are then joined together in a building dock or slipway (ships were previously built in the dock from the keel up). These are then coated after surface pretreatment with a coating system according to the specifications. Multiple coating of the sections takes place in the open air, in large shipbuilding halls (usually a covered dry dock or covered slipway) or in specially equipped blasting and coating shops. Areas left free of coating for welding are finished on the completed hull on the stocks or in the dock. In smaller shipyards, the hull is completely coated once it is assembled on the stocks or in the dock.

Corrosion protection begins with primary surface pretreatment according to standard specifications on degrees of preparation. All steel plates and sections used to construct the ship are completely cleaned of mill scale, rust and other impurities by blasting in automated plants. This gives the steel surface a specific roughness to ensure good coating adhesion. Subsequently, a shop primer (solvent- or water-based) is sprayed on which protects the steel until further coating is applied as well as enabling the steel to be welded. Steel plates and sections are often treated with a shop primer by the supplier. Surface treatment of the assembled steel plate sections, or of the complete hull, is carried out by secondary surface preparation, which can be partial blasting with a dry or wet agent, power tool (rotating wire brush or disc) or by angle grinding. This removes corrosion on welding seams as well as all impurities, and roughens the surface. Since not all impurities, like grease, oil or salt, can be removed by derusting, suitable methods for cleaning need to be considered, such as cleaning with solvent or cleaner to remove oil and grease or with fresh water to remove salt. At several shipyards, sections are treated in dedicated blasting and coating shops.

In enclosed areas, ventilation systems are used and may include dust and VOC abatement. Blasting grits can be collected and treated for reuse and/or recycling.

The coating of yachts is carried out either by a specialist team within the yard or by specialist subcontractors who can achieve the quality of finish required for the yachts. Increasingly, water-based shop primers are being used for both steel and aluminium yachts. The application process for superyachts is according to ISO standards.

4.2.2 Ship repair and ship maintenance

Repair and maintenance (including coating) of the hull is carried out during dry docking in graving (concrete) or floating (steel) docks. Depending on the condition of the surface, the damaged areas are locally cleaned, prepared and recoated, or, in rare cases, the coat is completely removed from the hull for recoating. Cleaning of the areas to be treated can be by dry or wet blasting or high-pressure fresh water jetting. More than 50 % of the areas to be blasted are ‘spots’; the others are larger areas but almost never complete stripping.

Every 2 to 5 years, the antifouling coating on the ship’s hull is renewed in dry dock depending upon the type of coating and the service time of the vessel. The complete hull is coated with solvent-based antifouling applied by airless spraying. The overspray is partially emitted into the environment, depending on the control measures in force.

The coatings are specified by the shipowners. Large repair yards may treat four or more ships simultaneously, with coatings specified from different suppliers. Application of coatings contributes to up to 15 % of the turnover of repair and maintenance yards. In parallel, a lot of additional work is done by the yard while the ship is being coated. This work contributes to an additional turnover for coating but is only done at that yard as the ship is undergoing coating. In this way, the application of the coating indirectly contributes to a far higher percentage of the turnover than the coating alone.

4.2.3 Coating of ships

The preparation for, and application of, coatings for new-build construction and for maintenance is usually carried out in areas open to the outside air.

Corrosion protection of the hull
Coating is carried out according to the maintenance and docking plan of the ship. Coating systems are chosen by the shipowner taking into account the lifetime of the antifouling coating and the required corrosion protection and colour. The areas to be coated are degreased, prepared and the specified coatings (usually epoxy coatings, polyurethanes and acrylics) are applied. This is usually done by airless spray. The coatings meet visual requirements, such as colour and gloss, as well as resistance to mechanical and corrosive action. Coating materials are generally supplied in 20-litre cans, although for large-scale applications 1 000-litre reusable (IBC) containers can be used. However, in the case of maintenance and repair yards of ships above 15 000 GT, they are not commonly used as each individual client buys their own coating at the exact quantity needed for each coat. Larger containers would create additional costs and coating leftover requiring disposal.

Tie coat (hull)
As a tie coat (coupling agent) between the corrosion protection coat and the final antifouling coat, a solvent-based, one- or two-component vinyl resin or epoxy tie coat is applied. The tie coat is also applied using the airless spraying technique. The layer thickness amounts to approximately 75-100 µm.

Antifouling (hull)
[78, TWG 2005] [123, Kiil et al. 2006] [202, SEA SMRC 2017]

Antifouling coats are applied to ship hulls to prevent settlement and growth of fouling organisms (bacteria, algae and animals). This can in some cases also be done by applying fouling-release coatings (see Section 4.4.7). Settlement of fouling increases the surface roughness, leading to increased frictional resistance, which in turn leads to increased fuel consumption to keep the same speed or decreased speed at the same fuel consumption. Up to 150 kg of organisms can settle on one m^2 of surface area within 6 months. The increased frictional resistance can raise the fuel consumption and thereby the ship’s emissions by up to 40 %. This will result in either increased bunker costs or expenses due to lost earnings or time delays. Fouling of the ship hull also decreases the manoeuvrability of the vessel and increases the possibility of premature corrosion. Furthermore, by applying an antifouling coat, the potential for transmigration of fouling organisms is also decreased. Therefore, application of antifouling is a matter of importance from environmental, safety and economical points of view.

Regulation (EU) No 528/2012[23] regulates the use of biocides and biocidal products, e.g. antifouling, in Europe. Worldwide, the use of antifouling coats is regulated by the IMO International Convention on the Control of Harmful Anti-Fouling Systems on Ships that prohibits the use of harmful organotins in antifouling coats used on ships and establishes a mechanism to prevent the potential future use of other harmful substances in antifouling systems. To date this Convention only considers organotins as harmful substances.

Coating of the superstructure and freeboard
The coating systems for the superstructure and freeboard are also chosen by the customer. The damaged areas are degreased, prepared and coated with the specified coats (usually solvent-based epoxy coatings, polyurethanes, acrylics), usually applied by airless spray. In holds and water tanks, single and multilayered epoxy resin (two-component) coatings are generally used.

4.2.4 Coating repair and maintenance of yachts

Yachts are leisure vessels with a length of up to 180 m, although there have been recent developments of up to 190 m and 200 m. Yachts are already partly coated before assembly. Depending upon customers’ requests, the applied coating system varies and for this reason only one option is described below.

Large yachts are made of shipbuilding steel and aluminium, but the majority of yachts (the smaller vessels) are made from FRP (fibre-reinforced plastic). Parts of the whole yacht or only the superstructure may be made of aluminium or composite materials. Sanding takes place between the application of coating layers. Depending on the material, pretreatment and application of the primer are different. The use of water-based materials for coating yachts is increasing as well as other new ways of applying coatings like wrapping (foil application).

Although airless spraying is widely used and accepted, rollers and brushes are still in use, depending on the kind of coating used and quality required.

Pretreatment and primer application on shipbuilding steel
First the hull and the superstructure are treated by grit blasting and then either a filler based on zinc phosphate or a chrome- and zinc-free shop primer is applied as a primer in order to obtain the correct profile and a smooth finish (e.g. covering welding roughness). Both materials are solvent-based epoxy resins. The layer thickness varies from 40 µm to 60 µm.

Pretreatment and primer application onto aluminium
For the degreasing and removal of oxidised layers, aluminium surfaces are treated with cleaning agents. Afterwards, a two-component epoxy primer or a one-component PVC primer is applied. Similarly to the coating of ships, a corrosion protection coat is sprayed onto the primer layer. This solvent-based epoxy material is applied by the airless technique in two to four layers with a thickness of approximately 120 µm each. The antifouling is usually applied directly to the epoxy coat. If a tie coat is used, it is a solvent-based, one-component vinyl coat, which is applied via airless spraying. The layer thickness amounts to about 40 µm.

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[23] Regulation (EU) No 528/2012 of the European Parliament and of the Council of 22 May 2012 concerning the making available on the market and use of biocidal products.

Afterwards, two layers of a solvent-based antifouling material are applied by airless spraying or by roller. The thickness of each layer of antifouling coating is approximately 100 µm. Usually, copper-based, self-polishing antifouling coatings are used. However, they may also contain other biocides.

Coating of the superstructure

Like the hull, the superstructure is made of shipbuilding steel or aluminium and is also coated with two layers of a solvent-based (one- or two-component epoxy or polyurethane coat) corrosion protection material. It is applied using the airless spraying technique. The layer thickness applied amounts to about 120 µm.

After the corrosion protection coat has dried, filling materials are applied onto the aluminium and shipbuilding steel of the superstructure in order to obtain the correct profile and a smooth finish (e.g. covering welding roughness). The materials are applied using trowels, long boards and bations, spatulas. They may be solvent-free or contain approximately 80 g/l benzyl alcohol. Sanding takes place in between these processes.

After the filling, a solvent-based two-component polyurethane filler or a solvent-based epoxide filler is applied by using airless spraying techniques. The layer thickness applied is in the range of 50-100 µm. A primer/undercoat is applied over the filler.

The yacht is taken for sea trials when the appropriate coat has dried; this may or may not be the primer coat. After the trials, the yacht is cleaned with fresh water and sanded and then the final topcoat is applied.

The topcoat is applied by using a wet-on-wet spraying technique, and two or three layers are applied. The materials used are generally solvent-based, two-component, polyurethane combination lacquers. The complete layer thickness amounts to approximately 100 µm.

In several Member States where yachts are repaired or maintained, the removal of antifouling from yachts is carried out using techniques to collect and treat the removed antifouling to prevent water pollution.

4.3 Current consumption and emission levels in the coating of ships and yachts

[155, TWG 2016] [202, SEA SMRC 2017]

Data from three installations (one from Finland, one from Portugal and one from the UK) were submitted for the data collection.

4.3.1 Mass balances

[155, TWG 2016]

Submitted data for two installations show an average coating consumption per m^2 of coated surface that ranges from 0.4 kg up to 2 kg.

Data for one installation (Plant #076) on the solvents content show a considerable variation due to contract quality specifications: 18 wt-% (2013), 27 wt-% (2014) and 40 wt-% (2015).

4.3.2 Consumption

4.3.2.1 Materials

[78, TWG 2005]

For the coating of ships, solvent-based coats are usually applied. Depending on the material used, the solvent content is in the range of 20-40 wt-%. Due to the processing conditions (humidity, temperature, air draught, etc.) and surface conditions, water-based coats only have a limited area of application (only partly used for interior areas and prefabricated parts). Consumption of materials will depend on the size of the vessel, specifications to be met, etc.

The material consumption in repair yards for medium-sized ships (> 15 000 GT) is approximately 15 tonnes per coated merchant ship (based on data from Portugal, Greece, Malta and Italy). The corresponding VOC usage is approximately 6 tonnes. A large repair yard can repair from 60 up to 150 ships with an average size of 40 000 GT (or above) per year.

In a new-build shipyard, the material consumption for complete coating of one 40 000 GT ship is approximately 68 tonnes. HDW Kiel in Germany processes up to 59 t/yr of solvent for a maximum of five ships a year. Blohm + Voss GmbH in Hamburg, Germany processes about 60 t/yr of organic solvents.

4.3.2.2 Water

[155, TWG 2016]

In repair and maintenance yards, the consumption of fresh water for high-pressure cleaning (between 220 to 340 bar) of the complete hull varies between 500 tonnes and 2 000 tonnes for medium-sized ships (>15 000 GT).

Reported data on water consumption indicate a specific water consumption that varies between 0.1 m^3/m^2 and 1.1 m^3/m^2 of coated surface.

The reported techniques for reduction of water consumption are:

- control of water usage by applying (ultra-)high-pressure (U)HP water washing of the vessels prior to coating;
- oil skimmer for the treatment of waste water from cleaning which may facilitate its reuse.

4.3.2.3 Energy

[155, TWG 2016]

Submitted data on energy consumption show a specific energy consumption range that varies between 0.01 MWh/m^2 and 0.67 MWh/m^2 of coated surface. There are two important parameters that have to be taken into consideration:

- the specific energy consumption is directly related to the degree of utilisation of the production capacity: the greater the throughput the lower the specific energy consumption value; and
- the uncertainty as to whether the reported energy consumption data refer only to the STS activity or whether they include other non-associated activities (definition of the energy boundaries of the STS activity, see also Section 17.5.2).

4.3.3 Emissions

[78, TWG 2005] [155, TWG 2016] [202, SEA SMRC 2017] [212, TWG 2018]

4.3.3.1 Emissions to air

Processes in shipyards are generally carried out outdoors, in dry docks, in open workshops or on the quay. Therefore, all emissions generated by grinding and blasting (dust) or painting operations (overspray and VOCs) are emitted as fugitive emissions.

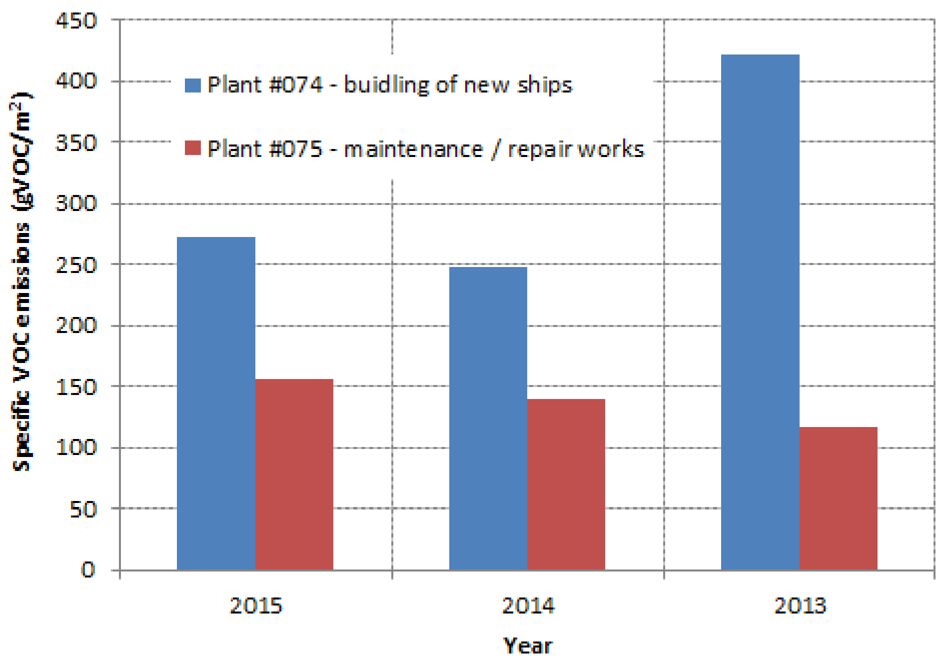
Emissions of environmentally hazardous materials from coating processes in the construction of new ships can be reduced effectively by the utilisation of closed workshops for coating and blasting operations. These may also be used for the construction of block stages – sections of a new or significantly upgraded ship that are prefabricated and then lifted into place. Closed workshops may have air extraction with filters for dust and/or off-gas treatment units for VOCs.

As far as technically possible, paint and varnish systems with an average solvent content of 20 % to 25 % are used for initial and new coatings on ships. Overall, a limit on the total emission of 100 g of solvent per square metre of coated surface is maintained. For the refinishing of ships, paint and varnish systems are used, which on average have a solvent content of up to 40 %. The applied state of the art for reducing VOC emissions should be regularly reviewed, adjusted and demonstrated to the competent authority [DE comment #272 in [212, TWG 2018]].

In repair yards for medium-sized ships (> 15 000 GT, with an average 70 000 GT), the coats used contain on average about 30-40 % organic solvents. About 150 g VOCs are emitted per m^2 coated, as the antifouling coats form the largest amount of coat applied.

A full coating scheme for a new superyacht has a VOC consumption for the underwater area up to 500 g VOCs/m^2 and above the waterline up to 250 g VOCs/m^2. New yacht construction is usually carried out in closed facilities, and also using rollers and brushes, which have high application efficiency with no overspray. For large (super and mega) yachts, this will be according to the client’s specification. Repair and maintenance of the large megayachts may be done in docks, but for most of them maintenance and repair are also carried out in closed facilities.

Submitted SMB data for two plants show that total VOC emissions expressed against the production throughput vary between 117 g VOCs/m^2 and 422 g VOCs/m^2 (see Figure 4.1).



Source: [155, TWG 2016]

Figure 4.1: Total emissions of VOCs expressed in g VOCs per m^2 of coated surface for two plants for the period 2013-2015

As the activity is mainly carried out under non-contained conditions, the fugitive VOC emissions are equal to the total emissions.

The figures reported on the solvent flow in waste (parameter O6 of the solvent mass balance) for the two installations show a range from 5 % up to 60 % of the solvent input.

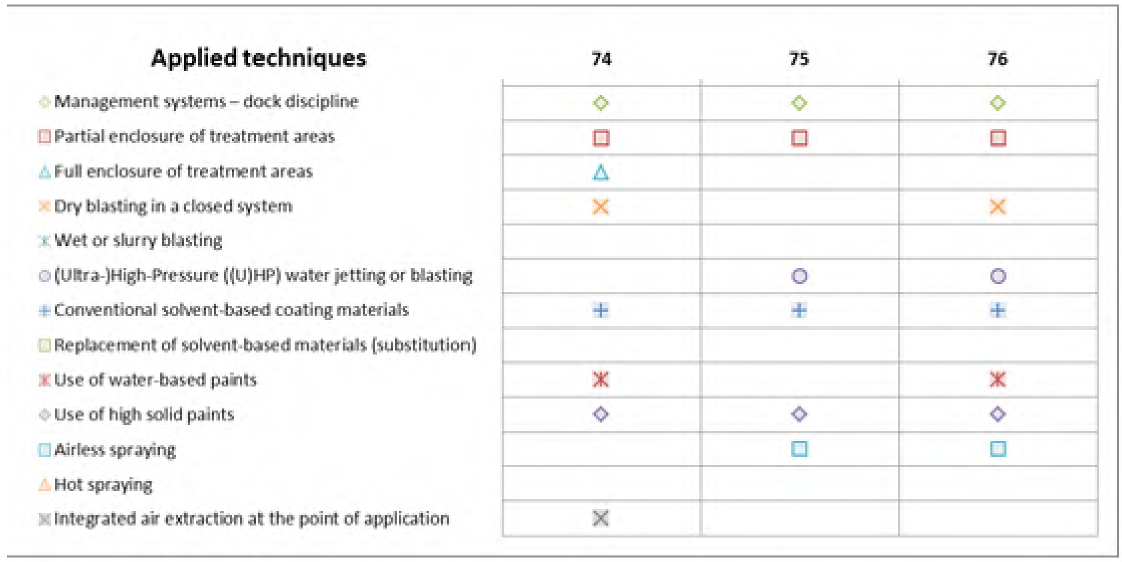
Reported data on total emissions of VOCs expressed as kg of VOCs per kg of solid mass input are presented in Table 4.1.

Table 4.1: Total emissions of VOCs expressed in kg VOCs per kg of solid mass input for the period 2013-2015

Plant	Activity type	Year of current layout	Total emissions of VOCs (kg of VOCs per kg solid mass input)		
			2015	2014	2013
074	Building of new ships and yachts	2011	NI	NI	NI
075	Maintenance/repair works	2001	NI	NI	NI
076	Maintenance/repair works	1985	0.37	0.36	0.35
*	Maintenance/repair works	NI	0.41	0.45	0.39

* Additional anonymised data submitted by industry (May 2018).
NB:
NI: No information available.
Source: [155, TWG 2016]

The techniques applied for the minimisation of total emissions at three of these plants are presented in Figure 4.2.



Applied techniques	74	75	76
◇ Management systems – dock discipline	◇	◇	◇
□ Partial enclosure of treatment areas	□	□	□
△ Full enclosure of treatment areas	△		
× Dry blasting in a closed system	×		×
× Wet or slurry blasting			
○ (Ultra-)High-Pressure ((U)HP) water jetting or blasting		○	○
+ Conventional solvent-based coating materials	+	+	+
□ Replacement of solvent-based materials (substitution)			
✱ Use of water-based paints	✱		✱
◇ Use of high solid paints	◇	◇	◇
□ Airless spraying		□	□
△ Hot spraying			
☒ Integrated air extraction at the point of application	☒		

Source: [155, TWG 2016]

Figure 4.2: Reported applied techniques for minimisation of emissions of VOCs

4.3.3.2 Emissions to water

Maintenance operations generate wasted blasting materials, coat residues, used containers and overspray. There may be other residues from maintenance, such as oil residues (containing hydrocarbons), mud, scrapped materials, etc. After maintenance operations, all wastes are collected and the dock is cleaned to prevent emissions to the water entering the dock. Waste water collected can be treated by several techniques as described in Section 4.4.9. The treated water is either disposed of or reused.

Where water blasting or slurry blasting is used to avoid dust emissions from blasting, the process water is commonly treated either in integrated equipment or at a waste water treatment plant. The water is usually reused.

A COM study[24] identified the main parameters and other substances of interest that may be discharged in waste waters and therefore to be considered for the data collection. In addition to the ones set out in Table 4.2 below, organotin compounds and biocides were identified as relevant but no data were collected. However, only two sets of data were received from shipyards: one with a waste water treatment plant and one applying coarse filtration.

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[24] COM working document EIPPCB 09/06/2016: Assessment of Technical Working Group (TWG) data submitted on metals and other emissions to water for their consideration as Key Environmental Issues for installations carrying out IED Annex 1 6.7 activities.

Table 4.2: Shipyard waste water data

Type of WWT	Plant #075					Plant #076				
	Coagulation, flocculation and sedimentation. Combined treatment for all shipyard activities (not only for STS activity)					*In situ* coarse filtering in dock bottom with hay bales and hessian, direct discharge				
Parameter	Average	Maximum	Minimum	Monitoring frequency	Type of sampling	Average	Maximum	Minimum	Monitoring frequency	Type of sampling
	(mg/l)					(mg/l)				
TSS	8.2	21	4.5	Monthly	Time-proportional composite sample	15.5	34.9	1.6	Monthly	Spot (grab) sample
COD	39.8	86	10	Weekly	Time-proportional composite sample	NI	NI	NI	NI	NI
Zn	0.08	0.14	0.05	Monthly	Time-proportional composite sample	NI	NI	NI	NI	NI
Ni	NI	NI	NI	NI	NI	0.01	0.06	< 0.01	Monthly	Spot (grab) sample
Cd	0.016	0.05	0.002	Monthly	Time-proportional composite sample	< 0.01	< 0.01	< 0.01	Monthly	Spot (grab) sample
Pb	NI	NI	NI	NI	NI	0.01	0.09	< 0.01	Monthly	Spot (grab) sample
Cu	0.11	0.25	0.03	Monthly	Time-proportional composite sample	0.12	1.98	< 0.01	Monthly	Spot (grab) sample
Cr	NI	NI	NI	NI	NI	0.01	0.08	< 0.01	Monthly	Spot (grab) sample
Sn	0.019	0.04	0.01	Monthly	Time-proportional composite sample	NI	NI	NI	NI	NI

Source: [155, TWG 2016]

4.3.3.3 Waste generation

[155, TWG 2016] [202, SEA SMRC 2017]

Waste from the maintenance operations of ships includes:

- organic cleaning solvents;
- coat sludges/residues; it is reported that waste coats represent 2.5 % up to 8.5 % of total coating consumption with an average solvent content of about 30-40 %;
- contaminated coat containers, brushes and rollers;
- used/contaminated blasting materials (e.g. used grit);
- filters;
- oil residues (containing hydrocarbons);
- mud;
- scrapped materials.

One plant reported the use of reusable containers for coatings.

During the coating of ships, especially in maintenance operations, large amounts of wasted blasting materials are generated. Like all the other wastes, wasted blasting materials are disposed of in licensed facilities.

4.4 Techniques to consider in the determination of BAT for the coating of ships and yachts

[155, TWG 2016] [202, SEA SMRC 2017]

In Chapter 17, techniques are discussed which might also be applicable to the coating of ships and yachts. In Table 4.3, the general techniques relevant for the coating of ships and yachts that are described in Chapter 17 are shown. These techniques are not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 17.1.

Table 4.3: Reference to techniques generally applicable to the sector

Technique	Section number
Environmental management techniques	17.1
Storage and handling of raw materials	17.2
Monitoring	17.3
Water use and waste water generation	17.4
Energy management and energy efficiency	17.5
Raw material management (including substitution)	17.6
Coating processes and equipment	17.7
Drying and/or curing techniques	17.8
Cleaning techniques	17.9
Off-gas extraction and treatment	17.10
Waste water treatment techniques	17.11
Waste management techniques	17.12
Odour emissions	17.13

4.4.1 Management systems – dock discipline

Description

As part of the EMS (see Section 17.1), the set of procedures, functions and task definitions, and working methods, for the prevention or limitation of emissions such as dust emissions to air, emissions to water, and quantity of waste generated.

Technical description

This is a specific management system defining the different entities responsible for performing works in dry docks and slipways, including the preparation for docking, careening and undocking vessels. It also includes the maintenance, repair or building activities carried out in dry docks and slipways, such as surface treatment operations (cleaning, removal of old coat and antifouling, etc.). It controls the collection of wastes, during operations and before dock flooding, and the forwarding of wastes to licensed receivers for their further appropriate management and/or disposal.

Dock discipline also covers other issues that assist in reducing pollution, such as when and where to carry out potential polluting activities. For example, describing in under what wind conditions grit blasting and spraying in the open air can be carried out, requiring these activities to be carried out at the bottom of the dock or slipway and portable equipment to be used (nets, water curtains, etc.).

It may contain part of, or all, the requirements of an EMS (see Section 17.1).

Achieved environmental benefits

Minimisation of environmental impacts from the installation.

Environmental performance and operational data
See Technical description above.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation
Meeting legislation provisions for health and safety and the environment for air pollution, water pollution and waste management, particularly as these provisions apply to ports, harbours and enclosed waters, etc.

Example plants
Widely applied in the industry.

Reference literature
[78, TWG 2005] [121, Portugal 2006] [153, Bert de Vries VNSI 2011]

4.4.2 Techniques to reduce dust emissions

4.4.2.1 Partial enclosure of treatment areas

Description
Fine nets and/or water spray curtains are used around areas where grit blasting and/or airless spray coating are carried out to prevent dust emissions. They may be permanent or temporary.

Achieved environmental benefits
Reduction in emissions of drifting particles from grit blasting and spray coating, either by reducing wind strength or by trapping particles.

Environmental performance and operational data
There are reports of practical difficulties using nets and the larger the ship in comparison with the dry dock, the more difficult they are to use. They cannot be used in repair yards for medium-sized ships (> 15 000 GT) in large dry docks and the following are typical examples of problems encountered:

- variations in the size and type of ship, the ships may overhang the dock ends, etc.;
- interference with cranes and other equipment; and
- problems with access for other maintenance operations.

Where used, the nets are usually placed at one or both ends of a dock, around smaller docks or between the ship and the dockside.

Cross-media effects
Energy consumption for pumping water sprays or curtains, and possible treatment of the waste water.

Technical considerations relevant to applicability
Applicability may be restricted by the shape and size of the area to be enclosed. See Environmental performance and operational data above. Water spray curtains may not be applicable in cold climatic conditions.

Driving force for implementation
Low cost compared to full enclosure.

Example plants
Plants #076, #075 and #074 in [155, TWG 2016].

Reference literature
[5, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005] [122, CEPE 2006] [151, CESA 2011] [154, Nordic Council of Ministers 2016] [155, TWG 2016]

4.4.2.2 Full enclosure of treatment areas

Description
Blasting and/or airless spray coating are carried out in halls, closed workshops, areas tented with textiles or areas fully enclosed with nets to prevent dust emissions. Air from the treatment areas is extracted and may be sent to off-gas treatment.

Technical description
Enclosed areas are used to control the local working environment, enabling temperature and humidity control for working and surface preparation, protection from rain, etc. Enclosed areas usually have air extraction for occupational health reasons, and this can be used in conjunction with off-gas treatments to control the emissions of environmentally harmful materials. The equipment may be for dust abatement and/or with an off-gas treatment unit for VOCs.

Some areas, such as slipways, ship's blocks and small docks can be temporarily or semi-permanently enclosed or ‘tented in’ (e.g. portable structures or tenting kept on site for long periods of time). This assists control of dust from blasting and overspray, but, unless the area is sufficiently enclosed, adding off-gas treatment for dust and VOC reduction is likely to require the treatment of large volumes of air with high energy usage. If the enclosure has a flexible construction or is not sufficiently enclosed the extraction for treatment of VOCs may not be possible.

Tenting may also be applied between a ship and the dockside, to help prevent the drift of dust and overspray and keep rain off prepared and freshly coated areas.

Achieved environmental benefits
Retention of particles from blasting and spraying. Removal of dust and/or VOCs from the extracted air streams by off-gas treatment becomes possible.

Environmental performance and operational data
The technique provides improved quality control of processes and working environment. It can increase available working time during the day and/or year.

Cross-media effects
Energy used for air extraction.

Technical considerations relevant to applicability
Applicability may be restricted by the shape and size of the area to be enclosed.

Enclosed halls are more often used for fabrication and building of ships.

Permanent workshops can be used for preparing steel plates, sections and block stages in new construction. In some cases, whole docks may be enclosed. The docks used for the repair and maintenance of ships are not enclosed (and possibly not those used for some megayachts).

For yachts, the preparation and coating areas are usually enclosed, either permanently or semi-permanently, both for new build and repair and maintenance, due to the requirements of ISO 19494.

Economics

This technique implies the capital cost of the construction of workshops, and the capital costs and running costs of abatement equipment.

Driving force for implementation

Improved quality control of coating processes and internal climate control (i.e. weather protection) allowing for all-day/year-round working. Legislation for health and safety and dust.

Example plants

Plant #074 in [155, TWG 2016], HDW Kiel, Germany.

Reference literature

[5, DFIU et al. 2002] [78, TWG 2005] [122, CEPE 2006]
[154,Nordic Council of Ministers 2016] [155, TWG 2016]

4.4.2.3 Restrictions for adverse weather conditions

Description

Where the treatment areas are not fully enclosed, blasting and/or airless spray coating are not carried out if adverse weather conditions are observed or forecast.

Technical description

A technique used by yards with no full containment facilities is the restriction of coating removal and airless spray coating when adverse weather conditions are observed or forecast. Adverse weather conditions are significant wind speed (variable within each yard, depending on available facilities and their location) and adverse dominant wind direction (e.g. towards watercourses, housing and other sensitive targets).

Achieved environmental benefits

Reduced dust emissions.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

- Low cost, requiring only simple monitoring equipment.
- Lost working time when conditions are adverse.

Driving force for implementation

Adverse reaction from public affected by dust and overspray.

Example plants

Generally applicable where no full containment is in place.

Reference literature

[151, CESA 2011]

4.4.3 Surface preparation

In new build and for new materials, the surface requires pretreatment to provide adhesion. For repair and maintenance, old coat layers are removed, particularly loosely adhered and damaged areas. The preparation method is defined in the agreed coat specification, depending on the coating system to be applied and the warranty given.

Some techniques use an abrasive material to remove the coating layers, and of these a few create a large amount of dust. The used abrasive material can be recovered and reused or disposed of as waste, depending on the technique used. With all techniques, it is good practice to remove the residues from dry docks before flooding (see dock discipline, Section 4.4.1).

4.4.3.1 Dry blasting in a closed system

Description
Dry blasting using steel grit or shot is carried out in closed blasting systems equipped with a suction head and centrifugal blasting wheels.

Achieved environmental benefits
Benefits include low dust emissions. The blasting material may be recovered for reuse, therefore there is less waste. Removed antifouling and coating are recovered with the blasting material and separated for disposal.

Environmental performance and operational data
Mechanical blasting equipment is operated by hand or fixed to the arms of tool carriers and passed along the area to be treated by remote control.

A typical system for new-build preparation may be steel shot-blasting applied in a closed loop and at a pressure of about 5 bar.

Technical considerations relevant to applicability
Generally applicable. It can be used for the removal of rust and old layers of coat from decks and external sides including the hull. It is also used in primary surface preparation of steel plates before fabrication.

Driving force for implementation

- Control of dust emissions.
- Health and safety at work.
- Reduced waste management costs.

Example plants
Plants #076, #074 in [155, TWG 2016]. Widely used in shipyards and other sectors.

Reference literature
[38, TWG 2004] [78, TWG 2005] [122, CEPE 2006] [155, TWG 2016]

4.4.3.2 Wet blasting

Description
Blasting is carried out with water containing a fine abrasive material, such as a fine cinder (e.g. copper slag cinder) or silica.

Achieved environmental benefits
This technique avoids the generation of dust emissions.

Environmental performance and operational data

With water blasting techniques, the waste water can be collected in the dock, pumped into tanks and treated prior to discharge. Additional hosing down with fresh water is necessary to remove the wet abrasive from the surface.

Cross-media effects

Waste water generation, increased waste from the abrasive.

Technical considerations relevant to applicability

May not be applicable in cold climatic conditions and/or in enclosed areas (cargo tanks, double bottom tanks) due to heavy mist formation.

Economics

One shipyard commented that grit blasting with water injection gives the best result with regard to surface, but in particular to cost [154, Nordic Council of Ministers 2016].

Example plants

Plant #076 in [155, TWG 2016] reported that this technique is allowed by its permit if fugitive emissions are prevented and that it is occasionally applied.

Reference literature

[5, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005] [122, CEPE 2006]
[154, Nordic Council of Ministers 2016] [155, TWG 2016]

4.4.3.3 (Ultra-)High-pressure ((U)HP) water jetting or blasting

Description

(U)HP blasting is a dustless surface treatment method using extremely high-pressure water. There are also options with or without an abrasive.

Technical description

There are several techniques categorised according to the water pressure used: low-pressure water cleaning (< 340 bar), high-pressure water cleaning (340-700 bar), high-pressure water jetting (> 700 bar), ultra-high-pressure water jetting (> 2 000 bar). By varying the water pressure, single layers of coat or the entire coat system can be removed. (U)HP blasting is a dustless surface treatment method using extremely high-pressure water and no abrasive. There are also methods that combine the use of water with an abrasive.

One advantage of (U)HP blasting is that water penetrates deep into the metal pores, allowing an efficient removal of chlorides, much more so than in dry blasting. Also, poorly adhering coating is efficiently removed in (U)HP blasting since water forces its way through and under the coating, breaking the bond and shearing it off.

Achieved environmental benefits

(U)HP blasting has several environmental advantages. In most cases, no abrasives are used and dust formed of paint residues is bound in water, which minimises dust emissions and waste generation. Only paint waste needs to be collected and disposed of safely. The amount of waste material to be disposed of is kept low.

Generally, noise is comparable to traditional dry blasting methods, whereas in advanced models noise is efficiently reduced by vacuum or use of a box around the spear head.

Source: [154, Nordic Council of Ministers 2016]

Figure 4.3: Box around the spear head in some more advanced robot models

Environmental performance and operational data

(U)HP blasting is generally considered a fast method compared to traditional dry blasting. Treatment efficiency for (U)HP blasting can be 20-30 m^2/h up to 350 m^2/h depending on the model. Estimates vary a lot and depend on various site-specific factors and thus can only be considered indicative.

In advanced (U)HP models, the work is carried out remotely. The nozzle is attached to the work surface by vacuum, which at the same time sucks off the removed waste material and waste water. The waste water is treated before discharge or it can be filtered and reused and the sludge can be collected in bags.

The nozzle can furthermore be encapsulated in a box, which further reduces the noise. Use of a robot also minimises the health and safety risks of blasting. This is also an important issue since conditions can be extreme outdoors and in confined spaces such as inside tanks. Shipyard employees are at an increased risk of exposure to toxic dusts, high noise levels, and a range of other health and safety hazards. Also, if (U)HP blasting is used manually, specific safety clothing is needed because of the extremely high pressure.

Emissions are very much case-specific.

Specific water consumption is small, typically less than 0.06 m^3/m^2 of treated surface. When using a robot, the waste water may also be collected directly in tanks. In some models, water can be collected, filtered and reused, which also means easy separation of waste for controlled disposal.

Cross-media effects

Paint waste which may contain removed antifouling or lead or chromium pigments from older coatings requires collection and managed disposal.

Technical considerations relevant for applicability

(U)HP blasting may not be applicable in cold climatic conditions, or due to surface specifications (e.g. new surfaces, spot blasting).

UHP blasting and other wet blasting methods are replacing traditional dry blasting techniques as technical tools for UHP water jetting are becoming more economical and adapted to the multitude of applications needed (e.g. ship-shaped areas, spot blasting, existent paint edge feathering).

The efficiency of UHP blasting varies case by case, as demonstrated by a comprehensive study carried out by a Finnish shipyard to compare UHP and traditional blasting methods which has ended up using UHP blasting (see (Peled 2013) in [154, Nordic Council of Ministers 2016]).

(U)HP blasting is not suitable for all services and conditions. (U)HP water blasting is not applicable in cold climatic conditions, below -5 °C. Furthermore, (U)HP blasting does not create the same rough surface as dry blasting methods, which is necessary for the adequate adherence of some coating systems. Therefore, the technology is generally not applicable for new surfaces. The applicability of (U)HP blasting together with a specific coating needs to be verified with the paint supplier and usually it must also be approved by the client.

Current (U)HP blasting equipment nozzles are not small enough to allow proper execution of 'spot blasting' and to be carried with handheld devices [PT comment #32 in [212, TWG 2018]]. The robotic versions currently on the market, on the other hand, are not versatile enough to be applicable for the sometimes small vessels and limited surface areas to be blasted [154, Nordic Council of Ministers 2016].

Economics

The disadvantage of (U)HP blasting is higher investment and maintenance costs compared to traditional methods (investment costs and maintenance costs are double or more than those of traditional methods). Many case-dependent factors affect the overall costs, labour time, waste management costs, etc. In particular, waste management costs can be significantly higher in dry blasting than in (U)HP blasting. The amount of waste material to be disposed of is very low compared to conventional techniques. The consumption of blasting media and the generation of waste with other blasting techniques is higher than when using (U)HP blasting. Waste management costs can vary from tens of euros per tonne up to hundreds of euros per tonne depending on whether the waste can be recovered as material or needs to be disposed of as hazardous waste [154, Nordic Council of Ministers 2016]. When using water as a blasting medium, other costs should be considered: primary treatment of the water to be used for blasting (conductivity and chloride content requirements), containment and waste water treatment for reuse of waste water, costs with fresh water supply and waste water treatment [SEA SMRC comment #61 in [212, TWG 2018]].

Driving force for implementation

Legislation controlling dust emissions in the environment and health and safety in the workplace.

Example plants

Widely used. Plants #075 and #076 (preferred option) in [155, TWG 2016].
Den-Jet, Denmark and Hammelmann / Hammeli Oy, Finland.

Reference literature

[5, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005] [122, CEPE 2006]
[154, Nordic Council of Ministers 2016] [155, TWG 2016] [212, TWG 2018]

4.4.3.4 Stripping of coatings by induction heating

Description

An inductor head is moved over the surface, causing localised fast heating of the steel to lift old coatings.

Technical description

An inductor head is moved over the steel surface, transferring high-frequency electric currents to steel, creating a localised, controlled fast heating of the steel. This results in rapid disbanding of coatings of up to 20-25 mm. The induction head is mounted on an electrically driven semi-robotic platform.

Achieved environmental benefits

- No dust emissions.
- Lower noise emissions.
- Reduced energy costs.
- Reduced waste quantities and the waste produced is more easily managed.
- Reduced waste water emissions, as waste is easily gathered without contacting water.

Environmental performance and operational data

The removed coating peels in strips with minimal production of dust and noise, reducing environmental emissions and the need for protective gear, particularly in closed environments such as tanks.

The system can operate on curved and vertical surfaces. It operates with higher stripping rates than blasting, and lower energy costs. Less downtime and fewer operator hours are required.

New coatings can often be applied directly to the cleaned surface with no further preparation. Other work such as maintenance and inspection can be carried out at the same time.

The system was developed for the cleaning and recoating of tanks, which is also carried out for tankers in ship repair yards and is entirely compatible with cleaning.

Technical considerations relevant to applicability

The system requires a minimum steel thickness of 5 mm to prevent damage to the internal (backside) coating or insulation materials.

It may also not be applicable for surfaces with components sensitive to induction heating like insulation on the back side of the steel (flammable or heat-sensitive), or in the vicinity of equipment sensitive to electrical equipment [SEA SMRC comment #64 in [212, TWG 2018]].

Driving force for implementation

- Speed of coating removal.
- Lower energy costs.
- Lower waste management costs.

Example plants

- Removal of anti-skid deck coating, USS Nimitz.
- Oresund Drydocks, Landskrona, Sweden – (Repair Shipyards).
- Repsol Petronor Refinery, Bilbao.

Reference literature

[212, TWG 2018] [203, Gabe et al. 2016]

4.4.3.5 Underwater hull and propeller cleaning system

Description

Underwater cleaning system using water pressure and rotating polypropylene brushes.

Technical description

Cleaning and maintenance of the hull and propellers of ships and vessels is carried out under water. The cleaning system is in most cases operated by water pressure and rotating polypropylene brushes. The equipment is able to remove marine fouling and reactivate the existing antifouling system applied to the ship hull when previously painted.

The system consists of a hull cleaning machine with curtains preventing pollutants from escaping a filter system. The system is operated by a diver using a mounted video camera and lights to document the results. The vacuum allows the cleaning machine to be kept tight to the treated surface (hydraulic pressure is 10 bar/1 000 l per minute in one application). The equipment works with water pressure. It sucks the removed marine fouling and used water through a filter arrangement before discharging them to the sea.

Seawater is used to develop the pressure. The machine is supplied with a hose to collect the waste water for treatment.

The filter system has changeable filters suitable for the paints and marine fouling system. Before any operations are launched, a dye trace test is completed to ensure the pressure is working and the water is sucked to the waste water treatment system. The brushed-off fouling will be retained in the filter bags, while the cleaned water flows back into the sea.

When the filters are replaced, the used filter bags are kept in waterproof containers. When the hull cleaning is completed, the filter bags will be delivered to the local waste handling plant. The waste handling plant will receive information about the fouling and a copy of the vessel’s antifouling certificate, enabling the treatment plant to dispose of the filter bags according to the applied environmental regulation.

The equipment contains a number of brushes (often two or three) designed for the job, the fouling to be removed and the paint system applied. The pressure and the water flow direction can be changed.

Achieved environmental benefits
The hull cleaning technology will reduce the need for and the frequency of blasting of ships, saving water, energy and reducing potential emissions to the environment by traditional blasting methods.

All hull cleaning machines are water-driven and therefore there is no risk of oil spills as may occur during treatment with oil hydraulic machines.

Environmental performance and operational data
See Technical description above.

Technical considerations relevant to applicability
The methods can be applied to all kinds of ships and both sides of the ships can be treated with the same equipment. Not applicable for ships in full dry dock.

Economics
The operating cost is USD 3.5 per m^2 (2018 data) for light to medium fouling, including collection of waste materials.

Reference literature
[154, Nordic Council of Ministers 2016]

4.4.4 Material-based techniques (substitution)

In general, the client specifies the coat systems to be used. The specification is also influenced by the warranty conditions of the coat. The yards have no influence on the coating system to be applied.

4.4.4.1 Water-based coatings

Description
For a general description, see Section 17.7.2.2.

Achieved environmental benefits
Reduced VOC emissions.

Environmental performance and operational data
Longer drying times are required, although these can be shortened with good ventilation and, in some cases, heating. There are problems in application at low temperatures. Generally, the dry film thicknesses are lower on application.

Cross-media effects
Extra energy consumption if forced ventilation or heating is applied.

Technical considerations relevant to applicability
Water-based coats are available for some specific applications. Currently, water-based coats are the only viable alternatives to reduce VOCs in ship primers. For internal areas, solvent-free coatings are also available.

A water-based universal primer is widely used in Finnish yards for ships' internal areas. Solvent-based primer is only used in winter for outdoor application.

Water-based coats are not applicable on surfaces exposed to severe marine atmospheric conditions, e.g. heat, sun, rain and salt. The availability of water-based coats for ship and yacht manufacturing is as follows:

- Shop primers: water-based zinc silicate is available, but it is only sporadically applied. Water-based epoxy and modified alkyds are also available but not usually applied.
- Exterior of ships: water-based alkyd, epoxy and acrylate coats are available for yachts and occasionally applied. Water-based acrylate/alkyd and water-based zinc silicate are occasionally applied.
- Interior of ships: water-based systems are available; however, this poses difficulties in drying when applied in small and closed areas and they are only occasionally applied. They are not applied in storage areas because they are not sufficiently wear-resistant.
- For yachts, water-based coats are available; they are now increasingly applied as primers and internal primers. The finish quality has limited their application in topcoats.

Water-based antifoulings are also available, but only in the leisure craft sector.

Economics
The costs involved for the water-based coat system for newly built ships are higher compared to solvent-based coating systems. In the repair and maintenance of ships, incompatibility with old coat layers might require their removal by blasting, resulting in considerable costs.

Example plants
Plants #076 and #074 in [155, TWG 2016]. Widely used in Finnish yards. Increasingly used for yachts.

Reference literature
[5, DFIU et al. 2002] [11, InfoMil 2003] [38, TWG 2004] [78, TWG 2005] [155, TWG 2016]

4.4.4.2 High-solids coatings

Description
For a general description, see Section 17.7.2.1. The high-solids-based coats currently applied contain 150 g VOCs/l or more. Solvent-free two-component coatings can also be applied on ships. These coatings form a very hard, pore-free and very smooth surface and are therefore very resistant to seawater corrosion, oil products and chemicals. They are also resistant to abrasion, such as floating ice encountered during navigation. However, the product range that can be used is very limited.

Achieved environmental benefits
Reduced VOC emissions.

Technical considerations relevant to applicability
The applicability for ship and yacht manufacturing is as follows:

- Shop primers: high-solids coatings are not applied as the film thickness is higher than required (only 20 µm required).
- The outside of ships and yachts for underwater areas, the external area, in holds and water tanks: high-solids epoxy coatings are widely applied. The VOC content of the coat applied on parts below the waterline is generally 150 g/l or more.
- Internal areas of ships: high-solids epoxy coatings are available.
- Yachts: high-solids coatings may be used but generally they are not. They can be applied below the waterline. High-solids coatings are sometimes also applied on interiors.

Economics
The costs involved for the coat system for newly built ships are low. In the repair and maintenance of ships, incompatibility with old coat layers might require their removal by blasting, resulting in considerable costs.

Example plants
Widely used. Plants #074, #075 and #076 in [155, TWG 2016].

Reference literature
[5, DFIU et al. 2002] [11, InfoMil 2003] [38, TWG 2004] [78, TWG 2005]
[155, TWG 2016]

4.4.5 Additional corrosion protection – cathodic protection

Description
In addition to protective coating systems, the immersed surface of ships can be protected against corrosion by applying cathodic protection (e.g. impressed current or sacrificial anodes). It is also used in ships' ballast tanks. Cathodic protection is an additional corrosion mechanism and does not replace coating systems.

Achieved environmental benefits
It may assist in increasing the periods between repair of the coatings and therefore a reduction of the spraying activities and VOC emissions from the shipyard may be achieved.

Technical considerations relevant to applicability
Used worldwide on all kinds of ships, both for professional and (less commonly) recreational use.

Example plants
Widely used.

Reference literature
[11, InfoMil 2003] [38, TWG 2004] [78, TWG 2005]

4.4.6 Coat application techniques and equipment

4.4.6.1 Hot spraying

Description
For a general description, see Section 17.7.3.13. On ships, hot airless spray is used to apply solvent-free two-component coatings. Layers of 300-1 000 microns are achieved.

Achieved environmental benefits
VOC emissions are significantly reduced and, compared to conventional airless spraying (see Section 17.7.3.8), the number of layers can be reduced.

Environmental performance and operational data
Computerised on-site mixing is required to achieve the proper mixing ratio. Working time is short with a pot-life of only 10 minutes. The equipment used for hot spraying is difficult to repair.

Cross-media effects
Energy is used for heating.

Technical considerations relevant to applicability
This technique can be applicable for the coating of large surfaces on the interior and exterior of the ship.

Economics
The costs for these coatings are higher compared to conventional coatings; however, application time is shorter and so is the drying time. The equipment costs for hot spraying are higher.

Reference literature
[11, InfoMil 2003] [78, TWG 2005]

4.4.6.2 Integrated air extraction at the point of application

Description
A mobile coat application head with an integrated overspray extraction system which extracts air at the point of spraying. This is analogous to robot spraying.

Achieved environmental benefits
Due to the increased efficiency, the material consumption, the VOC emissions and also the overspray emissions are significantly reduced. Overspray can be reduced to 5 % of the material input.

Technical considerations relevant to applicability
These coat application units can only be used for even, perpendicular surfaces, and not, for example, on curved bow and stern sections or flat bottoms.

Driving force for implementation
Health and safety.

Example plants
Plant #074 in [155, TWG 2016], Blohm + Voss GmbH, Hamburg, Germany. HDW Kiel, Germany.

Reference literature
[5, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005] [155, TWG 2016]

4.4.7 Alternatives to antifouling paints based on biocides

For information on the environmental impacts of using antifouling coats based on biocides, see Section 4.2.3. Please note that the techniques presented in the following subsections, which are alternatives to the use of antifouling coatings based on biocides, are mainly related to the environmental performance of the ship and not of the plant (shipyard).

4.4.7.1 Fouling-release coatings based on silicones

Description
Silicone coats have a low surface tension (non-stick) with the effect that the fouling organism cannot establish a firm attachment to the coating surface. Fouling may attach to the surface during idle periods, but currents created over the paint surface during sailing faster than a certain minimum speed will clean the surface. Silicone paints are applied by airless spraying.

Achieved environmental effects
Fouling-release coatings do not contain any biocides. They provide very smooth surfaces, resulting in the potential for lower frictional resistance. This may decrease fuel consumption or increase speed compared to self-polishing biocide-containing paints.

Fouling-release coatings do not eroded or polished during service time and as such the paint is kept intact during the service period.

Environmental performance and operational data
During application of silicone coatings, overspray to surfaces to be coated with other types of paint must be prevented due to later adherence problems. Application and repair of silicone paints need to be done strictly according to a specified procedure.

Technical considerations relevant to applicability
Fouling organisms will be able to settle on the silicone paints during idle periods. In order for the release effect to work during the sailing period, a certain speed has to be achieved. Today, the technology can be used on ships with short idle periods and a minimum speed of 15-17 knots. Silicone paints are not suited to vessels exposed to a lot of mechanical damage. Therefore fouling-release coatings are still considered to be niche products for special vessel types.

Economics
Costs of silicone paints are considerably higher compared to antifouling paints containing biocides.

Example plants
Used worldwide.

Reference literature
[78, TWG 2005]

4.4.7.2 Hard, smooth coating with frequent mechanical cleaning

Description
Anti-fouling coatings may be replaced by the use of hard, resistant coating materials reducing fouling adhesion and by brushing and scraping off fouling at short intervals.

Brushing and scraping off fouling at short intervals and the use of hard, resistant coating materials is an alternative to antifouling coats. There are a variety of devices with rotary brushes which can remove the fouling during short downtimes.

Achieved environmental benefits
This antifouling method does not use heavy metals or biocides.

Environmental performance and operational data
The disadvantages of the procedure are short cleaning intervals and possible damage to the anti-corrosion paint system.

Cross-media effects
This method may entail the risk of the introduction of new species from the world seas to the local marine environment.

Underwater brushing creates an uncontrolled risk of water pollution during such diving operations.

Technical considerations relevant to applicability
This process is suitable for ships operating in brackish or fresh water at lower temperatures.

Reference literature
[5, DFIU et al. 2002] [33, Watermann et al. 2003] [78, TWG 2005]

4.4.7.3 Electrochemical processes

Description
Anti-fouling coatings may be replaced by applying a voltage potential at the vessel surface. This causes electrolysis. Fouling is inhibited by toxic chlorine compounds produced at the surface (in salt water) and/or the pH value at the surface is shifted which inhibits the settling of fouling. This technique abates corrosion.

Achieved environmental benefits
This antifouling system does not contain biocides.

Environmental performance and operational data
The amounts of copper released are comparable to copper-based antifoulings. This method has proved to be very effective against fouling.

Cross-media effects
The electrodes can be made of copper, resulting in the emission of copper ions which are toxic to the fouling organisms. Toxic chlorine compounds are produced.

Reference literature
[5, DFIU et al. 2002] [33, Watermann et al. 2003] [78, TWG 2005]

4.4.8 Off-gas treatment

Description
For a general description, see Section 17.10.

Emissions from painting and blasting activities can be reduced effectively by using closed workshops (see Sections 4.4.2.2 and 17.10.2.1). These can be equipped with off-gas treatment techniques as described in Section 17.10.

For example, VOC-containing off-gases from spraying can be adsorbed via activated carbon (see Section 17.10.6.2). Alternatively, the organic solvents can be treated in a thermal oxidiser (see Section 17.10.5). Where concentrations of VOCs allow, the solvent can be regenerated by absorption, or the thermal oxidiser used can be regenerative and recover the heat from the oxidation process.

Dust and overspray particles may be treated by techniques described in Section 17.10.4.

Achieved environmental benefits
Benefits include a significant reduction in VOC and/or dust emissions.

At an example plant, an off-gas treatment installation of 300 000 m^3/h capacity is used. VOC emissions are reduced by 75 % and an average clean gas concentration of 23 mg/m^3 is achieved (data for 2005).

Efficient ventilation and dust abatement systems enable a five-fold change of air each hour and, in the cleaned air, dust concentrations of less than 5 mg/m^3 can be achieved.

Environmental performance and operational data
Dust levels may have to be reduced prior to VOC abatement.

Cross-media effects
Energy consumption for off-gas extraction and treatment.

Technical considerations relevant to applicability
Applicable to the refurbishment of shipyards.

Economics
High costs are involved. The investment for the example plant was about EUR 21 million. The annual operating cost is about EUR 1 million, which is slightly lower than the operating cost for the conventional process. This also included filter systems for grit blasting operations (2005 data).

Example plants
HDW Kiel, Germany.

Reference literature
[5, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005]

4.4.9 Waste and waste water management

4.4.9.1 Segregation of waste and waste water streams

Description
Docks and slipways are constructed with:

- a system to collect and handle dry waste effectively and keep it separate from wet waste;

- a system to separate waste water from storm water and run-off water.

See also Section 17.12.1.

Achieved environmental benefits

- Reduces water pollution.
- Facilitates waste handling, storage and subsequent management.

Technical considerations relevant to applicability

As this involves construction work, it is only applicable to new docks and slipways or major upgrades of existing ones.

Example plants

Widely applied.

Reference literature

[151, CESA 2011]

4.4.9.2 Waste water treatment

Description

Use of appropriate waste water treatment (WWT) systems that are able to effectively remove various pollutants from waste water, e.g. oil, grease, paint residues potentially containing heavy metals and biocides. See also Section 17.11.

Technical description

Waste water can be treated prior to discharge, either at the source (e.g. when slurry blasting) or it can be collected and sent to a waste water treatment plant, either on or off site. The treatment required will depend on the substances present and the discharge point (to surface waters such as the harbour, or to the municipal foul sewer). Section 17.11 discusses several waste water treatment techniques and provides other sources of information.

Achieved environmental benefits

Reduction in water pollution, particularly in enclosed harbours or estuarial areas.

Environmental performance and operational data

The following are examples of waste water treatment:

(i) When using water blasting techniques, the waste water can be collected in the dock, put into tanks and fed into waste water treatment plants (see Section 4.3.2.2).

(ii) At one installation, the waste water treatment is carried out in several steps consisting of precipitation and flocculation (such as by using iron (III) chloride), followed by separation and filtration. To reduce the volume and weight of waste produced, the separated sludge is pressed prior to disposal. The cleaned waste water is reused or, in the case of surplus water, discharged as waste water. With this system, emission levels for filterable substances of 10 mg/l can be achieved after treatment.

Cross-media effects

Any energy and chemicals used in treatment.

Technical considerations relevant to applicability

Generally applicable.

Economics

Costs are dependent on the size of the installation. In example (ii) given above, the cost in Germany for the complete plant including installation was about EUR 100 000 (in 2000).

Costs for water treatment installations in ship repair yards dealing with medium-sized ships (> 15 000 GT) are quoted as exceeding EUR 2 million.

Driving force for implementation

Complying with water, port and harbour pollution legislation.

Example plants

Flender-Werfft, Lückbeck, Germany.
See also Table 4.2.

Reference literature

[5, DFIU et al. 2002] [78, TWG 2005]

4.4.9.3 Waste management and minimisation

Description

As part of the dock discipline (see Section 4.4.1), management of waste by:

- minimising; recovering, reusing and recycling (particularly dry blasting grit);
- storing wastes safely in designated, labelled containers in covered areas.

Technical description

See also Section 17.12.

The following residues are collected and their disposal is managed according to the relevant legislation and procedures. This is particularly important prior to flooding a dry dock:

- paint residues that have been removed;
- paint leftovers, and used paint recipients;
- coating overspray;
- used and contaminated blasting materials;
- cleaning materials;
- mud, oily residues and other materials that have been scraped off or removed.

Some materials, such as used dry blasting grit and scrap materials, may be collected separately to assist their recycling and reuse.

Recycling of wasted dry blasting grit (copper slag) is only possible for other activities (e.g. in construction or as filling material).

Achieved environmental benefits

Prevention of contamination of the water environment.

Environmental performance and operational data

See dry dock discipline, Section 4.4.1.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable. Dry blasting grit (copper slag) at maintenance and repair yards needs angularity to achieve the surface preparation for coating. Therefore recovered grit may not be suitable for this purpose [PT comment #43 in [212, TWG 2018]].

Economics

- Cost reduction derived from reusing materials (especially suitable sorts of dry blasting grit).
- Cost recovery from recycling scrap materials.

Driving force for implementation

Complying with water pollution prevention, port waste and harbour waste management regulations.

Example plants

Widely practised.

Reference literature

[78, TWG 2005] [121, Portugal 2006] [212, TWG 2018]

5 COATING OF AIRCRAFT

5.1 General information on the coating of aircraft

[176, ASD 2017] [258, ASD 2019]

In this section, the painting of civil aircraft is described. Due to different processes, this section is divided into construction and maintenance.

For maintenance, the paintwork is repaired or applied completely new, and the entire paint application is carried out manually. The selection of the coating system depends on manufacturer defaults, international regulations and the requirements of the customer.

According to the statistics of an industrial federation, the total turnover of aeronautics was EUR 162 billion for 2016, with shares of 72 % for the civil field and 28 % for the military field. Aeronautics includes all certified flying objects, manned and unmanned, along the life cycle, including maintenance repairs and operations and air traffic management ground systems. In 2016, the total employment of the sector was 543 000 workers, of which 66 % is related to the civil field [258, ASD 2019].

5.2 Applied processes and techniques in the coating of aircraft

[176, ASD 2017]

5.2.1 Construction

Aircraft need to be protected against corrosion for their entire life of around 25 years, therefore only specific paint systems can be utilised, as with the maintenance of aircraft, whilst also taking customer requirements into consideration.

5.2.1.1 Painting of components and detailed parts – structural coating

Components are mostly partially painted before assembly takes place. These parts are coated with a primer (containing chromates in the case of metallic parts, chromate-free in the case of composite parts) and may be subsequently painted with a topcoat or varnish. A wash primer is only applied in exceptional cases, i.e. touch-up and repair. Where production processes allow sufficient throughput surface, spraying is sometimes automated for accelerated drying of components either in a flow process or by the use of combination painting and drying (e.g. with convection dryers and infrared dryers). Parts that are delivered by external manufacturers are normally supplied coated with a basic primer and topcoat if requested (in the case of aluminium parts the basic primer contains chromates, but chromate-free primer is used for composite components).

Chromates have been used for over 50 years as a corrosion inhibitor in the protection of metallic surfaces, fulfilling the demanding technical, safety and airworthiness requirements of the aerospace and defence sector. With the use of chromates, corrosion protection can be afforded for lengthy periods, thus providing high levels of anti-corrosion reliability in products with long life cycles, even in extreme conditions.

In some very specific cases, e.g. structural applications on certain materials (composite, titanium), a non-inhibited primer can be used.

However, despite intensive research efforts carried out over the past decades by the sector, there are currently no chromate-free alternatives available for some specific processes in the aerospace and defence sector fulfilling the required level of performance, reliability and safety. The process for the aerospace and defence industry in terms of qualification and certification of alternatives has been reflected in an EASA/ECHA report[25] which has been drawn up jointly with industry.

In the frame of the REACH Regulation [47, EU 2006], applications for authorisation to continue using some chromates in applications such as paints, primers, surface treatment and hard chrome, for which no suitable alternatives will be available for implementation before the respective ban dates (2017 and 2019), have been made to the European Chemicals Agency. These collective applications have been prepared in the frame of industry consortia with the main actors from the aerospace and defence sector and the chemical industry.

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[25] An elobration of key aspects of the authorisation process in the context of aviation industry, EASA-ECHA, April 2014. DOI: 10.2823/9437.

5.2.1.2 Painting of exterior surfaces

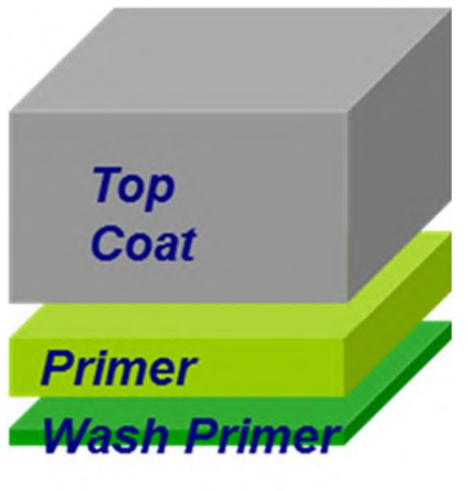
Outside surfaces of the completed aircraft are coated manually. As the final lacquer finish is applied after the final assembly of the aircraft, only coatings that cure at an ambient temperature can be used. At present, predominantly high-solids paints (with a solvent portion of between 30 % and 40 %) are used, and this is standard in the aeronautical industry. However, conventional solvent-based paints (with solvent contents of about 55-65 %) might still be used by companies producing small and/or military aircraft.

As with maintenance, the coating of new planes is carried out in closed workshops. The applied coatings cure at ambient temperatures. Often the hull is coated and completely dried first. Then, the hull is covered with masking materials and the wings and tailplane are subsequently painted.

5.2.1.2.1 Conventional paint scheme

[176, ASD 2017]

The painting process is subdivided into application of the wash primer, application of the primer and application of the topcoat.



Source: [176, ASD 2017]

Figure 5.1: Conventional paint scheme

Conventional solvent-based paints contain the following solvent content by weight:

- corrosion prevention compound: 45-50 % solvent content;
- structural wash primer: 70-90 % solvent containing chromate, based on polyvinyl butyrate, or epoxy or polyurethane resin;
- structural basic primer: 50-73 % solvent containing 5-25 % chromate, based on epoxy or polyurethane resin;
- structural basic primer (non-inhibited): 71 % solvent, chromate-free (higher VOC solvent content inputs if for chromate-free solutions);
- structural topcoat: 55-65 % solvent;
- varnish / fastener protection: 45-60 % solvent;
- external intermediate coat: 70-80 % solvent.

The selection of the lacquer system depends on manufacturer defaults, international regulations and customer requirements. It is not common practice to treat the off-gases containing solvent.

Solvent-based paints can be used in all phases of the painting operation (wash primer, primer, topcoat, clear coat and repair), and can be used on metals and plastics. Since the manufacturer's corrosion protection guarantee lasts for 25 years, only specific paint systems can be utilised. When low-VOC alternatives (with suitable properties and suitably qualified) exist, these are preferred.

Pretreatment
Before the exterior surfaces are coated, impurities, e.g. kerosene, oils and grease, are removed. The hull, wings and tailplane are cleaned with cleaning agents. The surfaces are sanded and then cleaned again.

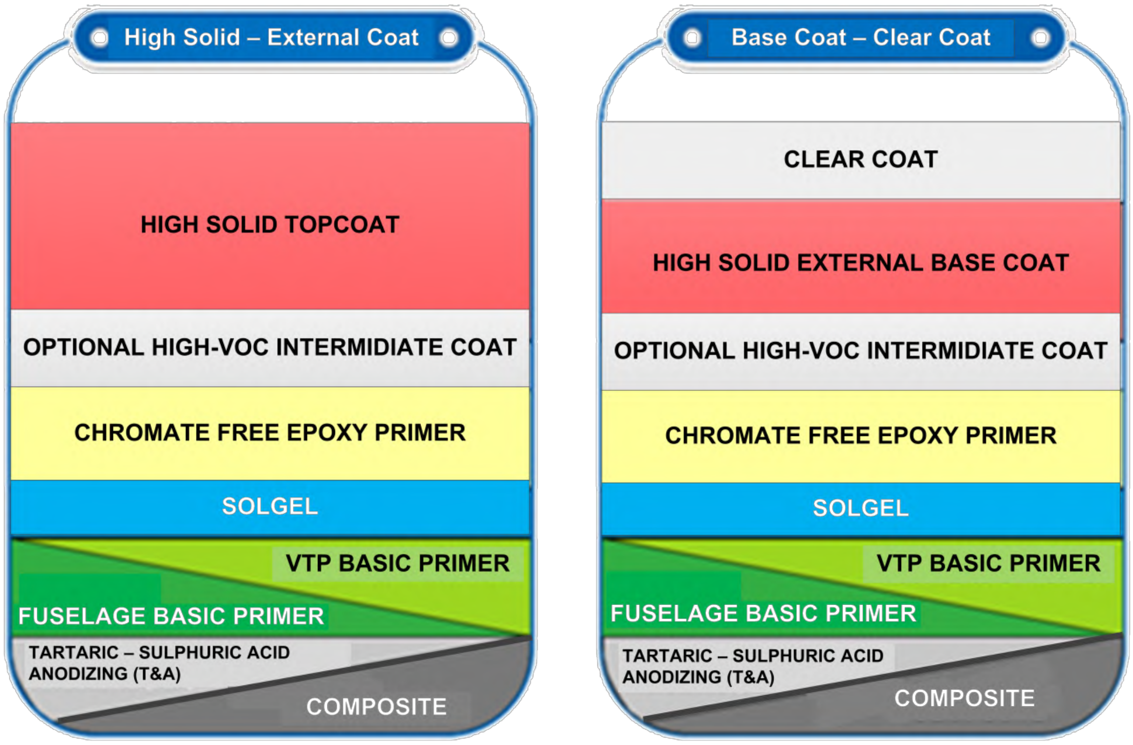
Application of the wash primer
After pretreatment, the wash primer is applied manually by using electrostatic spraying techniques. The wash primer is a solvent- and chromate-containing material based on polyurethane or epoxy resins or polyvinyl butyrate (PVB). The solvent content amounts to about 70-90 %. For increased corrosion protection, strontium or zinc chromate is necessary. The layer thickness varies from 8 µm to 10 µm. After application, evaporation of solvents takes place at ambient temperature.

Application of the primer
After the wash primer, a solvent-containing primer based on epoxy resin or polyurethane is applied. This is done manually via an electrostatic spray application. The solvent content of these materials varies from 50 % to 65 %. The content of strontium or zinc chromate amounts 10-20 %. The applied layer thickness averages 15-25 µm. The material cures at ambient temperature.

Application of the topcoat
The topcoat can be very different according to customers' requests. Solvent-based two-component paints with a solvent content of 55-65 % are exclusively used. The topcoat is applied in several layers (two to four according to the colour) via electrostatic spraying. Depending on the applied colour, the layer thickness amounts to 60-100 µm. When the first layer has been applied, a technical waiting time must be respected before the next layer can then be applied during a limited over-coating time window. This is repeated until the required number of layers has been reached. Subsequently, the topcoat layers are dried. Afterwards, the decoration colours are applied either via a number of topcoat spray applications for each colour or by decorative adhesive films. At the request of a customer, a clear coat can be applied on top of the topcoat.

5.2.1.2.2 High-solids paint scheme

The current standard external paint system consists of a high-solids chrome-free epoxy primer and a high-solids polyurethane topcoat applied on top of the basic protection of the detailed parts (see Section 5.4.1.1). High-solids base coat and clear coat combinations are increasingly used instead of the topcoat. A wash primer is no longer used. The customer can select an option, which consists of applying a solvent-based intermediate coat between the high-solids chrome-free epoxy primer and the topcoat (or the base coat), in order to improve the strippability of the paint system for a later maintenance repaint.



NB: PA: pre-applied.
Source: [176, ASD 2017] [ASD comment #1 in [212, TWG 2018]]

Figure 5.2: High-solids paint scheme

5.2.1.3 Temporary corrosion protection

The so-called 'temporary corrosion protection' is obtained by application of water-rejecting layers in the internal area of the aircraft. The material remains in the plane permanently. The main areas are, for example, doors, gates, wheel wells and cargo storage areas and any locations where high corrosion risks or condensation may occur. Temporary corrosion protection is not applied within fuel tank boundaries. The temporary corrosion protection materials are solvent-based, wax-like substances. The application takes place with a brush or via spraying. The solvent content of the products amounts to about 40-60 %.

5.2.2 Maintenance

[5, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005]

The paint application is carried out in closed workshops where temperature and air humidity can be regulated. For the deposition of overspray from exhaust air streams, wet dust collectors are installed. The applied paints dry at ambient temperature.

5.2.2.1 Paint removal

In the context of maintenance, the primary coat and the topcoats are removed every 6 to 8 years. If an airline company changeover takes place, paint removal is undertaken sooner. This is most common for leasing companies. The paint removal (and new paint application) is done for optical reasons and for examining the structure for wear and corrosion. Paint removal is usually done chemically. Water blasting, which was favoured for environmental reasons, is no longer applied due to the causation of excessive mechanical stress. The aircraft is cleaned with a water-based, alkaline cleaning agent. After drying the windows, running gear and parts consisting of fibre-reinforced plastic, composite materials are masked. The following paint removal process is done via acid cleaning or by mechanical sanding. For acid cleaning, a water-based benzyl alcohol formic acid is applied with airless spraying techniques. The sealants in the seams are manually removed. For composite materials and partly for metal surfaces, pretreatment is done by sanding.

5.2.2.2 Cleaning

Macerated paint layers are removed by water. Subsequently, aqueous-alkaline neutralisation and cleaning takes place. Before paint application, the surfaces are cleaned manually with organic solvents and cleaning wipes. In general, a mix of butyl acetate and butyl alcohol is used as solvent.

5.2.2.3 Pretreatment

Before the primer is applied, a solvent-based wash primer is applied onto metal surfaces. This material contains 76 % organic solvents and about 14 % zinc chromate (in the solids content). The material is applied via an electrostatic spray application. The wash primer is not applied onto composite materials.

5.2.2.4 Primer

Two different materials are used as primers:

- primer based on polyurethane or epoxy with a solvents content of 70 % without chromate; and
- primer with strontium chromate (about 20 % of the solids content) and about 67 % organic solvents.

Primers containing chromate are used for increased corrosion protection for climate conditions with a high humidity and high salinity of the atmosphere or at the request of a customer. Application is carried out manually via electrostatically assisted spray applications.

5.2.2.5 Topcoat

Conventional two-component paints with a solvent content of about 61 % and three-component high-solids paints with a solvent content of about 43 % are used as topcoats. Both paints are free of chromate and lead. The application is carried out manually by electrostatically assisted spraying.

5.2.2.6 Clear coat

Conventional topcoats are generally coated with a clear coat layer. If high-solids topcoats are applied, an additional clear coat layer is not necessary. It is only used at the request of a customer. The same application method as for topcoats is used.

5.3 Current consumption and emission levels in the coating of aircraft

[5, DFIU et al. 2002] [155, TWG 2016] [212, TWG 2018]

5.3.1 Construction

5.3.1.1 Material consumption

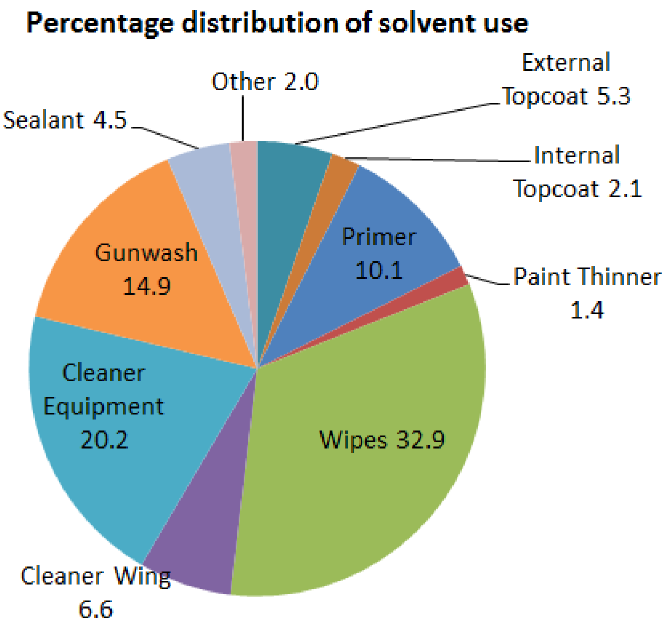
The material consumption necessary for the coating of an aircraft is necessarily related to the total surface to be coated but also depends on customers' specific requests. In addition to the exterior surface, the surface of coated component parts also has to be taken into account. The average cycle time for a single aisle (SA) aircraft is approximately 5 to 6 days and between 7 to 18 days for large or very large aircraft (LA) depending on the complexity of the livery. A significant part of the time is needed for masking and finishing. An important proportion of the total amount of paint consumed is necessary for the coating of component parts. Table 5.1 shows general average information for an A320 (SA) and an A330 (LA).

Table 5.1: General information on coating of an Airbus A320 (SA) and an Airbus A330 (LA)

Category	SA – A320	LA – A330
Area to paint	> 760 m^2	> 2 200 m^2
Quantity of paint	~ 600 l	~ 1 500 l
Final mass on aircraft	~ 120 kg	Between 330 kg and 400 kg
Average number of coatings	5 (> 4 000 m^2)	5 (> 10 000 m^2)
Average cycle time	5 to 6 days	Between 7 and 18 days
Source: [ASD comment #4 in [212, TWG 2018]]		

For the coating of exterior surfaces of an Airbus A320 the total exterior surface area of the completed aircraft is over 760 m^2 and for an Airbus A330 it is 2 200 m^2. The applied dry material has a total weight of 330-400 kg for an Airbus A330 [ASD comment #5 in [212, TWG 2018]].

The percentage distribution of solvent use per process at one installation (components production) is presented in Figure 5.3. It is worth noting that cleaning activities represent about 75 % of total solvent use (product cleaning accounts for ~ 40 % and equipment cleaning ~ 35 %) [Plant #078 in [155, TWG 2016]]. For the whole sector, the cleaning activity is less significant and represents approximately 50 % to 60 % of the total solvent use [ASD comment #7 in [212, TWG 2018]].



Source: Plant #078 in [155, TWG 2016]

Figure 5.3: Percentage distribution of solvent use per process for one installation (components production)

5.3.1.2 Water consumption

Water consumption data were reported by two installations: the first with a total consumption of the order of 6 600 m^3/yr with the major consuming sector being the wet scrubbers for VOC emission abatement [155, TWG 2016]. The second reported figure was 18 000 m^3/yr with the most significant consuming sector being related to osmosis and humidification processes. STS activities represent approximatively 3 % to 6 % of the total water consumption of sites [ASD comment #9 in [212, TWG 2018]].

5.3.1.3 Energy consumption

The majority of the energy consumption is due to requirements for air extraction/circulation during STS activities.

In general, the total energy consumption is of the order of tens of thousands of MWh and energy metering is performed.

The main identified techniques for decreasing energy consumption and improving the energy efficiency are:

- exhaust air heat exchange in ventilation systems of all hangars with estimated energy savings of the order of 20-30 %;
- air recirculation of booth air during preparation, flash-off and curing processes;
- temperature and humidity optimisation of the process air with estimated energy savings of the order of 15 % (gas consumption);
- optimisation of energy consumption for the warm air circulation for curing, e.g. by using an air turbulator.

5.3.2 Emissions from construction processes

[155, TWG 2016]

Considering the activity of the biggest manufacturer of aircraft in Europe, the total VOC emissions were approximately 1 000 t/yr for a production capacity of about 700 aircraft in 2016. The emissions of VOCs were mainly due to cleaning (products and equipment) and painting activities [ASD comment #11 in [212, TWG 2018]].

The painting of component parts is generally carried out in different plant locations to plants dedicated to final assembly and final painting of the whole aircraft.

Therefore, the technique to reduce VOC emissions is to reduce the amount of VOCs while performing cleaning activities using pre-impregnated wipes or in the coatings used, for example by using high-solids and/or two-component coatings as described in Chapters 5.2 and 5.4.

5.3.2.1 Total emissions of VOCs

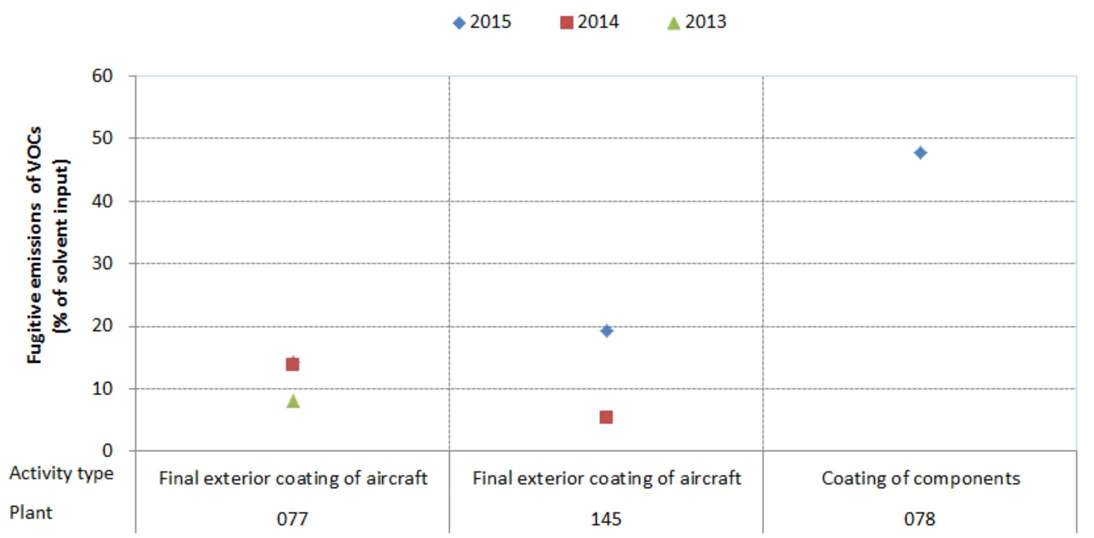
On average, the total VOC emissions per kg of solid mass input are of the order of 0.55-0.6 kg for coating of exterior surfaces of assembled aircraft as presented in Figure 5.4. For sites where the proportion of the activity of components coating is higher, the total emissions of VOCs expressed as a percentage of the solvent input is higher.

Source: [155, TWG 2016]

Figure 5.4: Total emissions of VOCs expressed in kg VOCs per kg of solid mass input

5.3.2.2 Fugitive emissions of VOCs

Reported data on solvent mass balances from three installations show that fugitive emissions vary from less than 10 % up to 50 % of the solvent input (see Figure 5.5). For sites where the proportion of the activity of components coating is higher, the percentage of fugitive emissions might be higher as is represented in the Figure 5.5.

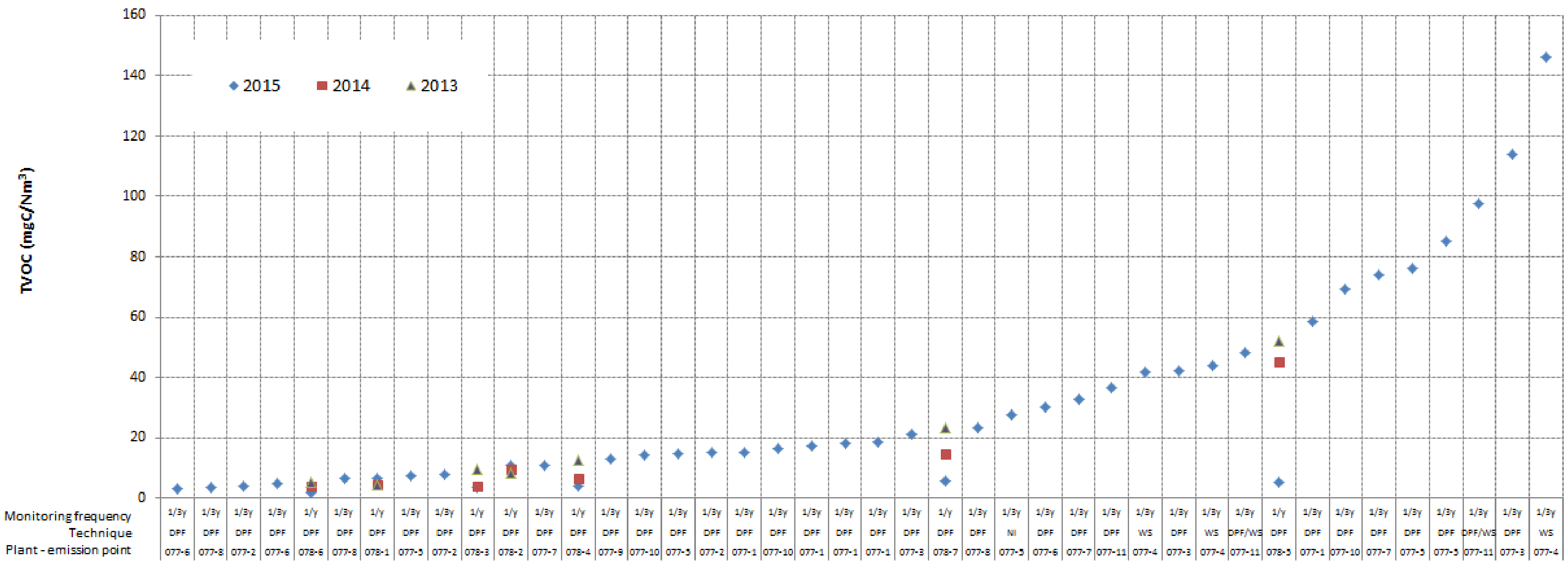


Source: [155, TWG 2016]

Figure 5.5: Fugitive emissions of VOCs expressed as a percentage of the solvent input for the period 2013-2015

5.3.2.3 TVOC emissions in waste gases

Reported values for periodic monitoring of TVOC emissions in waste gases are presented in Figure 5.6.



Source: [155, TWG 2016]

Figure 5.6: TVOC emissions in waste gases (periodic monitoring) - Average values for the period 2013-2015

Although the applied abatement techniques focus mainly on dust abatement, the reported VOC concentration values are generally low. It should be noted that the reported waste gas flow rates vary from 20 000 Nm^3/h up to 180 000 Nm^3/h [155, TWG 2016]. Nevertheless, a representative range of flow rates for the activity in the aircraft sector is from 20 000 Nm^3/h up to 350 000 Nm^3/h with some paint shops having a flow rate up to 550 000 m^3/h [ASD comment #14 in [212, TWG 2018]].

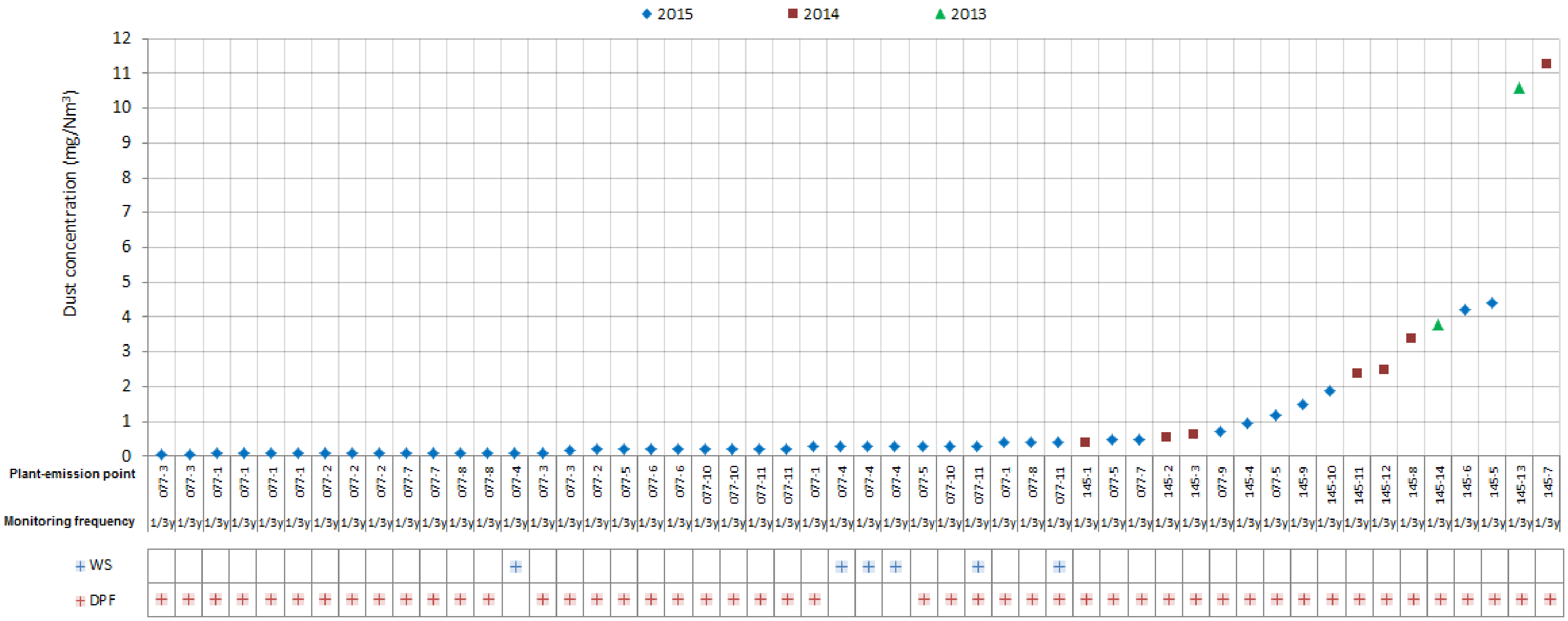
5.3.2.4 Dust emissions in waste gases

Total dust emission data reported from the reference installations are presented in Figure 5.7. In general, the achieved dust emission concentration values are below 3 mg/Nm^3. Reported chromate dust values are lower than 0.002 mg/Nm^3.

The basic statistical parameters of the reported dust concentration values for 2015 are presented in Table 5.2.

Table 5.2: Statistical parameters for dust emissions in waste gases in 2015

No of points	**Average** (mg/Nm^3)	**Median** (mg/Nm^3)	**25th percentile** (mg/Nm^3)	**75th percentile** (mg/Nm^3)
42	0.53	0.20	0.10	0.40
Source: [155, TWG 2016]				



Source: [155, TWG 2016]

Figure 5.7: Dust emissions in waste gases (periodic monitoring) - Average values for the period 2013-2015

5.3.2.5 Emissions to water

Along with the paint sludge, waste water is generated from the wet deposition of overspray. The treatment of waste water is similar to the processes used in the serial painting of passenger cars.

Data on emissions to water were only submitted for one plant (out of the three participating in the data collection) and with only one value for hexavalent chromium [155, TWG 2016].

5.3.2.6 Waste generation

The following table summarises the main types of waste generated in the coating of aircraft and their characteristics.

Table 5.3: Waste generation data from the coating of aircraft

Waste type	Source	Average solvent content (%)	Recycling or disposal route
Solvent leftovers	Production processes	100	Delivered off site
Paint sludge	Production processes	30-55	Delivered off site
Waste solvent	Cleaning processes	75-100	Delivered off site
Waste base coat	Production processes	30-40	Delivered off site
Waste hardener	Production processes	50	Delivered off site
Paint filters	Production processes	0	Delivered off site
Empty paint containers	Production processes	NI	Delivered off site

NB:
NI: No information provided.
Source: [155, TWG 2016]

The proposed techniques for the minimisation of generated waste are as follows:

- use of reusable containers to reduce the amount of scrap metal;
- recovery of used solvent from the gun cleaning which in one case is done by an external contactor;
- recovery of used solvents by distillation (for one plant the estimated initial recovery rate was 60 vol-% with a declining trend over time);
- dewatering of sludge from the waste water treatment facility using centrifuges and decanters.

5.3.3 Maintenance

Due to different geometries of aircraft, the consumption and emission values are given for a Boeing 747-400 (see Table 5.4). For this type of aircraft, about 2 780 m^2 has to be painted. The data come from Lufthansa Technik, Germany from 2001.

Table 5.4: Material consumption for a Boeing 747-400 at Lufthansa Technik

Process	Material	Material consumption (kg)	Solvent content (%)	VOC emissions (kg per B747)
Paint removal	Chemical stripping agent	3 000		No VOCs (1)
Pretreatment	Wash primer based on polyvinyl butyrate containing chromate	240	76	182
	Primer containing chromate	450	67	301
	Primer chromate-free	450	71	319
Cleaning	Butyl acetate, butyl alcohol	200	100	200
Topcoat	High-solids	1 200	43	516
	Solvent-based	1 300	61	793
Clear coat	Solvent-based	1 200	65	780

(1) No VOCs according to the definition of the IED.
Source: [5, DFIU et al. 2002]

Depending on the paint system utilised, the VOC emissions amount to 1.2-2.3 t per coated Boeing 747-400. If high-solids topcoats are used, the VOC emissions amount to about one tonne less, compared to conventional topcoats and an additional clear coat layer. Off-gas treatment equipment, e.g. oxidisers, are not installed due to large volume flows (approximately 450 000 m^3/h) and low VOC concentrations.

Different types of aircraft are completely or partly coated in the plant; the coating of 150 aircraft (A300) per year is considered as a benchmark for calculating the level of VOCs being emitted in one year. For 2000, it was calculated that 67 t VOCs was emitted. The emission value of 150 kg/h is exceeded temporarily for some coating processes due to simultaneous paint application by several employees (up to 12 painters).

5.4 Techniques to consider in the determination of BAT for the coating of aircraft

In Chapter 17, techniques are discussed which might also be applicable to the coating of aircraft. In Table 5.5, the general techniques relevant for the coating of aircraft that are described in Chapter 17 are shown. These techniques are not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 17.1.

Table 5.5: Reference to techniques generally applicable to the sector

Technique	Section number
Environmental management techniques	17.1
Storage and handling of raw materials	17.2
Monitoring	17.3
Water use and waste water generation	17.4
Energy management and energy efficiency	17.5
Raw material management (including substitution)	17.6
Coating processes and equipment	17.7
Drying and/or curing techniques	17.8
Cleaning techniques	17.9
Off-gas extraction and treatment	17.10
Waste water treatment techniques	17.11
Waste management techniques	17.12
Odour emissions	17.13

5.4.1 Material-based techniques

5.4.1.1 High-solids paints

[176, ASD 2017] [212, TWG 2018]

Description
For a general description, see Section 17.7.2.1.

High-solids solvent-based paints contain the following solvent contents by weight:
- external primer: 20-25 % chromate-free solvent, based on epoxy resin;
- external topcoat: 30-35 % solvent, based on polyurethane resin;
- external base coat: 30-35 % solvent, based on polyurethane resin;
- clear coat: 45-50 % solvent, based on polyurethane resin.

For structural coating applications, basic primers (30-40 % solvent content) and topcoats (35-45 % solvent content) are available as high-solids variants.

Achieved environmental benefits
This technique is used to minimise VOC emissions, where applicable, compared to conventional solvent paint systems.

Environmental performance and operational data
The optical surface qualities and technical properties of high-solids paints are equal to or even better than those of conventional paints.

Cross-media effects
The use of chromate-free materials implies a higher percentage of VOC input. Modification of painting equipment is required.

Technical considerations relevant to applicability
Applicable for the external coating of new aircraft in specific cases.

Economics
Material costs and the costs of paint removal for maintenance operations are higher compared to conventional solvent-based materials.

Driving force for implementation

- Substitution of conventional solvent-based paints in some specific cases.
- Less material needed for similar coating thickness.
- Reduced fire hazard.

Example plants
Plants #077, #078 and #145 in [155, TWG 2016].

Reference literature
[155, TWG 2016] [176, ASD 2017] [212, TWG 2018]

5.4.1.2 Water-based paints

[176, ASD 2017] [212, TWG 2018]

Description
For a general description, see Section 17.7.2.2. Water-based paints are used in structural applications (not used for external applications), for example as a basic primer (inhibited and non-inhibited), a topcoat and a varnish / fastener protection.

Achieved environmental benefits
Water-based paints have a lower VOC content than other conventional paints.

Environmental performance and operational data

- Water-based paints contains 250-350 g/l of VOCs.
- The colour uniformity can be improved.
- Despite minor modifications to equipment such as spray guns, recurring costs can be lower owing to a reduction in the paint quantity used due to lower film build up.

Cross-media effects
Paints containing chromate are still used for metallic parts (not for carbon-fibre-reinforced plastic (CFRP) parts).

Technical considerations relevant to applicability
These paints can only be used for some structural applications (not for external applications) for example as a basic primer (inhibited and non-inhibited), a topcoat and a varnish / fastener protection.

Economics
Despite minor modifications to equipment such as spray guns, recurring cost can be lower owing to a reduction in the paint quantity used due to lower film build-up.

In general, the cost of the paint is lower.

Driving force for implementation

- VOC reduction.
- Quality improvement: thickness of paint layer.
- Aesthetic improvement - less colour variation in assemblies prior to final paint as water-based and new generation of paints are made to a common colour-matching system (RAL) standard.
- Paint cost reductions.

Example plants
Plant #078 in [155, TWG 2016].

Reference literature
[155, TWG 2016] [176, ASD 2017] [212, TWG 2018]

5.4.2 Paint application techniques and equipment

5.4.2.1 Electrostatically assisted spraying

[176, ASD 2017]

For a general description, see Section 17.7.3.12. This technique is commonly applied for predominantly flat components.

Example plants
Plants #077, #078 and #145 in [155, TWG 2016].

5.4.2.2 Painting of components – enclosure and automated application

[176, ASD 2017]

Description
Component parts can be painted by applying painting processes in enclosed spray booths (see Section 17.10.2.1).

Achieved environmental benefits
Benefits include reduced fugitive emissions and noise. There is also a reduction in the volume of air to be extracted and therefore the energy used.

Technical considerations relevant to applicability
Applicable for paint application on small component parts.

Driving force for implementation
Workplace health and safety.

Example plants
Plants #077, #078 and #145 in [155, TWG 2016].

Reference literature
[155, TWG 2016] [176, ASD 2017] [212, TWG 2018]

5.4.2.3 Direct printing

[176, ASD 2017]

Description

Direct printing is a technology to directly print customised liveries on aircraft parts. The system uses solvent-based inks. The customised colour is composed of four different inks according to the CMYK colour spectrum (cyan, magenta, yellow, black). The printing device is moved across the part by a Cartesian automation system and is equipped with an additional third axis to follow simple 3D parts like the vertical tailplane or sharklets (wingtips).

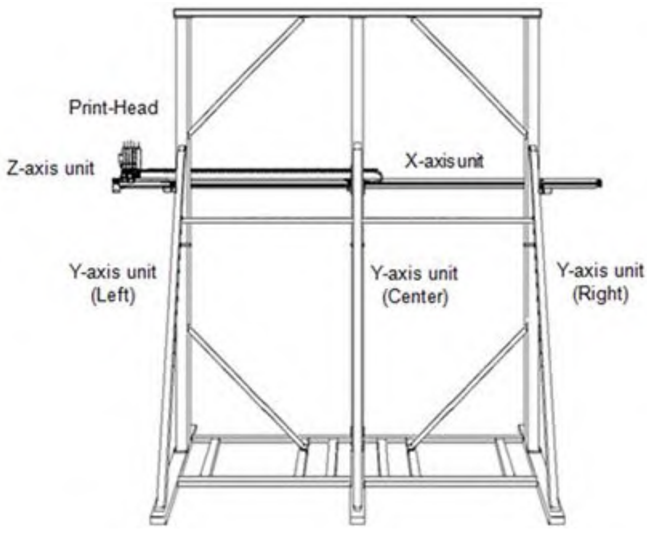
Technical description

The direct printing technology could be used to apply highly complex designs on aircraft parts, e.g. vertical stabiliser.

The main parts of the printing system are the workstation, the controller, the frame with x-, y-, and z-axes, the printhead including a distance-measuring unit and ink tanks. The CYMK system is the basic colour system of the machine. The printheads could be equipped with additional nozzles, e.g. for primer or spot colour.

Gantry unit

The basic principle is a Cartesian base frame with a printhead on a moveable sledge. The moveable sledge can move the z-axis. So the x- and y-axes can be constructed on rails which have a very high stability. Because of this stability, the necessary accuracy in repetition is achieved.

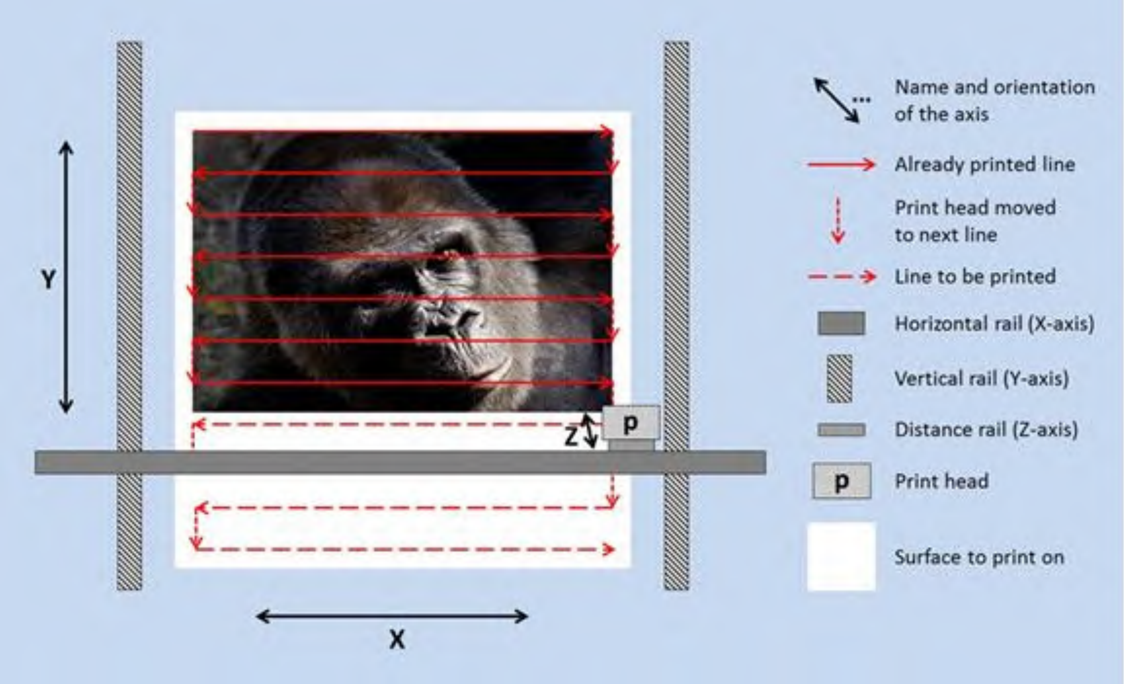


Source: [176, ASD 2017]

Figure 5.8: Gantry unit with all axes and printhead

Printhead

The printhead starts with the printing process in the left upper corner and moves in a straight line on the horizontal rail from left to right over the surface and applies the layer with piezoelectric jet valves. After a line ends, the whole horizontal rail with the printhead moves down, stringing the lines together, and creates the surfaces.



Source: [176, ASD 2017]

Figure 5.9: Operating principle of the x-, y-, z-axes frame

Process

Direct printing technology is used to apply decorative layers between the base coat or topcoat and the clear coat (see Figure 5.11). The direct printing process follows the process chain summarised below.

Source: [176, ASD 2017]

Figure 5.10: Process chain including direct printing

Source: [176, ASD 2017]

Figure 5.11: Comparison of BCCC (base coat / clear coat) system with direct printing in the BCCC system

Achieved environmental benefits

- Reduced paint material consumption and/or masking material.
- Less VOC emissions compared to painted logos.
- Reduced waste (less masking material) and higher efficiency (less overspray) during application.
- Elimination of adhesive film for decoration.
- Weight savings due to minimum layer thickness – fuel savings.
- Extended lifetime due to less erosion effects – resource savings.
- Reduced energy consumption due to lower requirements to air ventilation system.

Environmental performance and operational data

Example – Thomas Cook sunny heart design (first industrial application):

- Ink consumption: 500 ml.
- Delivery to customer: 05/2016 - Flight hours/cycles: 2 843 h / 823 – No cracks / peeling / delamination observed.
- Weight savings approximately 3 kg (190 g/m2).
- 20 h printing time (without workers) with one-side printing device (20-nozzle system).

Cross-media effects

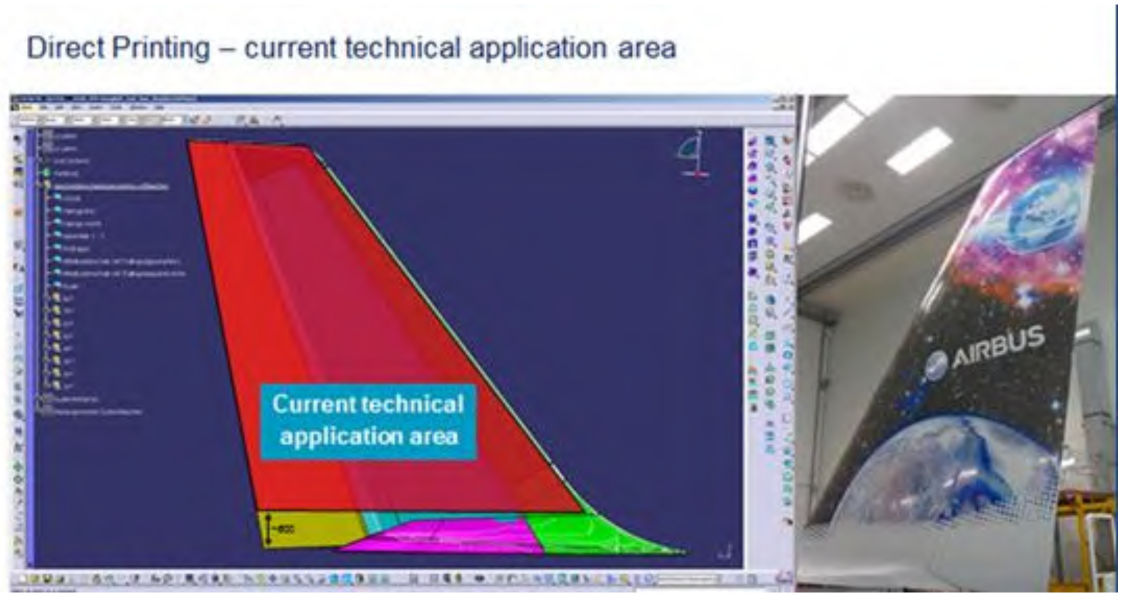
Use of acetone-based ink with vinyl resin (VR) pigments. The inks have a high VOC content. But only small amounts of ink are used/emitted in a wide time frame.

Technical considerations relevant to applicability

Colour reproducibility (colour shade)

The printing technology is based on the CMYK principle. This colour spectrum represents only a small part of wider colour spectrums, e.g. Pantone where most of the customised colours are defined. For this reason, the technology cannot be used to print all customer layouts (high risk of colour mismatch).

Accessibility
There is not full accessibility to all aircraft parts (even some parts of the VTP - vertical plane) due to the gantry unit being used as a guiding system for the printhead. The technology is currently limited to light contoured parts like the VTP and sharklets/wingtips.



Source: [176, ASD 2017]

Figure 5.12: Current technical application area

Economics
For an industrial printing device (2017 data):

- Investment: EUR 1.4 million excluding building costs.
- Ink price: EUR 700/l.
- Savings:
  - LT (loading and unloading time): up to 114 h for high-complexity VTP designs;
  - RC (receiving cost): e.g. EUR 7 000 for the Thomas Cook sunny heart adhesive film (total size only 17 m^2); full VTP decoration adhesive film up to EUR 25 000 (total size 43 m^2).

Driving force for implementation
Traditional methods have become insufficient with airlines’ desire for artistic designs, which has led to the development of a new technology to create complex livery paintings automatically and increase flexibility.

Example plants
The first prototype printing device is available at the Airbus Hamburg (Plant #077 in [155, TWG 2016]) multi-programme paint centre. The prototype is able to print on a 7 000 mm x 7 000 mm surface area with a maximum length of the z-axis of 450 mm. The printhead is equipped with 20 nozzles, 4 for each colour (cyan, magenta, yellow, black and white primer). The machine could be operated semi-automatically by nozzle cap (measuring plate) or by a laser tracker (contact-free).

Source: [176, ASD 2017]

Figure 5.13: The direct printing device

Reference literature
[155, TWG 2016] [176, ASD 2017] [212, TWG 2018]

5.4.3 Treatment of off-gases from external aircraft painting

[176, ASD 2017] [212, TWG 2018]

The application of paint onto aircraft is done in closed workshops (see Section 17.10.2.1) and completely by hand with an application gun. Off-gas treatment apart from overspray capture is not typically applied due to the substantial volume flows (about 450 000 m^3/h), the low VOC concentrations and the discontinuous operation of installations.

5.4.3.1 Wet washer

[176, ASD 2017] [212, TWG 2018]

Description
A wet washer is composed of a dry filter (glass fibre structure) and a water scrubber system (chambers where water conditioned with coagulant is sprayed).

Technical description
For a general description, see Sections 17.10.4.2 and 17.10.4.4. During painting, overspray arises (30 % to 50 % of paint used becomes overspray). An airflow drives the overspray into a dry filter (up to 90 % of overspray is captured in the mats), then into the wet washers (the remaining overspray is captured). Dry filters and wet washers can capture overspray but only the wet washer can capture VOC emissions.

Threshold values of a carbon measurement system are used to start/stop the wet washer pump. This way of working limits electrical consumption and targets the maximisation of VOC reduction. It is recommended to exchange the water of the scrubber during and after painting.

Achieved environmental benefits

VOC emissions reductions (capturing part of the soluble VOCs), reduction in dust emissions, reduction of chemicals used for waste water treatment and of electrical consumption.

Environmental performance and operational data

To get better filtering surface and efficiency, the dry filter has to have a zigzag structure.

The efficiency of the technique regarding VOC emission capture can change depending on:

- type of painting operation (primer, topcoat, etc.);
- solubility of the solvent used in the paint;
- speed of air stream: when the flow rate of the extracted air is halved (300 000 m3/h).

Cross-media effects

- Energy consumption for the ventilation system and for pumping water into the wet washer.
- Waste generation due to the use of dry filter mats.
- Waste water coming from the wet washer. Attention needs to be paid to the COD levels in the waste water.

Technical considerations relevant to applicability

Dry filters and wet scrubbers need to be combined for better efficiency (capture of dust and VOCs) and for improving maintenance costs. When dry filters and wet scrubbers have been operated alone, some technical issues can occur (increased cost of maintenance).

Economics

The cost for facilities in terms of investment or recurrent operations is highly significant.

Investment costs:

- Dry filter.
- Wet washer scrubber.
- Adaptation of the ventilation system (the most costly asset).

Operational costs:

- Ventilation maintenance (very high significant costs).
- Dry filter lifetime – requires regular changes.
- Wet washer cleaning (approximately every 2 years).
- Waste water treatment maintenance.
- Paint cleaning in the ventilation and mixing room.

Example plants

Plant #077 in [155, TWG 2016].

Reference literature

[155, TWG 2016] [176, ASD 2017] [212, TWG 2018]

6 COIL COATING INDUSTRIES

6.1 General information on coil coating

[22, ECCA 2004] [38, TWG 2004] [78, TWG 2005] [212, TWG 2018]

The definition of a coil coating process according to EN-10169-1:2010 is as follows: *'A process in which an (organic) coating material is applied on rolled metal strip in a continuous process which includes cleaning, if necessary, and chemical pretreatment of the metal surface and either one-side or two-side, single or multiple application of (liquid) paints or coating powders which are subsequently cured or/and laminating with permanent plastic films'*.

The substrate is normally either cold-rolled~~,~~ zinc- or zinc-alloy-coated steel (75 %) or aluminium (25 %) expressed as a percentage of the surface area. Of the coatings, 95 % consist of paints and 5 % of plastic laminates.

The coil coating process gives the option of a wide range of colours, gloss levels and surface textures. The coil can be delivered in coil form, slit or as cut lengths; it can be subsequently bent, profiled, deep-drawn, fastened, etc., without damaging the surface coating. All stages and parameters of the process are under continuous control, e.g. pretreatment deposition, coating thicknesses, colour, gloss, adhesion and mechanical qualities of the coating.

6.1.1 Size of the coil coating industry

Most of the coil coaters in Europe belong to large steel or aluminium groups, normally supplying big quantities of pre-coated metal. Some coil coaters such as coaters of narrow strips and specialised service centres, deliver smaller and more customised quantities to the user.

The number of coil coating lines continues to grow across the world as the market for pre-painted metal grows; in 2017 there were around 575 in 61 different countries (excluding North and South America) compared to the 390 in 2004 [ECCA comment #36 in [212, TWG 2018]].

Table 6.1 gives the number of production lines by country in Europe and their annual capacities of pre-painted steel and aluminium. It is not known if all of these fall within the scope of the IED.

Table 6.1: Number and capacities of European coil coating lines

Country	Number of production lines	Capacity	
		Steel (kt/yr)	Aluminium (kt/yr)
Austria	2	300	
Belgium	6	830	8
Czech Republic	2	50	*
Denmark	1	20	*
Finland	2	310	-
France	15	1 649	128
Germany	26	1 507	420*
Greece	4	25	30
Italy	27	1 669	95*
Netherlands	7	380	20*
Poland	4	340	-
Portugal	4	147	-
Romania	2	170	-
Slovenia	1	NA	-
Slovakia	1	105	-
Spain	21	585	59*
Sweden	5	215	0.5
United Kingdom	7	503	*
Total	**137**	**8 805**	**166.5**

* Steel and aluminium data are not split so the total has been considered in the steel figures.
Source: [ECCA data, comment #2 in [212, TWG 2018]]

Pre-painted sheet metal products are widely used in industries as varied as building and construction, consumer products, the automotive industry, furniture, lighting, consumer packaging, etc. The European and American demand for pre-painted metal is shown in Table 6.2; the European market has doubled in size since the early 1990s and further growth is forecast [ECCA comment #38 in [212, TWG 2018]].

Table 6.2: Coil coating statistics for 2016

Association	Steel		Aluminium	
	(kt)	(%)	(kt)	(%)
ECCA	5 205	57	386	43
NCCA	3 978	43	513	57
Total	**9 183**	**100**	**899**	**100**

NB:
ECCA: European Coil Coating Association.
NCCA: National Coil Coating Association (of the United States).
Source: [ECCA data, comment #3 in [212, TWG 2018]]

6.2 Applied processes and techniques in coil coating

[22, ECCA 2004] [38, TWG 2004] [174, Finland 2017] [175, ECCA 2016] [212, TWG 2018] [264, TWG 2019]

A coil coating line coats both sides of a metallic substrate with either a paint or a laminate or both. One side is coated with a primer and topcoat, which provides the aesthetic and functional performance of the product; the reverse side is coated with a primer and/or backing coat.
The typical metallic substrates are:

(a) hot-dip galvanised or electroplated steel;
(b) uncoated cold-rolled steel;
(c) aluminium.

Other metals such as stainless steel and copper alloys may also be coated for niche applications.

Coil coating lines in Europe are either of the following:

(i) Plants that are located on large steel or aluminium manufacturing installations (usually referred to as an integrated site) where the coil coating process is one of several manufacturing processes that are operated by the installation owner. In these circumstances, the electrical, water and other services required by the coil coating plant(s) are usually part of the overall infrastructure that supports the installation. The installation usually develops an environmental management plan which minimises its environmental impact through a holistic approach across all the different plants and processes that are located on the site. This can directly impact the operation of the coil coating plant, e.g. use of by-product gas in the thermal oxidiser rather than flaring it, and the environmental metrics associated with the line, e.g. energy consumption.
(ii) Plants that are the sole occupant of a site dedicated to the operation of the coil coating process. In some cases, more than one coil coating plant may be part of the same installation. Services associated with coil coating plants are clearly identified and quantified. In these cases, the environmental management plan for the installation is strongly focused on the operation of the coil coating plant(s).

The industry operates a number of different manufacturing configurations for the coil coating plants that produce pre-painted metal. These are as follows:

(a) Stand-alone: this is the most common configuration and is detailed in Section 6.2.1.1.
(b) Combiline: recent innovation by the industry where the hot-dip galvanising and organic coating/curing processes are combined in one continuous manufacturing plant. These may be purpose-built plants or are created by retrofitting the coating/curing units to the existing metallic coating plant (see Section 6.2.1.2).
(c) Specialist: where organic coating and drying equipment has been installed on a plant that produces steel for specific markets, e.g. electrical steels, packaging steels which are not usually supplied by traditional coil coating plants. The coating operation adds a final organic layer to the speciality steel where the metallurgical properties of the product are of primary importance (unlike in typical coil coating).

6.2.1 Typical coil coating line process description

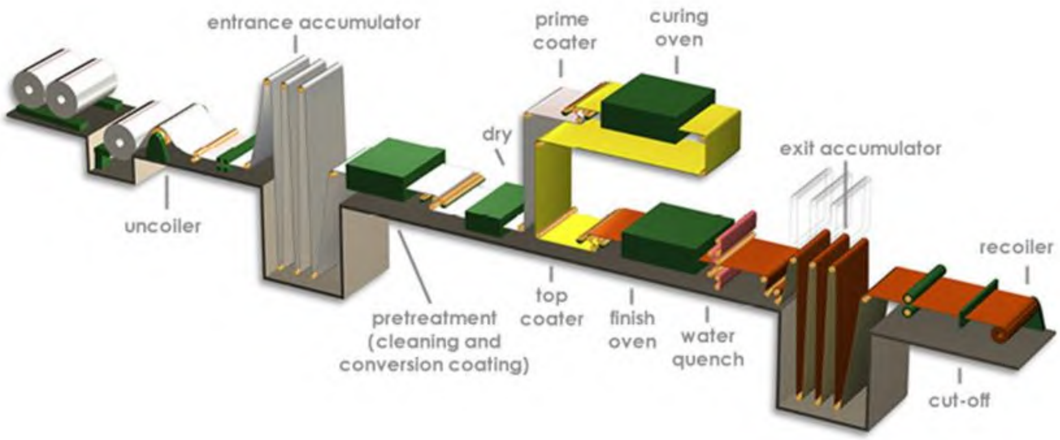
6.2.1.1 Stand-alone line

The most common case is an organic coil coating line comprising decoilers, an entry strip accumulator, cleaning, conversion coating, primer coating, finish coating, an exit accumulator and recoilers. This configuration allows the line to operate continuously at high speed for 7 days

a week, 24 hours a day, for maximum efficiency. All process parameters are controlled to assure effective operation.
Table 6.3 shows the typical operating parameters of an organic coil coating line, and Figure 6.1 the basic layout of the line.

Table 6.3: Typical operating parameters of an organic coil coating line

Parameter	Value
Operating speeds (m/min)	30-180
Gauge (mm)	0.1-3
Width (mm)	150-2 700
Coating thickness (µm each side)	3-200
Source: [22, ECCA 2004] [38, TWG 2004] updated by ECCA comment #67 in [212, TWG 2018]	



Source: [ECCA comment #39 in [212, TWG 2018]]

Figure 6.1: Typical layout of a coil coating line

The next sections explain the different parts of the coil coating line in more detail.

6.2.1.1.1 Entry

The coiled strip is fed into the line by a coil car and pay-off reel. The coil is checked to ensure compliance with quality standards and then passed through a shearing process to remove any damaged material from the leading edge. A stitch or weld is created between the leading edge of the new coil and the end of the coil already being processed in the line, to allow a continuous flow of material through the processing section. The strip then goes through a notcher, which allows the stitch to be tracked through the line.

6.2.1.1.2 Leveller

Tension levelling may then be used to ensure that a good standard of flatness is achieved. This is required to facilitate the passage of the material though the roller coaters and ovens, and to meet customer requirements. Poor strip shape can result in an uneven paint layer and scratches. The location of the leveller can in some cases be after the entry accumulator.

6.2.1.1.3 Accumulator

After the leveller, the strip enters an entry accumulator. This normally operates to full capacity but will release stored strip to allow sufficient time for the entry section to stop and stitch or weld coils together.

6.2.1.1.4 Cleaning section

It is common to have a preclean section before the entry accumulator because some lines operate with coils of cold-rolled steel (CRS) which were previously oiled to prevent corrosion. It is very difficult to guide an oiled strip, so precleaning the strip before the accumulator makes it possible to operate at a normal speed. In some cases, lines may have cleaning sections before and after the accumulator. However, the most common substrate (hot-dip galvanised (HDG) coil) does not require cleaning before the accumulator and in some cases may not require cleaning at all, in which case the line does not have this section.

The strip is chemically cleaned and degreased in a warm aqueous cleaning solution, via a dip and/or spray system (sprayed both sides). It is essential that the surface of the strip is free from impurities, such as grease, oil or abraded metallic fines, so that it can be fully coated with the conversion coating, thus ensuring the optimal performance of the final product. Cleaning is followed with hot and cold water rinses to remove all residual chemicals. A squeegee roller set-up is generally used to ensure low carryover from the degreasing section and to minimise the amount of waste water.

6.2.1.1.5 Conversion coating (pretreatment)

The strip is dried prior to being treated with a conversion coating. A pretreatment is required to ensure the correct adhesion of the paint layer(s) and good corrosion-resistant behaviour in the final product. The choice of the chemicals used in the pretreatment process is based on their ability to achieve these two objectives.

Based on the REACH legislation [47, EU 2006] concerning the use of hexavalent chromium (Cr(VI)) chemicals in pretreatment systems (sunset date: 21.9.2017), the European coil coating industry has developed a range of Cr(VI)-free products which provide the required levels of adhesion and corrosion resistance. There are some coil coating lines which continue to use Cr(VI) systems under authorisation by REACH; it is anticipated that the use of Cr(VI) systems in the industry will continue to decline as suitable alternatives are found for the specific niche product-market combinations that currently require Cr(VI) pretreatment [ECCA comment #7 and DK comment #13 in [212, TWG 2018]].

For metals such as cold- and hot-rolled steel and various forms of galvanised steel, a coating of iron or zinc phosphate, or titanium-fluoride-based treatment, may be applied instead. Special additives will also typically be used to promote the coating deposition on different metals and to increase process efficiency [ECCA comment #7 in [212, TWG 2018]].

The coating can be applied via a chemical roller coater (‘chemcoater’, which does not require rinsing[26]) or by a spray or dip followed by squeegee rollers. Some coatings require a final rinse to remove any residues left on the strip which is dried before entering the coating section.

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[26] Also known as ‘dry-in-place’ or ‘no-rinse’.

6.2.1.1.6 Primer coat application

The painting process comprises two stages, namely the primer application and the finish application. In the first stage, the strip passes through a roller coater machine that applies a primer to one or both sides of the strip. The roller coater can be adjusted in order to regulate the amount of paint applied onto the strip surfaces. Application operations are carried out in an enclosed area with forced ventilation to ensure safe working conditions for personnel. A meter roll presses the strip towards a pick-up roll and helps to control the wet film thickness of the paint. Normally primer paint is applied using the two-roller technique (pick-up roller and application roller).

After application of the primer, the strip passes through an oven at the appropriate temperature for the desired residence time to ensure that all the volatiles are removed and that the paint is properly cured. This will be dependent on the paint system applied and the cross-sectional area of the strip. After the oven curing, the strip is cooled by an air and/or water cooling system.

6.2.1.1.7 Finish coat application

Once dried, the strip passes through a second roller coater machine, which applies the finish paint coat to either one or both surfaces. A similar or different coating may be applied to the reverse side of the coil. Paint can be applied to either or both the top and bottom sides of the strip using two rollers (pick-up and application rollers) or three rollers (meter, pick-up and application rollers) depending on the product. In the finish coater, there are two different painting heads for the top side of strip and also two different painting heads for the bottom side. This makes it possible to do a quick colour change on either side of strip. Again, the thickness of the paint applied to each side of the strip can be controlled. The strip then passes through an oven set at an appropriate temperature to ensure that all the volatiles are removed and that the paint is fully cured. After the oven curing, the strip is cooled by an air and/or water cooling system.

All finish coating operations are normally carried out in an enclosed area that is adequately ventilated to ensure safe working conditions for personnel under local and European regulations.

6.2.1.1.8 Embossing and laminating

Embossing rolls are used to imprint patterns or textures into the thicker coatings (such as plastisol products). Embossing is followed by quenching and drying.

For the production of laminated materials, rolls of thin polymer film are bonded to the strip. When producing laminated materials, adhesive is applied by a finish coater and activated in an oven before processing through the laminator and water cooling.

6.2.1.1.9 Cooling systems

In order to minimise water usage, an evaporative or other cooling tower may be used to provide a closed system for strip cooling when it is consistent with the product quality requirements.

6.2.1.1.10 Exit

After being cooled, the strip passes through an exit accumulator and guillotine/shears. This accumulator allows the line to run continuously while the exit section slows or stops in order to remove a finished coil. The strip is inspected and tested to ensure that it complies with quality standards and is then coiled onto a tension reel. The completed coil is removed and strapping is applied. It is then identified and moved to the packing area, where it is packed according to customer requirements.

6.2.1.2 Combiline

[175, ECCA 2016] [212, TWG 2018]

Hot-dip galvanised steel is the most common substrate used in the steel coil coating industry. A number of installations contain both hot-dip galvanising and coil coating plants and the idea of merging these two processes on the same industrial line has been developed due to its potential as a cost-effective industrial layout.

Over the last decade, the technical improvements of both the paints used in coil coating and the associated curing technology have made it possible to combine the hot-dip coating and organic coating in one continuous production plant. Combilines are now producing coil-coated steel in Europe and in other parts of the world. Some companies have chosen to invest in new facilities containing both process steps; others have chosen to retrofit the organic coating and curing units onto an existing galvanising plant [ECCA comment #40 in [212, TWG 2018]].

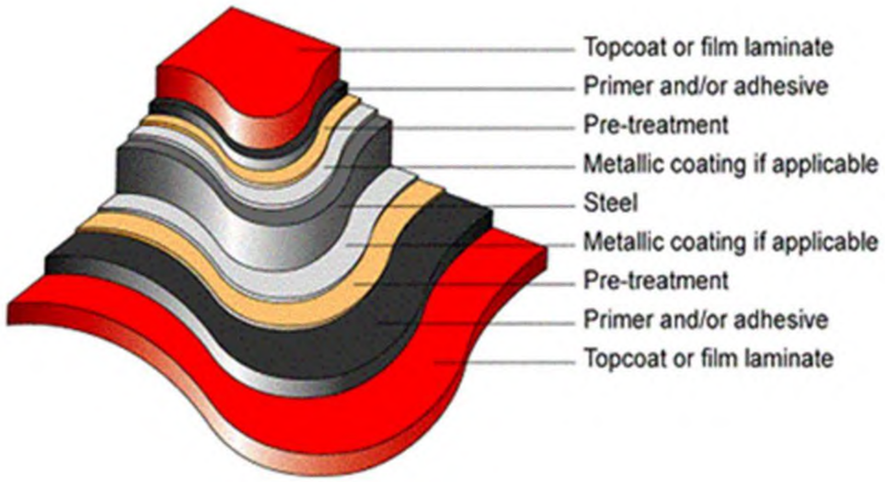
The painting section is generally located right after the temper mill of the hot-dip galvanising line, in the central section of the line (i.e. in between the two accumulator towers). The line speed is the same for galvanising and for painting. For the coating activity, the strip passes through the same process steps as in the case of a stand-alone coil coating line.

6.2.2 Coating types

[22, ECCA 2004] [38, TWG 2004] [175, ECCA 2016]

As the coil coating line has the ability to apply paint or laminate to a substrate, a large variety of products can be manufactured. The coatings, which mainly include polyesters, polyvinylidene difluoride (PVF_2 or PVdF), polyurethanes, plastisols, epoxy and epoxy phenolic coatings, primers, backing coats and laminates, are typically applied in thicknesses of between a few microns and 200 microns. It is also possible to find some polyamide or acrylic coatings. The paint usually contains the appropriate additives or particles that will also give the correct overall characteristics (gloss, mechanical properties, durability).

A flexible anti-corrosive primer or a base coat is applied onto the pretreated metallic strip to give good adhesion and durability to the subsequently applied topcoat. For each product, the coating is built up in a number of layers. A typical example for coated steel material can be seen in Figure 6.2.



Source: [22, ECCA 2004]

Figure 6.2: Typical layers of a coated steel product

Table 6.4 lists some typical organic coating types used in the coil coating industry.

Table 6.4: Organic coating types used in the coil coating industry

Coating	Dry film thickness (µm)	Resin types	Solvent content (%)	Solvent types	Cure temperature (°C)
Primers Conventional	4-9	Epoxy/urea, epoxy/melamine, polyester/melamine, polyurethane, acrylic	50-70	High-boiling aromatics; alcohols; glycol ethers/esters; high-boiling esters	210-230
Primers High build	12-25	Polyester/melamine, polyurethane	40-50	High-boiling aromatics; alcohols; glycol ethers/esters; high-boiling esters	210-230
Backing coats	4-15	Polyester/melamine, epoxy/melamine, epoxy/phenolic, alkyd/melamine	50-70	High-boiling aromatics; alcohols; glycol ethers/esters	180-250
Topcoats					
Polyester	18-25	Saturated polyesters cross-linked with melamine-formaldehyde resins	35-55	High-boiling aromatics; glycol ethers/esters; high-boiling esters/alcohols	210-250
SMP (silicone-modified polyester)	As above	As above except for silicone modification in the polyester resin	45-55	High-boiling aromatics; glycol ethers/esters; high-boiling esters	210-250
Polyurethane	20-30	Saturated polyesters with urethane cross-linking	30-50	High-boiling aromatics; glycol ether/esters; high-boiling esters	220-250
PVDF PVF_2	20-25	Polyvinylidene difluoride + acrylic polymer	40-65	High-boiling aromatics; glycol ethers/esters; high-boiling ketones	240-260
PVC plastisol	100-200	Polyvinyl chloride + plasticisers	<10	High-boiling esters; high-boiling aliphatics	190-210
Water-based products (includes some primers and backing coats)	10-25	Acrylic/melamine	5-15	High-boiling esters; glycol ethers/esters	220-230
Non-stick bakeware coatings	12-15 (2-coat 7+7)	Polyether-sulphone, PTFE	65-80	Butyrolactone; high-boiling aromatics	350-370
Laminate film coatings	15-120	Polyvinyl chloride (PVC), polyvinyl fluoride (PVF), polyethylene terephthalate (PET), acrylic, polypropylene	0	None in film, but used in primer/adhesive	Lamination at 180-230
Powder coatings	35-100	Polyester/epoxy polyurethane	0		200-250

Source: [22, ECCA 2004] [38, TWG 2004] updated by [175, ECCA 2016]

6.3 Current consumption and emission levels in coil coating

Data for 33 coil coating plants were received in the data collection and their analysis is presented in the following sections [155, TWG 2016].

6.3.1 Consumption

6.3.1.1 Materials

[22, ECCA 2004] [38, TWG 2004] [78, TWG 2005] [155, TWG 2016]
[175, ECCA 2016] [212, TWG 2018]

Table 6.5 lists the usage of various coating types for 2016.

Table 6.5: Paint usage in the European coil coating industry (2016 data)

Coating types	Relative usage (%)
Primers	**21.1**
Backing coats	**16.5**
Topcoats (listed below)	**62.4**
Polyester	67
PVdF (polyvinylidene difluoride)	3
PVC plastisol	13
Polyurethane systems	13
Water-based topcoats	0.1
Other	4
Total (t/year)	**203 025**

Source: ECCA comment #4 in [212, TWG 2018]

The following materials are used in organic coil coating processes:

- metallic substrates (i.e. steel, zinc-coated steel, aluminium, etc.);
- paint;
- solvents;
- cleaning and pretreatment chemicals;
- engineering oils;
- (demineralised) water;
- others: biocides, grease, cleaning materials.

Table 6.6 shows the inputs to the coil coating process, their uses and typical end-of-life destination.

Table 6.6: Inputs to the coil coating process, their uses and typical end-of-life destination

Substance	Use	Typical end-of-life destination
Inputs in solid form		
Metal strip (as coil)	Substrate	Product or scrap
Cleaning wipes (fabric)	Cleaning	Licensed removal
Inputs in liquid form		
Paint	Strip coating	Product / licensed removal / returned to paint supplier for reuse
Solvent	Cleaning and thinning paint	Licensed removal
Cleaning chemicals	Cleaning strip	Treatment plant / licensed removal
Pretreatment chemicals	Pretreatment of strip	Product / treatment plant / licensed removal
Paint stripper	Cleaning paint heads	Licensed removal
Water	Cooling/treatment	Waste stream / effluent
Engineering oils	Lubricant	Licensed removal
Coating oils	Anti-corrosion	Product / licensed removal
Biocides	Water cooling (→ longer use of water)	Waste stream effluent
Inputs in gaseous form		
Steam or hot water (1)	Strip drying / solution heating	Condensate – drain system
Natural gas (1)	Fuel	Combustion products to air
Hydrogen	Oven monitoring	Combustion products to air
Ethylene in air	Oven monitoring	Combustion products to air

(1) An alternative option is to use electricity.
Source: [22, ECCA 2004] [38, TWG 2004] [175, ECCA 2016]

Organic coating

For the coil coating sector, solvent-based coatings are the dominant systems used throughout the industry (see Table 6.5). Organic coating systems are based on polyester, polyurethane (or a combination of both), epoxy or epoxy-phenols, PVC plastisol and polyvinylidene difluoride (PVdF or PVF_2). For special surfaces, coatings with thermoplastic foils based on polyvinyl chloride (PVC) or polyethylene terephthalate (PET) are also commonly applied. They may also include polyvinyl fluoride (PVF) and other polymers. The resin base for primers may be epoxy, polyester, melamine, polyurethane or acrylic, depending on the particular specification. The primer is very important for the corrosion resistance because this layer contains the anti-corrosive pigments. The industry now uses a range of chromium(VI)-free pigments in the primers which provide the required in-service performance, particularly for building applications. Based on the REACH legislation [47, EU 2006], the sunset date of 22.1.2019 for chromate-containing pigments, such as strontium chromate, ensures that the use of such compounds in the industry will continue to decline as authorisation is required after that date.

The most frequently used solvents are shown in Table 6.7.

Table 6.7: Solvents most frequently used in organic coating

Type of solvent	Some examples
Alcohols	Diacetone alcohol
Glycol acetates	Propylene glycol methyl ether acetate, ethyl diglycol acetate
Glycols	Butyl diglycol, butylglycol, propylene glycol monomethyl ether
High-boiling esters	Dibasic esters, mixtures of refined dimethyl esters of adipic, glutaric and succinic acids
Ketones	Isophorone
Petroleum hydrocarbons	Commercial aromatic fractions, xylene
Source: [38, TWG 2004] [78, TWG 2005]	

The solvent-based paints currently applied have a solids content in the range of 30-70 wt-%. The applied layer thickness for systems based on acrylate, epoxy, polyurethane or polyester varies from less than 1 µm up to 50 µm; however, it is most commonly around 25 µm.

For plastisols with a solvent content of 5-10 %, a layer thickness of 200 µm is typical.

For powder coating systems, a common layer thickness is in the range of 60-100 µm.

Typical consumption figures in relation to the application of a layer thickness of 50-60 µm of powder or liquid coating to a square metre of coated coil is shown in Table 6.8.

Table 6.8: Typical paint consumption in coil coating

Paint system	Paint consumption (g/m^2 coil)
Solvent-based (50 wt-%)	32-53
Powder paint	60-80
NB: Due to the various coating systems and layer constructions, these figures represent only an approximation. *Source*: [5, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005]	

In large installations, solvents are used at a rate of hundreds of kilograms per hour.

Consumables containing non-solvents listed in Table 6.9 include cleaning and pretreatment chemicals.

Table 6.9: Chemicals containing no organic-not mixed with solvents

Process	Product	Application method	Substrate	Main components	Consumption rate (kg/1 000 m^2)
Cleaning	Alkali liquid	Spray	Cold-rolled steel, zinc-coated steel	Potassium hydroxide, sodium hydroxide, phosphates, sugar-based complexing agent, surfactants	1.6
Cleaning	Alkali liquid	Spray	Aluminium	Potassium hydroxide, sodium hydroxide, phosphates, sugar-based complexing agent, surfactants	2.5
Cleaning	Acid liquid	Spray	Aluminium	Sulphuric acid, phosphoric acid, hydrofluoric acid, surfactants	1.3
Pretreatment (1)	Alkaline oxide (stage 1)	Spray and immersion	Zinc-coated steel	Sodium hydroxide, sugar-based complexing agent, ferric nitrate, cobalt nitrate	4.8
Pretreatment	Alkaline oxide (final rinse)	Spray	Zinc-coated steel	Cr^{3+}, Zn, HF	0.94
Pretreatment	Zinc phosphate	Spray	Zinc-coated steel	Zinc phosphate	6.6
Pretreatment	Chrome-free (no rinse)	Chemcoater	Zinc-coated steel	Titanium, manganese, zirconium, phosphoric acid, organic polymer	0.4
Pretreatment	Chrome-free (no rinse)	Chemcoater	Aluminium	Titanium, manganese, zirconium, phosphoric acid, organic polymer	0.40
Pretreatment	Chrome-free (rinsed)	Spray and immersion	Aluminium	Titanium, zirconium,	2.00

(1) These application technologies are also suitable for the use of Cr(VI)-containing systems. Authorisation is required for the use of such systems following the sunset date for CrO_3 of 21.9.2017; these systems have been widely substituted by chromium(VI)-free products across the industry.
Source: [22, ECCA 2004] [38, TWG 2004] [78, TWG 2005] updated by ECCA comment #11 in [212, TWG 2018]

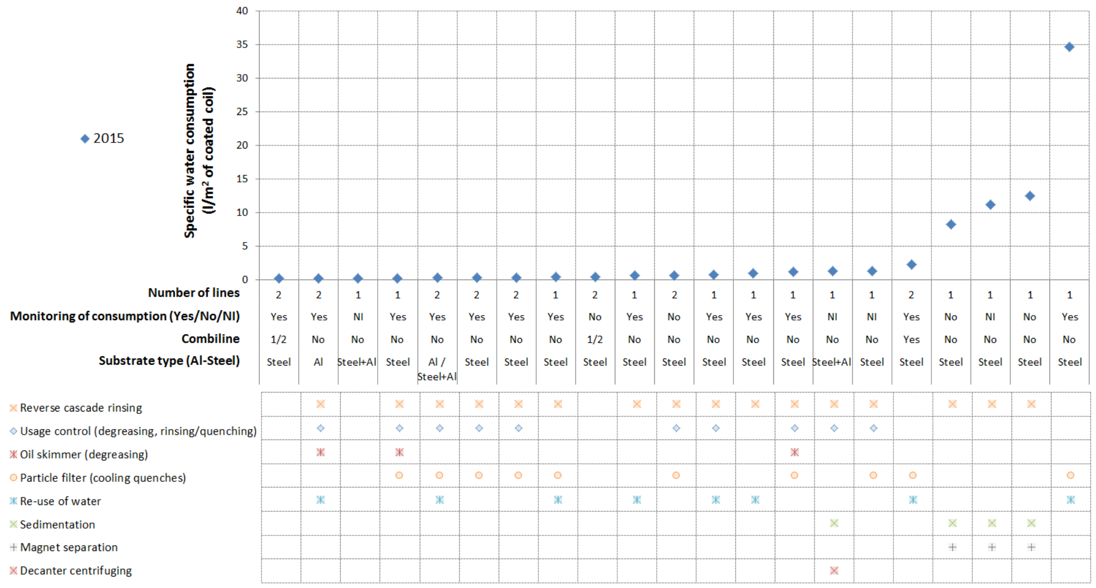
6.3.1.2 Water

[155, TWG 2016] [212, TWG 2018]

The main water usage is for the cleaning and pretreatment stations, although some is used in quenching after coating and embossing. Techniques for controlling and reducing water usage are given in the STM BREF [23, COM 2006]. Key techniques identified are [155, TWG 2016]:

- control of water usage in all water-using related processes – mainly in degreasing and rinsing processes and cooling quenches;
- reverse cascade rinsing for the degreasing and rinsing processes;
- treatment of recycled water from degreasing and cooling processes for reuse by using an oil skimmer, sedimentation, magnet separation, particle filter, or membrane filtration.

Reported values for specific water consumption in the industry are presented in Figure 6.3.



Source: [155, TWG 2016]

Figure 6.3: Specific water consumption expressed in l per m^2 of coated coil product (data for 2015)

Of the 21 specific water consumption values, 16 are below 1.3 l per m^2 of coated coil. The values higher than 1.3 l/m^2 of coated coil correspond either to combiline (one plant) or to cases where the once-through cooling water is included in the calculation of the specific water consumption (three cases). No indication of the reasons for the high specific water consumption was made available for the plant with the highest specific water consumption.

6.3.1.3 Energy

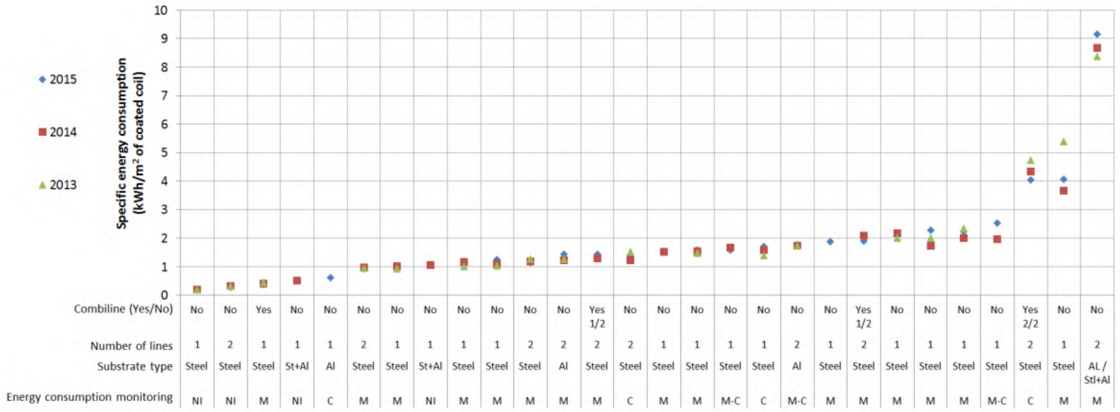
[22, ECCA 2004] [155, TWG 2016] [175, ECCA 2016] [212, TWG 2018]

Natural gas is normally used as the fuel source for the ovens when the paint is cured by convection. It is also used for the oxidiser (combustion process). Commonly, a regenerative or recuperative oxidiser is applied. The heat generated can be used in the process or can be used for steam generation or hot water. Natural gas can also be used to heat the no-rinse coating system oven, which dries the pretreatment solution that has been applied to the strip. Dampers and temperature gauges are used to ensure that the oven settings are controlled. In an integrated steel plant, the energy recovery system of the coating line can be connected to the overall energy system of the site.

Some lines use induction or near-infrared heating to cure or dry the paint; these units are usually found in combilines or in hot-dip galvanising (HDG) plants containing a retrofitted organic coating unit [ECCA comment #10 in [212, TWG 2018]].

Electricity is used to power the line and is sourced from the national grid. The main use of electricity is for process operations and coil movements with the overhead cranes and line drives, which are all electrically powered.

Reported values for specific energy consumption (total energy consumption for the coil coating plant expressed in kWh/m^2 of coated coil) are presented in Figure 6.4.



NB: M: measured, C: calculated, M-C: derived by a combination of measurement and calculation
Source: [155, TWG 2016]

Figure 6.4: Specific energy consumption expressed in kWh per m^2 of coated coil product for period 2013-2015

The main reported techniques for the minimisation of energy consumption are the following [155, TWG 2016]:

- thermal insulation of tanks and vats with heated liquids;
- air seals in dryer ovens;
- reduced air ventilation at idle operation or maintenance;
- exhaust air heat exchanger in ventilation systems;
- air extraction and energy recovery from the drying processes;
- air extraction and energy recovery for the cooling zone;
- heat recovery from off-gas treatment;
- central off-gas treatment with variable frequency drives.

6.3.2 Emissions

[5, DFIU et al. 2002] [22, ECCA 2004] [38, TWG 2004] [155, TWG 2016] [175, ECCA 2016] [212, TWG 2018]

Solvents are released as VOC emissions, especially during the process steps of coating (about 8 %), drying (about 90 %) and cooling with water and/or air (about 2 %).

In general, there are four main sources of emissions to air in a typical coil coating line. These are:

- fumes (mist) from the conversion coating section if a dry-in-place or dipping application is not used (spray application of Cr(VI) chemicals is no longer used in the European coil coating industry);
- paint/solvent fumes from the coaters and ovens;
- volatiles from the paint kitchen and mixing bays;
- emissions from the cooling system; these can be point source emissions or fugitive emissions.

Typical emissions to air are given in Table 6.10 below. All are point sources.

Table 6.10: Typical emissions to air from coil coating processes

Emission source	Pollutants emitted
Oxidiser	VOCs, CO, NO_X
Finish oven air quench	VOCs
Laboratory fume cabinet	Low-level assorted fumes
Occupational health vent from coating rooms	VOCs
Pretreatment scrubber exhaust	Mist with mineral content Potassium hydroxide Sodium hydroxide
Preclean scrubber	Potassium hydroxide Sodium hydroxide
HCl bulk tank scrubber	HCl fume
Flocculation tank fume	SO_2
Source: [22, ECCA 2004], [38, TWG 2004], [78, TWG 2005], [175, ECCA 2016]	

Typical emissions to air from point sources with abatement equipment are TVOC and oxides of carbon and nitrogen.

The TVOC and CO emissions for lines with abatement can vary depending on the product being produced. Those with high solvent loads can give rise to higher emission values than those with low solvent loadings. Thicker coatings (e.g. plastisols and laminates) can lead to lower emissions than thin coating layers.

The TVOC levels from unabated release points can vary and at times may be > 50 mg/m^3 due to intermittent localised activities within the coater house such as line cleaning and tray cleaning. However, their volume in comparison with abated emissions is still very low, although the emissions will need to be reviewed on a site-by-site basis.

Industry-wide clean gas TVOC concentrations are in general below 20 mg C/Nm^3 (see Section 6.3.2.2 below). Other emissions may include isocyanates from polyurethane products and fluorides from coatings containing fluoride where emission levels are typically < 0.1 mg/m^3.

However, fluorides are not emitted from the organic paint systems, and blocked isocyanates are used in most polyurethane coatings as this eliminates isocyanate emissions.
Table 6.11 shows some specific VOC emission values for different coating systems with an average coating thickness of 55 µm. The VOC content of the plant ovens is in the range of 8.75-9.3 g/m^3, which is about 22 % of the 40 g/m^3 LEL.

A wide range of abatement efficiencies for VOC emissions that occur throughout the coil coating process have been reported by a number of coil coating lines. Most plants reported an overall abatement efficiency in the range of 97-99 % while a small number of plants reported lower levels (see Section 6.3.2.1). This range of values may be a result of assumptions made in the solvent mass balance (SMB) calculation where considerable uncertainties may exist due to the nature of the coil coating process. In the case of a coating system with 50 wt-% solvent content in combination with a removal efficiency of 99 % in the oxidiser, about 0.04 kg solvents per kg of used coating solids are emitted.

Table 6.11: Total VOC emissions for several coating systems

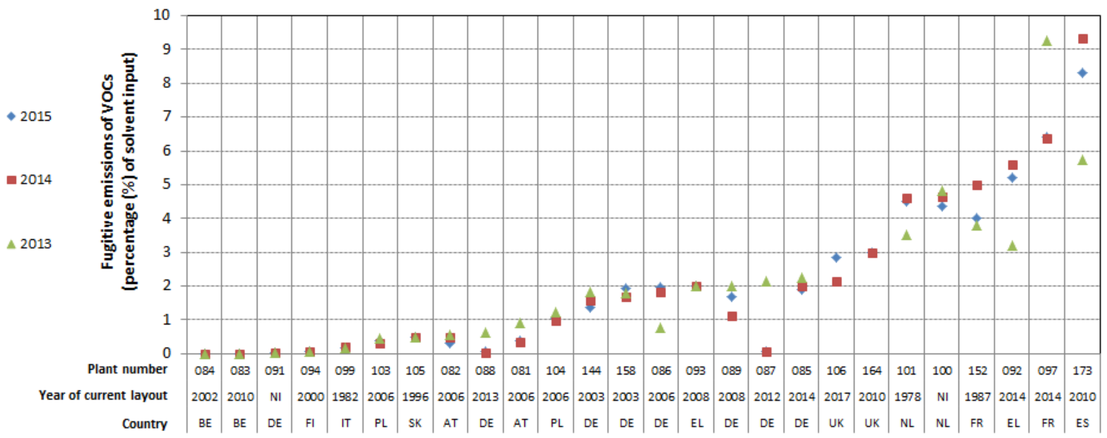
Coating system	Total VOC emission (g/m^2 coated coil)	Abatement technique
Solvent-based	0.73-0.84	Oxidation connected to oven
Solvent-based (50 wt-%)	28-29 (^{1})	None
Powder coating	0-0.8 (^{2})	None

(^{1}) Concentration values achieved with no further abatement of the air stream.
(^{2}) VOC emissions relate to curing reactions rather than solvents.
Source: [5, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005]

6.3.2.1 Fugitive emissions of VOCs

[155, TWG 2016] [212, TWG 2018]

The reported values of fugitive emissions as a percentage of the solvent input for the reference period 2013-2015 are presented in Figure 6.5.



NB: #081 & #082 data for 2011-2012-2013
Source: [155, TWG 2016]

Figure 6.5: Fugitive emissions of VOCs expressed as a percentage of the solvent input for the reference period 2013-2015

The main reported techniques for the limitation of fugitive emissions are related to [155, TWG 2016]:

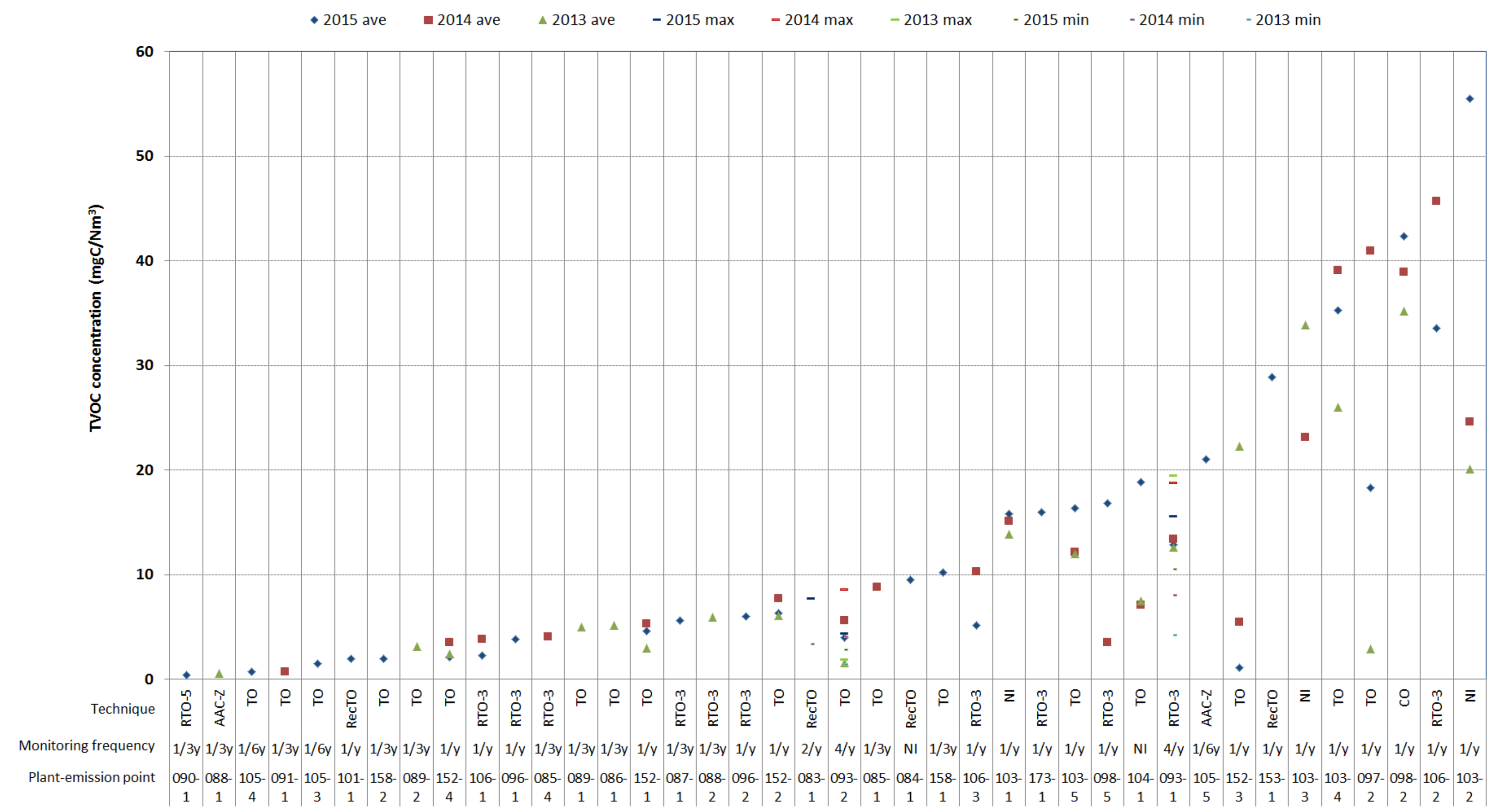
- general measures to prevent unplanned releases;
- safe storage and handling of hazardous material;
- enclosed application zones with air extraction and subsequent treatment;
- air extraction and subsequent treatment from the drying processes;
- air extraction and treatment from the cooling zone;
- substitution of coatings with a high solvent content by coating with a lower solvent content or a high solids content;
- enclosing of the paint preparation room (kitchen).

The great potential for improvements in fugitive emissions control is underlined by the reported reduction of the order of 30 % of the reported fugitive emissions (i.e. a reduction from 10 % to 7 % as a percentage of the total input) at one reference installation (Plant #097) achieved by implementing improvements in the paint rooms, especially by improving the extraction processes in the oven and the oxidiser area, and the extraction system above the paint coaters and the wet strip before it enters the ovens. This solution was appropriate for this line; other lines where the working environment surrounding the coaters differs in size and structure may need to find different improvement solutions.

All assessments of fugitive emissions contain uncertainties in the solvent mass balance calculations that need to be identified and minimised as far as possible when declaring operational levels and determining improvement targets for individual coil coating plants (see Sections 17.3.1, 17.3.2, 17.3.3 and 17.3.4).

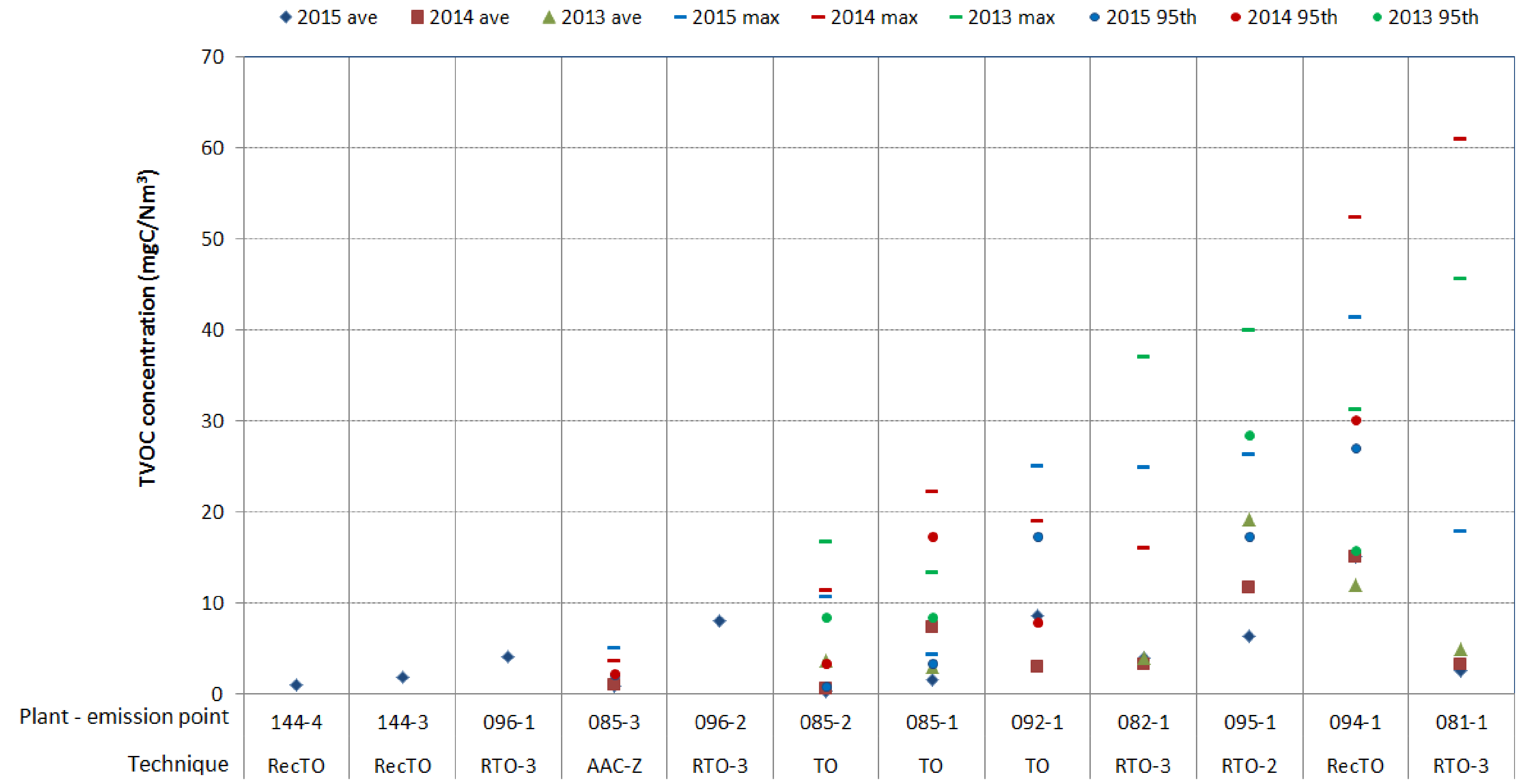
6.3.2.2 TVOC emissions in waste gases

Most of the reported TVOC emission data refer to periodic monitoring with frequencies that vary from four times a year up to once every 3 years (see Figure 6.6). Continuous monitoring is performed in fewer cases (see Figure 6.7) while in some cases both continuous and periodic monitoring are carried out.



Source: [155, TWG 2016]

Figure 6.6: TVOC emissions in waste gases (periodic monitoring) for the period 2013-2015



NB: Plant #081 and plant #082: instead of data from 2015, data from 2011 & instead of data from 2014, data from 2012.

Source: [155, TWG 2016]

Figure 6.7: TVOC emissions in waste gases (continuous monitoring) for the period 2013-2015

6.3.2.3 NO_X and CO emissions in waste gases

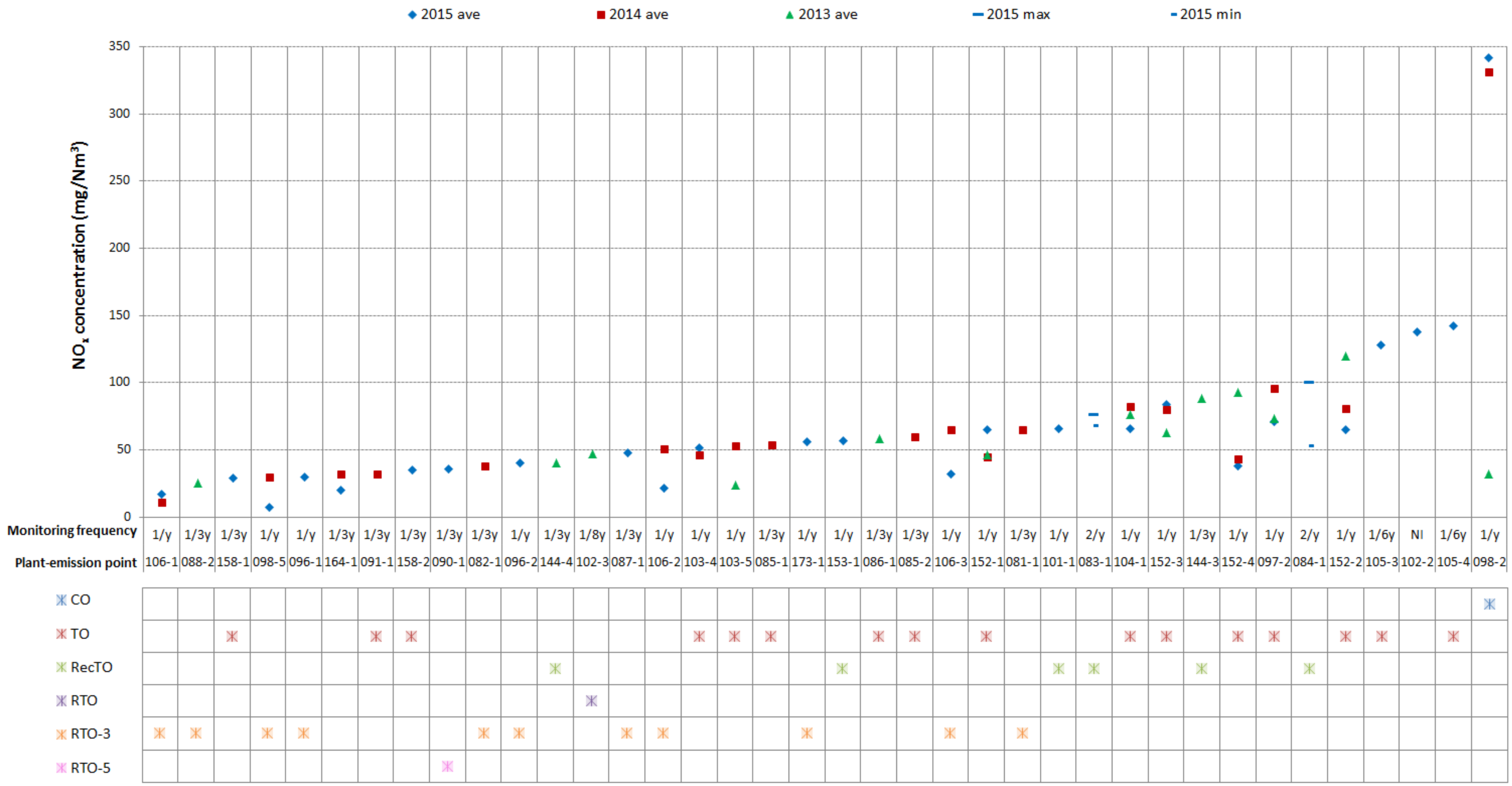
NO_X emissions result from the thermal abatement of TVOC emissions and are related to the technique applied and relevant conditions. In general, NO_X emissions are measured on a periodic basis, with frequencies reported to vary from twice a year up to once every 6 years.

No techniques were reported as being installed to reduce NO_X emissions, as the main target of the abatement process is the limitation of TVOC emissions. With only one exception, all reported values are below 150 mg/Nm^3, as an average over the sampling period.

Figure 6.8 shows the reported values for periodic monitoring of NO_X emissions in waste gases.

CO emissions also occur from the thermal abatement of VOC emissions and are related to the technique applied and relevant conditions. In general, CO emissions are measured on a periodic basis, with frequencies varying from monthly to once every 3 years.

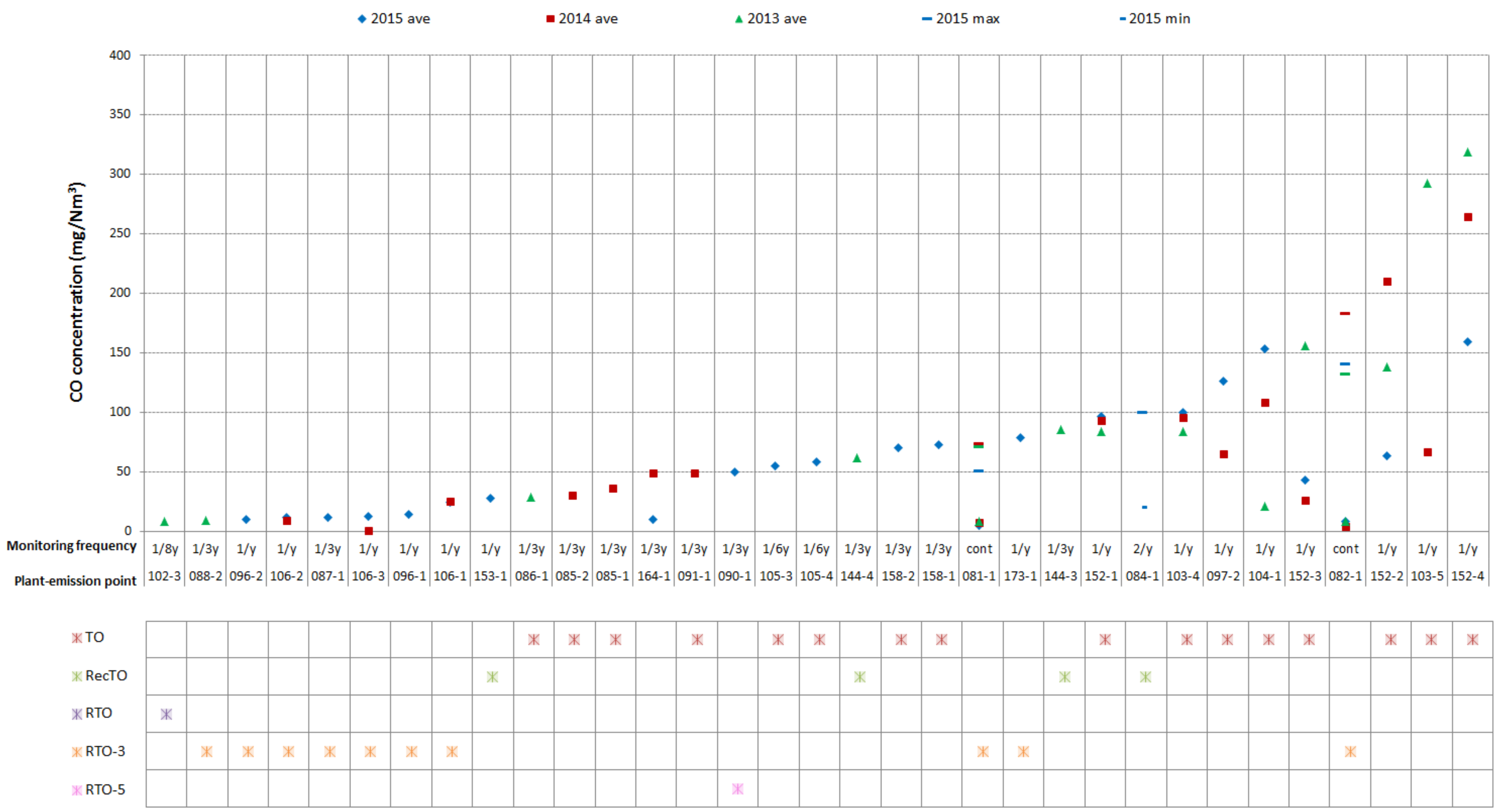
Figure 6.9 shows the reported values for periodic monitoring of CO emissions in waste gases from coil coating plants.



NB: #081 & #082 data for 2011 instead of 2015 and data for 2012 instead of 2014 / #102-2 data for 2005 instead of 2015.

Source: [155, TWG 2016]

Figure 6.8: NO$_X$ emissions in waste gases for the period 2013-2015



NB: #081 & #082 data for 2011 instead of 2015 and data for 2012 instead of 2014 / Data not shown for #083-1 (2015): ave:1178 mg/Nm^3, max:1788 mg/Nm^3, min:632 mg/Nm^3

Source: [155, TWG 2016]

Figure 6.9: CO emissions in waste gases for the period 2013-2015

6.3.2.4 Emissions to water

[5, DFIU et al. 2002][22, ECCA 2004] [23, COM 2006] [38, TWG 2004] [155, TWG 2016] [212, TWG 2018]

The main sources of waste water from a coil coating line are from the entry cleaning section and some pretreatment processes that require subsequent rinsing, and these are discussed in the STM BREF. Pretreatment processes may also be applied using the 'no-rinse method' (application by a roller technique). This method does not generate significant amounts of waste water. Pretreatment and cleaning solutions and their associated rinse waters can either be treated at an on-site effluent treatment plant or taken off site for treatment or disposal.

There are some emissions to the quench water used after curing in the primer and topcoat application and after embossing but these are not particularly significant. As all paint systems require quenching, there are no differences in the quantities of waste water generated for the different paint systems, but there may be slight differences in the actual levels/types of contaminants. The type of emissions from the cleaning and pretreatment sections for a steel coating line depends upon the metallic substrate and the chemical nature of the cleaning and pretreatment sections.

Data on emissions to water were reported by 11 installations [155, TWG 2016]. The parameters identified[27] as 'main parameters of interest' were: Cr_{total}, Cr(VI), nickel, zinc and fluoride. Other parameters of potential interest were DEHP and NP/NPE.

The main techniques applied are:

- coagulation and flocculation;
- neutralisation;
- sedimentation (settlement);
- precipitation;
- filtration;
- flotation;
- biological treatment.

The exact process sources of the waste waters are not entirely clear in all cases (although this was checked with the type of pretreatment given). In some cases, no information was given on whether waste water treatment (WWT) was carried out or the techniques applied. Although the values are small when broken down into categories, there appears to be no difference between emissions from dedicated WWT and combined WWT, or between installations discharging directly to surface waters and those discharging indirectly via urban waste water treatment plants.

Products for the European market are largely Cr-free. Four installations reported using Cr in pretreatments (but not whether Cr(III) or Cr(VI) was used). Of these, only one reported carrying out Cr(VI) reduction at the time of the data collection. There has been a strong trend towards using chromate-free pretreatment across the industry following the sunset date of 21.9.2017 under the REACH legislation [47, EU 2006], which means that authorisation is required for the Cr(VI)-containing systems. These authorisations, which may be granted where substitution is not viable or available for specific situations, are the subject of periodic review and the use of Cr(VI) is expected to continue to decline until a time when the industry will only use chromate-free pretreatments [ECCA comment #15 in [212, TWG 2018]].

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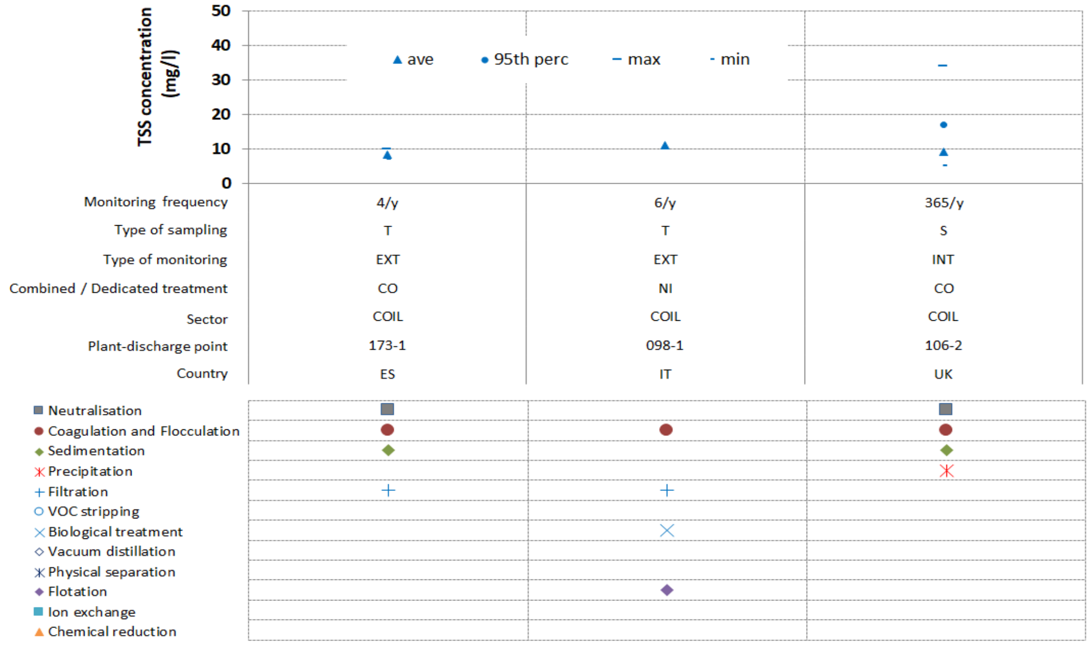
[27] COM working document EIPPCB 09/06/2016: Assessment of Technical Working Group (TWG) data submitted on metals and other emissions to water for their consideration as Key Environmental Issues for installations carrying out IED Annex 1 6.7 activities.

The reported concentration values for each pollutant are presented in the following sections. An explanation of abbreviations used for emissions to water data is provided in Table 2.22.

6.3.2.4.1 Total suspended solids (TSS)

Data for three emission points for direct discharge of TSS into the receiving water body were submitted and are presented in Figure 6.10.

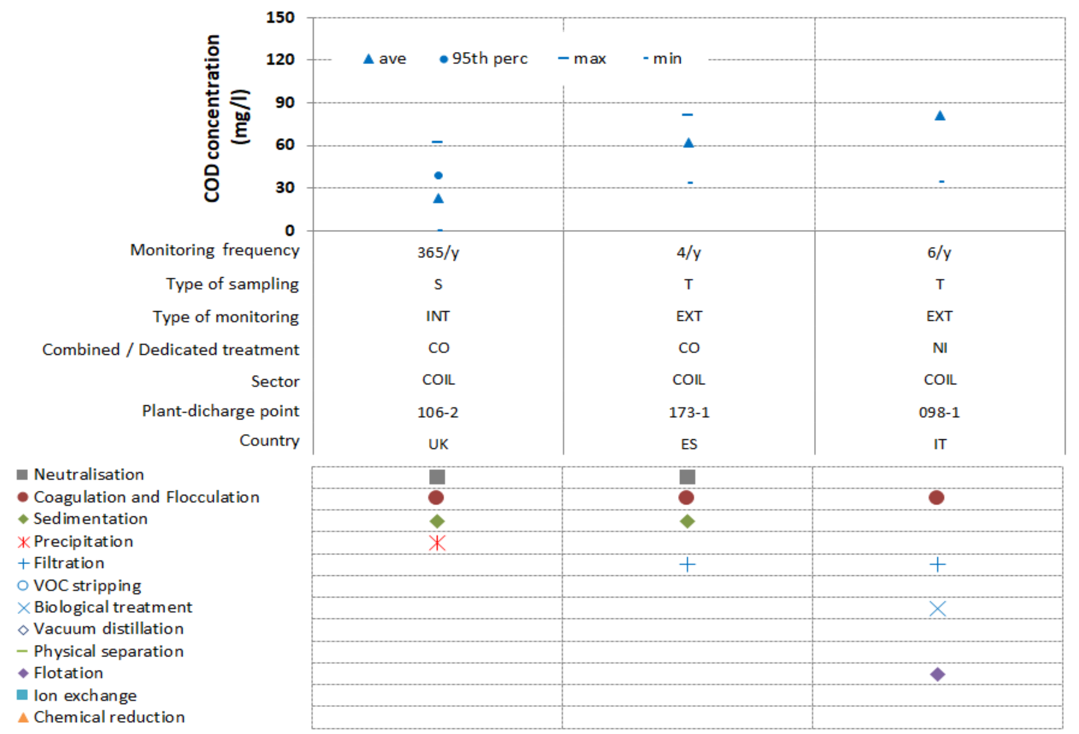


Source: [155, TWG 2016]

Figure 6.10: TSS concentration values for direct discharges of waste water from coil coating plants (data for 2015)

6.3.2.4.2 Chemical oxygen demand (COD)

Data for three emission points for direct discharge of COD into the receiving water body were submitted and are presented in Figure 6.11.

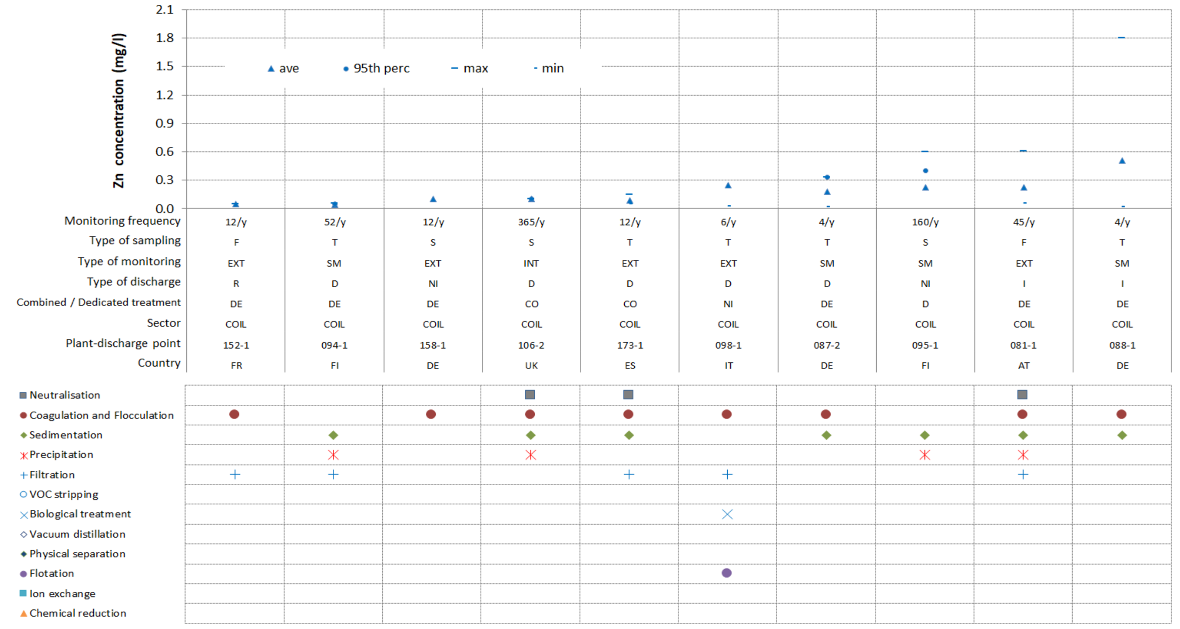


Source: [155, TWG 2016]

Figure 6.11: COD concentration values for direct discharges of waste water from coil coating plants (data for 2015)

6.3.2.4.3 Zinc (Zn)

Data for 10 plants were submitted for zinc emissions. The majority of reported maximum values (9 out of 10) are lower than 0.6 mg/l.

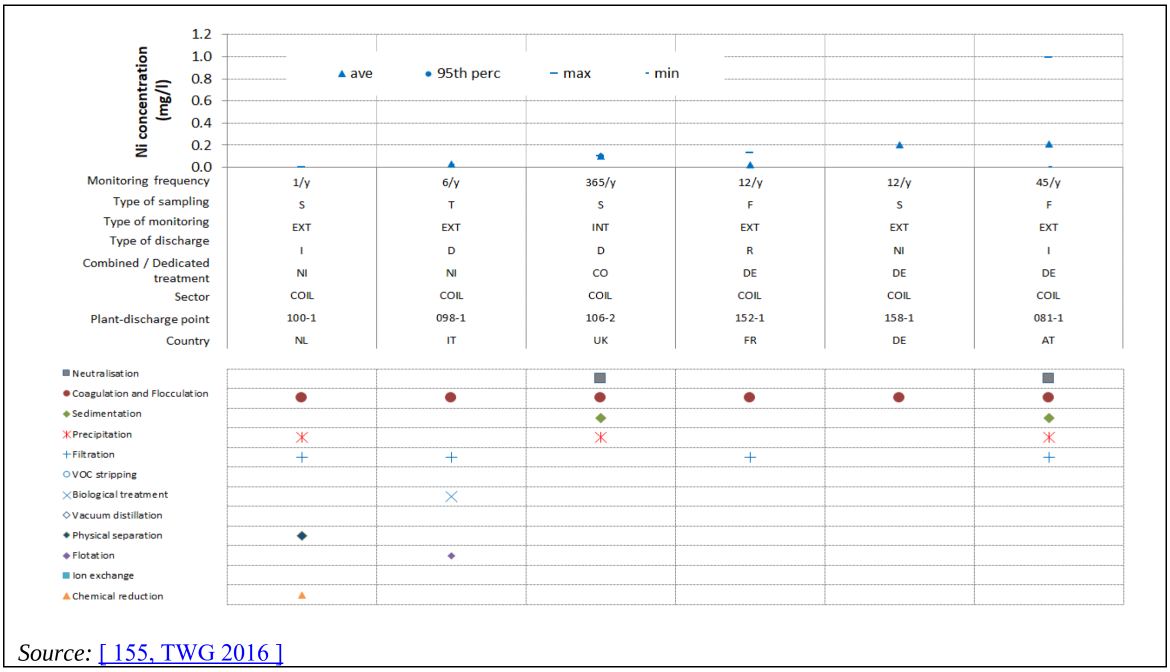


Source: [155, TWG 2016]

Figure 6.12: Zn concentration values for direct and indirect discharges of waste water from coil coating plants (data for 2015)

6.3.2.4.4 Nickel (Ni)

Data for six plants for nickel emissions to water were submitted. All reported values except one are lower than 0.2 mg/l.

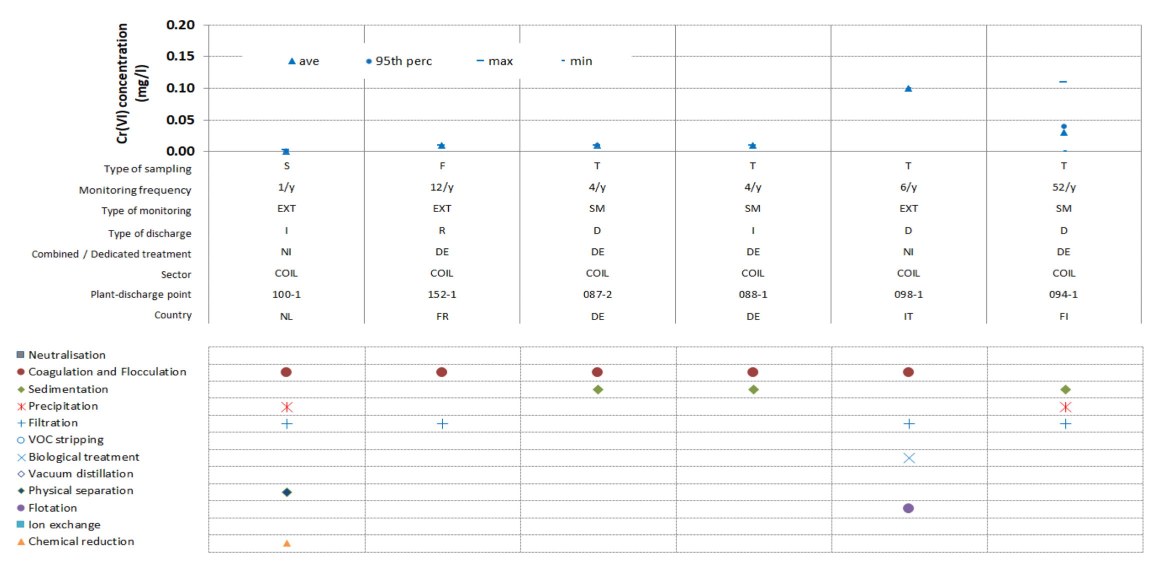


Source: [155, TWG 2016]

Figure 6.13: Ni concentration values for direct and indirect discharges of waste water from coil coating plants (data for 2015)

6.3.2.4.5 Hexavalent chromium (Cr(VI))

Data for six plants for emissions of hexavalent chromium to waste water were submitted. All values are lower than 0.11 mg/l and four out of six reported values are lower than 0.044 mg/l.

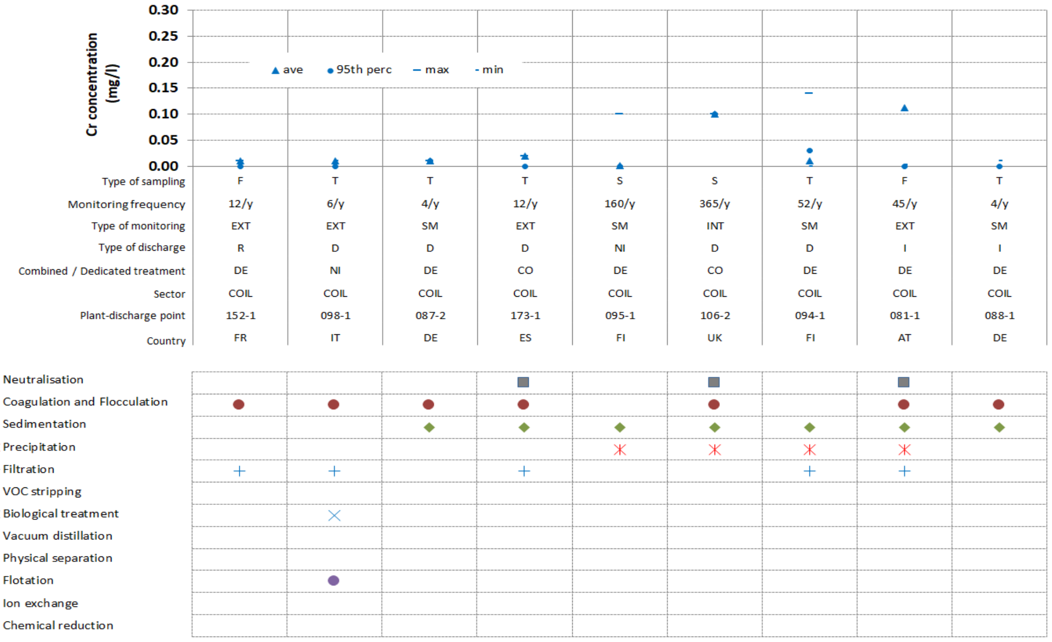


Source: [155, TWG 2016]

Figure 6.14: Cr(VI) concentration values for direct and indirect discharges of waste water from coil coating plants (data for 2015)

6.3.2.4.6 Total chromium (Cr_{total})

Data for nine plants for emissions of total chromium to waste water were submitted. All reported maximum values except two are lower than 0.14 mg/l. The reported values are presented in Figure 6.15.



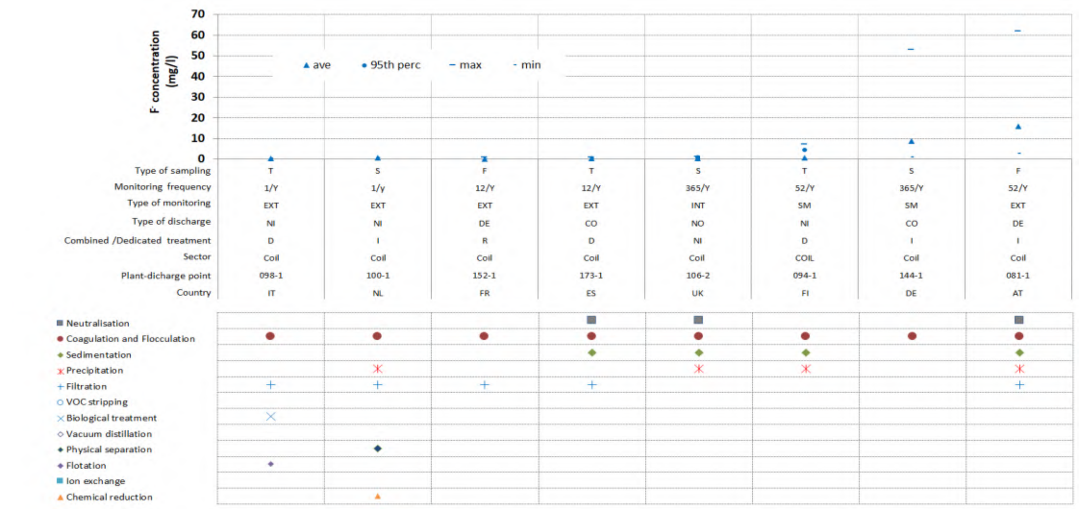
NB: Data not shown: plant #081-1 max value: 1.96 mg/l, plant #088-1, max value: 5.1 mg/l

Source: [155, TWG 2016]

Figure 6.15: Cr concentration values for direct and indirect discharges of waste water from coil coating plants (data for 2015)

6.3.2.4.7 Fluoride (F^-)

Data for eight plants for emissions of fluoride to waste water were submitted. The reported values are presented in Figure 6.16. All but two of the reported maximum values are lower than7 mg/l and only two values are of the order of 53-62 mg/l.

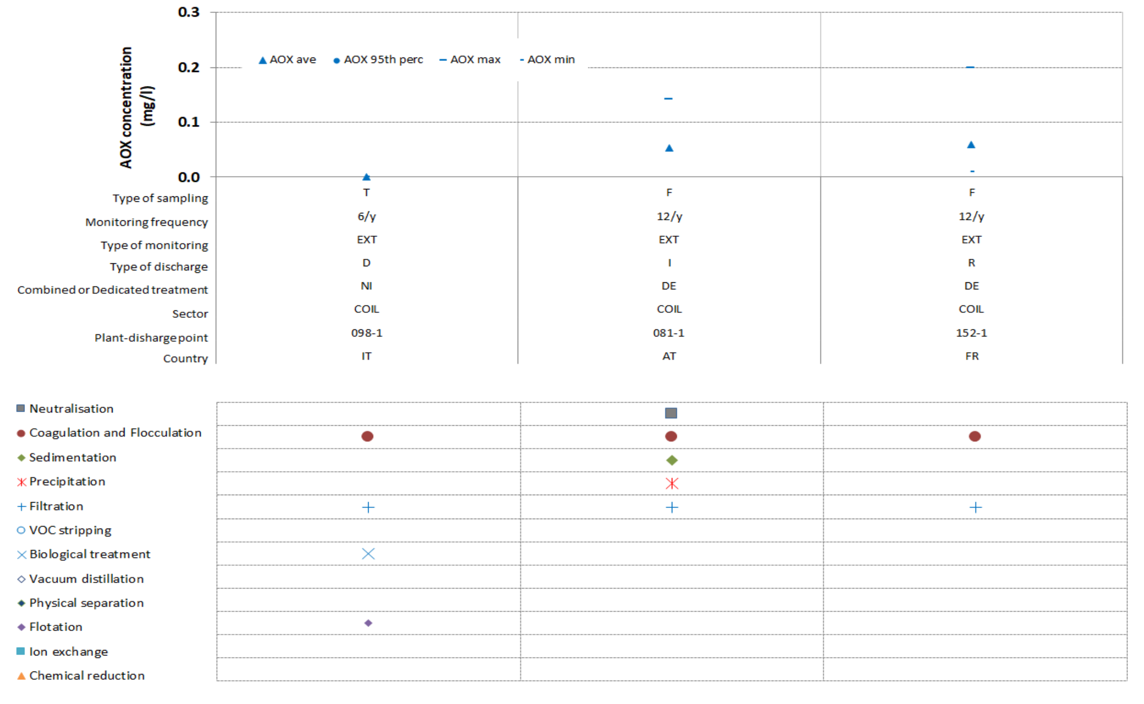


Source: [155, TWG 2016]

Figure 6.16: Fluoride concentration values for direct and indirect discharges of waste water from coil coating plants (data for 2015)

6.3.2.4.8 Adsorbable organically bound halogens (AOX)

Data for three plants for emissions of AOX to waste water were submitted. The reported values are presented in Figure 6.17. All reported maximum values are lower than 0.2 mg/l.



Source: [155, TWG 2016]

Figure 6.17: AOX concentration values for direct and indirect discharges of waste water from coil coating plants (data for 2015)

6.3.2.5 Waste generation

[155, TWG 2016]

The main types of waste generated from the coil coating process and their recycling or disposal route are presented in Table 6.12.

Table 6.12: Main types of waste generated in the coil coating industry

Waste type	Source	Quantity (kg waste per t of product)	Average solvent content (%)	Recycling or disposal route
Waste solvent	Cleaning processes	0.6-2.9	50-100	Delivered off site as hazardous waste
Waste paint and varnish containing organic solvents or other hazardous substances	Production processes	0.02-1.3	40-60	Delivered off site as hazardous waste
Oil emulsion waste	Waste water (pre)treatment	0.04-0.06	NI	Delivered off site as hazardous waste
Paint shop waste (filter materials, solvent-containing wipes and cleaning cloths)	Production / cleaning processes	0.3-2.4	35-50	Delivered off site as hazardous waste
Metal scrap (containers, drums, etc.) and plastic containers	Production processes	0.05-2.1	0.1-3	Returned to supplier
Solvent waste containing halogenated substances	Production processes	1.0-1.3	NI	Delivered off site as hazardous waste
Sludges from waste water treatment facility	Waste water (pre)treatment	0.3-0.8	5	Delivered off site as hazardous waste
PE/PVC waste films	Production processes	0.6-0.8	NI	Delivered off site as non-hazardous waste

NB:
NI: No information provided.
Source: [155, TWG 2016]

Applied techniques for the minimisation of waste generation

The main reported techniques used for the minimisation of produced waste quantities are [155, TWG 2016]:

- use of reusable containers in order to reduce the quantity of scrap metal;
- reusable cleaning wipes;
- reuse of returned paint from the coater head in the course of product change;
- distillation of used solvents;
- vacuum evaporator for the waste water from degreasing, rinsing and desmutting; this results in an increase of recycled water and a reduction in the physico-chemical sludge to be disposed of;
- filter press, centrifuges and decanters for waste water sludge to reduce the physico-chemical sludge to be disposed of;
- rinsing system in the pretreatment with no waste water generation;
- improvements to waste handling processes especially focusing on the elimination of sludge waste by increased frequency of collection and elimination of bulk tanker collection;
- reuse of water used to cool the strip after pretreatment.

6.4 Techniques to consider in the determination of BAT for coil coating

In Chapter 17, techniques are discussed which might also be applicable to coil coating. In Table 6.13, the general techniques relevant for coil coating that are described in Chapter 17 are shown. These techniques are not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 17.1.

The EGTEI background document for coil coating (see Annex 21.3.1) gives some data on the costs and benefits of some techniques to reduce VOC emissions at the European level. However, the EGTEI approach necessarily has to limit its complexity, and only key techniques are given without consideration of the other BAT factors, such as cross-media effects, or of the technical characteristics of individual installations.

Table 6.13: Reference to techniques generally applicable to the sector

Technique	Section number
Environmental management techniques	17.1
Storage and handling of raw materials	17.2
Monitoring	17.3
Water use and waste water generation	17.4
Energy management and energy efficiency	17.5
Raw material management (including substitution)	17.6
Coating processes and equipment	17.7
Drying and/or curing techniques	17.8
Cleaning techniques	17.9
Off-gas extraction and treatment	17.10
Waste water treatment techniques	17.11
Waste management techniques	17.12
Odour emissions	17.13

6.4.1 Solvent mass balance for a coil coating plant

[177, ECCA 2017] [185, ECCA 2017] [212, TWG 2018]

Description
For a general description see Section 17.3.1.

A detailed description of the SMB methodology proposed by industry (ECCA) together with an analysis of the main sources of uncertainty in the calculation of fugitive emissions can be found in Annex 21.5.2.

6.4.2 Material-based techniques (including substitution)

6.4.2.1 Conversion coatings

A conversion coating is a protective surface layer on a metal that is created by chemical reaction between the metal and a chemical solution. It can also provide improved adhesion for subsequent coatings, such as paint.

Conversion coatings are further discussed in the STM BREF [23, COM 2006].

Conversion coatings in coil coating have traditionally used Cr(VI) (chromate) rinses, after the pretreatment. However, under the REACH Regulation [47, EU 2006], the Cr(VI) compounds used in such rinses have passed their sunset date of 21 September 2017 and now require specific authorisation for each use (see also Section 6.2.1.1.5).

6.4.2.2 Chromium(VI)-free conversion coatings

[ECCA comment #17 in [212, TWG 2018]]

Chromium(VI)-free conversion coatings have now been developed for ‘dry-in-place’ application during the pretreatment stage of the process. Extensive R&D has produced a number of systems based on an appropriate combination of TiF_6 / ZrF_6 / phosphate / polymers for zinc-coated steel substrates and on TiF_6 / ZrF_6 / polymers for aluminium substrate.

6.4.2.3 High-solids coatings

Description
Solvent-based paints used in coil-coating have a solid content of approximately 40 %.

High-solids coating systems with a solids content of 70-95 % can also be applied in coil coating processes for some specific applications.

Technical description
See Section 17.7.2.1.

PVC plastisol coating is a common product in coil coating and it generally contains less than 10 % solvent. PVC plastisol is by far the most widely used high-solids coating in the coil coating industry accounting for 12.5 % of all topcoats in 2016 [265, TWG 2019].

Achieved environmental benefits
Reduced solvent loadings within the ovens may allow reductions in extracted airflows or increased line speeds for a certain concentration in the air.

Environmental performance and operational data
There is a trend to reduce solvent contents in other coating chemistries consistent with the application properties and performance demands of the finished product. It is however difficult to find a balance between coatability (i.e. low viscosity), realistic process conditions (i.e. roller coater parameters, especially roll pressure) and thickness (i.e. 20 µm dry thickness for a standard coil-coated product).
See also Technical description above.

Cross-media effects
When the target thickness is higher than with the standard coating, the low solvent concentration is balanced by the higher thickness; the overall solvent content in the air extracted from the oven remains roughly the same. If the target thickness is closer to that of standard coating, the reduction of solvent vapours in the waste stream may increase the demand for gas/fossil fuel in the oxidiser, and/or reduce the energy recovered for preheating the oven air.

Technical considerations relevant to applicability
Generally applicable where performance and economic criteria are met. Extra/different equipment is required for application of PVC plastisols.

Economics
Higher-solids-content coatings require application at a reduced wet film thickness to achieve the same final dry coating thickness. This places greater stresses on the application rolls and may incur higher maintenance costs and increased electrical energy to drive the coater.

Driving force for implementation

- For plastisol, the driving force is the market demand for this specific product.
- For other products, the main driver is the potential cost reduction with a lower price per applied micron as coil coaters buy paints per kilogram.
- There is generally pressure of both coil coaters and paint suppliers to lower the solvent content of the paints used in coil coating. It is however more a continuous improvement than a real breakthrough: there are only a handful of cases where it has been possible to cut the solvent content down to a value below 30 % without a significant change of the properties/cost of the final product.
- Health and safety requirements for VOC levels in paint-handling areas.

Example plants

Plants #152, #084, #086, #090, #095, #102, #106, #153 and #164 in [155, TWG 2016].

Reference literature

[5, DFIU et al. 2002] [22, ECCA 2004] [155, TWG 2016] [185, ECCA 2017]

6.4.2.4 Water-based paints/coatings

Description

Water-based paints contain water-dilutable or water-dispersible resins usually based on polyester, acrylic, melamine and epoxy resins. Most water-dilutable paints currently available also contain up to 20 % organic solvents as coalescents. See also Section 17.7.2.2.

Technical description

Water-based paint systems for coil coating are usually one-component paints. They are mainly based on polyester, acrylic, melamine and epoxy resin. Water-based paint systems normally have a water content of 10-65 wt-% and often also contain < 3-20 % organic solvents as a coalescent and for improvement of the properties of the wet film layer.

Achieved environmental benefits

See Section 17.7.2.2.

Environmental performance and operational data

See Section 17.7.2.2.

Cross-media effects

See Section 17.7.2.2.

Water has a higher energy of vaporisation than organic solvents, so water-based coatings in coil coating generally require greater energy inputs in the curing ovens.

Technical considerations relevant to applicability

This is a niche coating used in small quantities for coil coatings, as water-based paint systems are not applicable for a wide range of uses. Currently, processed water-based paints do not exceed 0.2 % of the total paint consumption in coil coating processes in western Europe. If water-based coatings are used, the application is mostly limited to primers and backing or base coats. Water-based coating systems have been used on some coil coating lines, but they are not applicable for a wide range of end use specifications. They may be used on lines dedicated to a limited product range where specific formulation development satisfies the performance demands.

Economics

See Section 17.7.2.2.

Driving force for implementation
See Section 17.7.2.2.

Example plants
Plants #081, #082, #089, #090, #092, #144 and #164 in [155, TWG 2016].

Reference literature
[5, DFIU et al. 2002] [22, ECCA 2004] [38, TWG 2004] [155, TWG 2016] [185, ECCA 2017]

6.4.2.5 Powder coatings

Description
See Section 17.7.2.6.

Technical description

The powder particles are normally applied by electrostatic charging in spray guns or a cloud chamber and are then attracted to the earthed metal strip as it passes. Application is generally carried out at one side of the strip with one layer with a typical layer thickness of 50 µm to 60 µm.

Achieved environmental benefits
See Section 17.7.2.6.

Environmental performance and operational data
The chemical pretreatment of the surface is similar to the application of solvent-based products. Drying or curing is typically carried out by a combination of infrared and circulating hot air, or with NIR or induction ovens. Object temperatures of 180-250 °C are achieved. The curing process is typically completed within 1.5-2 minutes.

Cross-media effects
See Section 17.7.2.6.

Technical considerations relevant to applicability
There is a severe reduction in line speed for powder application, melting, fusion, flow and cure, as most coil coating lines run at a far higher speed than that achieved using powder technologies (typically 150 m/min for recent coil coating lines versus 20 m/min for powder coating). Powder coating is therefore limited to low line speeds with some specific products, as there is also a very limited range of powder coating qualities that can be applied and cured in these short times.

Current technology cannot yet achieve uniformity in powder coatings at film thicknesses of less than 30 microns. Together, these limitations mean that a changeover to powder coatings is not feasible for conventional installations at present. This technique is especially used by the construction sector, e.g. for flat panels, window frames, sanitary cabins and by the sheet metal processing industry (computer enclosures and others). It is also used in small-volume niche products. Two-sided powder coating on a coil coating line is still problematic.

Economics
Production costs are higher compared to liquid coating processes due to the severe speed restrictions and the difficulty in controlling the applied film thickness.

Driving force for implementation
Elimination of solvents.

Example plants

There are very few full width powder coating installations in Europe for aluminium and steel coils.

Reference literature

[5, DFIU et al. 2002] [22, ECCA 2004] [78, TWG 2005]REFERENCE_BOOKMARK_13079 [185, ECCA 2017]

6.4.2.6 Laminate film coatings

Description

Use of polymer films applied onto the coil or web in order to give aesthetic or functional properties, which reduces the number of coating layers needed.

Technical description

For some specific end uses, solvent-free, solid polymer films are applied in coil coating plants. These films may be based on a number of polymers including:

- PVC (polyvinyl chloride);
- PVF (polyvinyl fluoride);
- PET (polyethylene terephthalate);
- acrylics;
- polypropylene.

In some cases, the films are coloured or opaque and may be decorated with printed patterns. In others, they are clear films offering specific properties of hardness, stain resistance, etc. In almost every case, the film is applied over a liquid paint base coat or adhesive layer. Specific equipment is needed to laminate the plastic film onto the strip.

Environmental performance and operational data

Films are applied by a pressure roll onto a preheated coating of appropriate base coat/adhesive, usually immediately after exiting the curing oven.

The relative environmental performance (versus standard paint) depends on the final composition of the coating system. If film is used instead of a normal paint layer, glued onto the web with preheated adhesive, there is no evidence of a better environmental performance than liquid coil coating. When the laminated film is applied on top of a paint system, then the overall raw material and energy consumption can be significantly lower.

Due to the high solvent content of the adhesives used to bond the laminate film, reductions in solvent emissions when using laminate films may be much less than would be expected [ECCA comment #19 in [212, TWG 2018]].

In some external applications, laminate films offer superior weathering performance. However, this is usually offset by the additional cost of the laminate film and its tendency to delaminate from the steel substrate. The primary use of laminate-based products is for interior applications where they offer a wide range of surface finishes, e.g. wood grain [ECCA comment #20 in [212, TWG 2018]].

Cross-media effects

The polymer films are produced off site by an extrusion or calendering process. The ordered width rarely matches the exact dimensions of the coils to laminate. The excess film is side-trimmed and is a process waste.

Technical considerations relevant to applicability
Generally used for very specific end use properties. Laminate film coatings cannot compete with liquid coil coating for all standard cases.

Economics
The process needs specific equipment. If this equipment was not installed when the line was built, it can be difficult and expensive to retrofit.

Laminated films are more expensive than conventional liquid coatings. The process is only of interest when some specific function is required that is difficult or impossible to achieve with liquid coating.

Driving force for implementation

- Product specifications and innovation.
- The process offers the possibility to deliver some niche products for specific purposes.

Example plants
Plants #081 & #082 (polyethylene protective films), #087, #088, #090, #094, #097, #101, #103, #105 and #152 in [155, TWG 2016].

Reference literature
[22, ECCA 2004] [155, TWG 2016]REFERENCE_BOOKMARK_13079 [185, ECCA 2017] [212, TWG 2018]

6.4.2.7 Radiation curing coatings (radcure)

See Section 17.7.2.3 and Section 17.8.5.

6.4.3 Coating application techniques and equipment

6.4.3.1 ‘Spray, squeegee and rinse’ application of conversion coatings

Description
Sprays are used for application of cleaners, pretreatments and for rinsing. After spraying, squeegees are used to minimise solution dragout, which is followed by rinsing.

Technical description
Spray application is carried out in closed cabinets. In all cases, the use of a further water rinsing step is absolutely necessary.

Iron phosphating products for cold-rolled steel strips are used together with a post-rinse, usually containing Cr(VI)-free complexes. The alkaline conversion coatings (cobalt-based or cobalt-free), in combination with Cr(VI)-free post-rinses, provide excellent paint adhesion and corrosion protection on zinc- or zinc-alloy- coated substrates.

Achieved environmental benefits
High durability is achieved.

Environmental performance and operational data
The process temperature is between room temperature and about 70 °C. The spray pressure applied is between 0.5 bar and 2 bar [185, ECCA 2017].

Cross-media effects
This technique causes a high consumption of surface treatment chemicals. There is a high dragout, causing polluted rinsing water for subsequent waste water treatment and additional waste.

Large volumes of water are needed for this process. It is possible to significantly lower these volumes with an appropriate design of the rinsing step (see example of cascade rinsing in Section 17.4.3) but water consumption will never fall to zero because the rinsing baths need to run with an overflow.

Technical considerations relevant to applicability
Generally applicable. This is a well-known and common application technology; however, it requires a high demand for chemical process control. Such a process is generally highly sensitive to temperature, chemical concentrations, cleanliness of the surface and conversion time. The deposition rate is therefore relatively difficult to adjust perfectly.

The maintenance of these closed cabinets is easier than a chemcoater.

Economics
The erection of such a surface treatment section requires a large amount of space. In most cases, cleaning and conversion baths are horizontal, which means that more than 50 m^3 is needed for a coil coating line running at a normal speed.

It is also possible to set up vertical baths but this makes the process control more difficult than with a horizontal system. Such equipment is then relatively cheap (compared to a chemcoater) but it can only be erected if the necessary space is available.

In terms of operating costs, waste water needs should be considered and this is generally a hidden cost because most water treatment plants collect water from different industrial processes and its global cost is rarely broken down.

Driving force for implementation
It is a well-known and safe technology.

Example plants
Widely used: Plants #081, #082, #101, #102, #103, #104, #105 and #158 in [155, TWG 2016].

Reference literature
[22, ECCA 2004] [155, TWG 2016], [38, TWG 2004] [185, ECCA 2017] [212, TWG 2018]

6.4.3.2 ‘No-rinse’ or ‘dry-in-place’ application of conversion coatings

Description
The ‘no-rinse’ or ‘dry-in-place’ technology used to apply conversion coatings which do not require a further water rinse, by roller coater (chemcoater) or squeegee rollers.

Technical description
The ‘no-rinse’ or ‘dry-in-place’ technology for applying conversion coatings does not require a further water rinse. It applies the pretreatment products by roller coater, chemcoater or squeegee rollers to the strip surface. Because it avoids aerosol formation, no pollutant can be measured in the air. Without any rinsing, the wet film is dried in place, using IR radiation or convection heat, and painted directly afterwards. This kind of process does not limit the line speed in the pretreatment section (no reaction time), needs no rinse stages after the pretreatment section, and generates extremely low levels of waste water. Another advantage, compared to the conventional rinse process products, is its suitability for multi-metal pretreatment.

Achieved environmental benefits

The water consumption is significantly lower than with a spray, squeegee and rinse system because there is no overflow. Chemicals are also consumed in the exact quantity required, avoiding over-consumption. The consumption of water and chemicals in a spray, squeegee and rinse surface treatment system is therefore significantly higher than the dry-in-place system.

Because of the low amount of waste water and of the low concentration of pollutants, no water treatment plant is necessary.

Small droplets or vapours of the chemicals used are generally harmful and alternative surface treatment methods can generally not be used without air extraction to remove mist and vapours from above the baths. This extracted air either is then released to the atmosphere (thus generating air pollution) or goes to the oxidation system (and then needs extra energy for treating cold moisturised air). With the dry-in-place technique, there are no mists and vapours. It means that there is no air pollution or requirement for extra energy for treatment of polluted air.

Environmental performance and operational data

Water quality in the last rinse of the cleaning section prior to the no-rinse conversion coating application must be carefully monitored by conductivity measurements.

The wet layer thickness applied depends on the application technique used and the concentration of chemical used. Drying takes place immediately after applying the conversion coating with infrared or hot air dryers and takes a short time.

Cross-media effects

Dryers require electrical energy or natural gas. The energy consumption is slightly higher than with alternative methods for surface treatment.

Technical considerations relevant to applicability

Generally applicable. This technology is currently well known and approved, and widely used across Europe.

Economics

There is a significant capital expenditure (CAPEX) for the erection of a surface treatment section. On an existing line, if the existing surface treatment is a spray, squeegee and rinse system, then the space and water treatment plant are generally already available and the investment cost is then a lesser consideration.

On a new line, the overall cost of a dry-in-place system is equivalent to the cost of a spray, squeegee and rinse system because of the lower space requirement and because no water treatment plant is needed.

Driving force for implementation

- Low consumption of surface treatment chemicals and very low volumes of waste.
- Lower risk of exposure to chemicals for the workers.

Example plants

Widely used across Europe. Plants #083, #084, #088, #090, #092, #093, #094, #095, #097, #144, #153, #164, #172 and #173 in [155, TWG 2016].

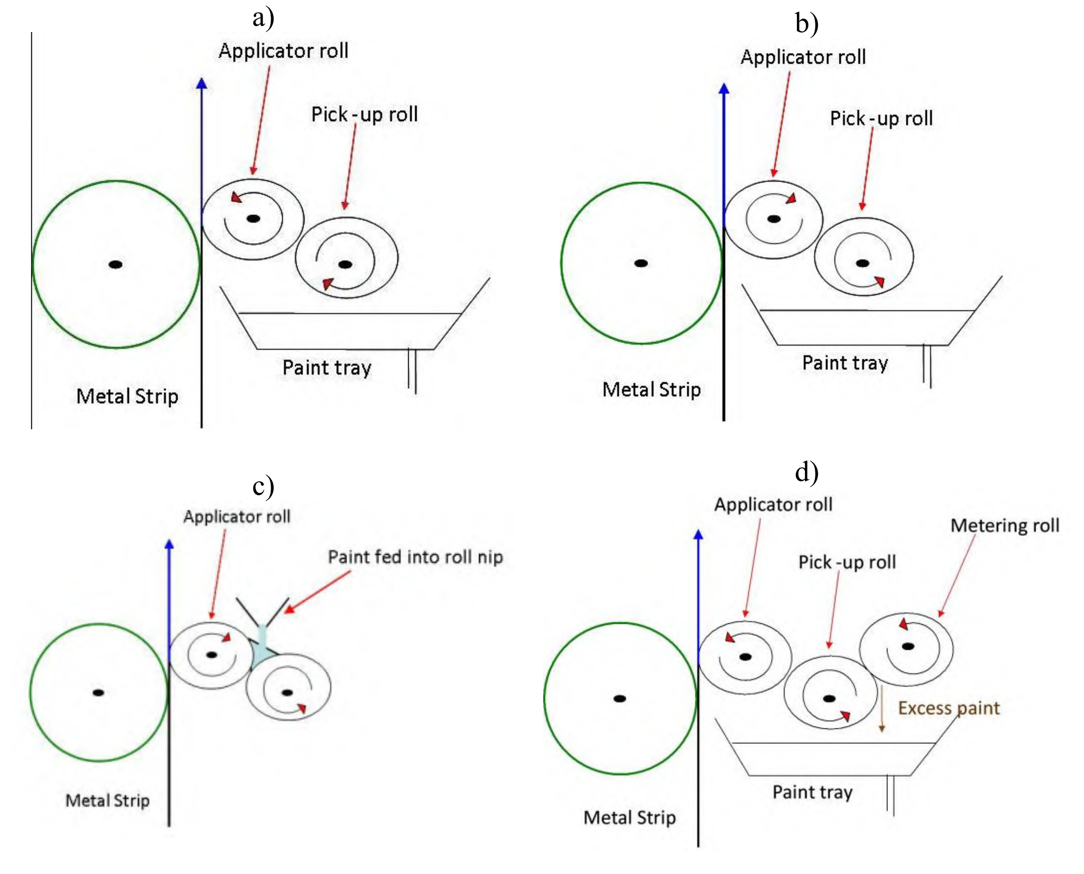
Reference literature

[22, ECCA 2004] [155, TWG 2016], [38, TWG 2004], [185, ECCA 2017]

6.4.3.3 Roller coating of paints

Description
See also Section 17.7.3.1.

A train of two or three rollers serves to pick up, meter and apply the coating at high speed onto the moving strip.



Source: [257, ECCA 2019]

Figure 6.18: Schematic of a roller paint coater: a) Two-roll coater, b) Two-roll forward coater, c) Nip feed roller coater, d) Metering roll

Technical description
There are different types of coater in use, e.g. with a horizontal or vertical strip path or with or without a counter roll (see Figure 6.18). Roller directions, rotation speeds, spacings and pressures are controlled to set the film thickness and to optimise the transfer properties and flow of the wet coating.

Roller coating is a mature technology which is constantly being improved, mainly with the objective of reaching the targeted thickness more rapidly, more evenly and more accurately.

Achieved environmental benefits
Very high transfer efficiency, approaching 100 %, thus achieving a high material efficiency for paint solids and solvents, and minimal waste of materials.

Environmental performance and operational data
Very high transfer efficiency due to:

- better mechanical precision of the coaters;

- better temperature management on the rolls and in the overall paint flow;
- progress in automation and the availability of some wet thickness gauges that give a fast and accurate thickness measurement which in return allow a closed-loop regulation (or at least the fast reaction of the operator).

The only loss is associated with material remaining in containers and pipework at the end of a product run. This is normally drained back into the original container for use on later occasions. After draining, final traces of the coating are cleaned up from the rollers and the equipment (rollers, paint tube) with an appropriate method.

The coaters are normally housed in enclosures to minimise the release of organic solvent vapours to the plant area. The coating housings are vented to the outside of the building with flow rates designed to maintain satisfactory working conditions at all times for the operators within the coating house. Beyond the positive consequences for health and safety, it also makes it possible to extract VOC-containing air from the working zone (see Section 17.10.2.1).

Most of the coatings are diluted with organic solvents to get the right viscosity and to reach the correct thickness of the paint. The solvents are vaporised in the oven and extracted to thermal off-gas treatment.

Cleaning a roller coater is generally difficult to do with a 100 % safe method and without using a significant amount of solvent. Today, manual cleaning is still the most common method but not the safest one.

The application rollers generally have a thick elastomeric, polyurethane coating which may become damaged, requiring refacing on a lathe. Ultimately, the coating must be renewed by a specialist contractor. The pick-up and metering rolls are normally steel and less prone to damage.

Regular maintenance of the rollers minimises paint wastage and solvent usage during production.

Cross-media effects
It may involve increased solvent use for cleaning as the safest cleaning methods tend to use more solvent.

Technical considerations relevant to applicability
This technique is used in virtually all coil coating lines using liquid paints. The method is of course not suitable for powder coating. In the case of paints with a high viscosity (high solids contents, for example), it is necessary either to have a more sophisticated roller coater and/or to accept a higher paint thickness.

Economics
This coating method is relatively expensive, with high initial costs. Depending on whether one side or two sides are painted, on the kind of products (and then on the configuration of the roller coater), and on the level of automation, the CAPEX can vary significantly. In most cases, in coil coating, the cost will exceed EUR 1 million and can be far higher.

Driving force for implementation
The technique provides a very high transfer efficiency and, therefore, minimal waste of materials. Typically, a roller coater is theoretically able to coat 20 ± 1 µm dry thickness in ideal cases; in the case of flat surfaces, it is far better than other coating methods. The high investment cost is then generally rapidly balanced by significantly lower operating costs.

Example plants
Established as industry standard and widely used.

Reference literature

[22, ECCA 2004], [38, TWG 2004], [185, ECCA 2017] [212, TWG 2018]

6.4.3.4 Cleaning of application equipment with air extraction and subsequent VOC abatement

Description

In coil coating plants, there are two recognised methods for the cleaning of machine parts and equipment:

- all cleaning takes place *in situ*, i.e. within the coating house/room with localised air extraction to ovens or abatement (see also Section 17.10.2.1);
- *in situ* cleaning for fixed equipment, with moveable items such as paint trays, pumps and stirrers removed to an ancillary cleaning station, see Section 17.9.7.

Wipes impregnated with solvents (see Section 17.9.4) are used when manual cleaning of the plant and equipment takes place. Disposable dirty wipes are retained in sealed containers and disposed of, usually by incineration. Reusable dirty wipes are also retained in sealed containers and are usually laundered.

In addition, cleaning with a high-pressure water spray (see Section 17.9.9) was also reported.

Achieved environmental benefits

Localised extraction to ovens/abatement reduces fugitive VOC emissions.

Environmental performance and operational data

Some, but not all, coating houses are equipped with localised extraction, with the extracted air directed into the oven/off-gas treatment system and the balance vented to the air. Where an ancillary cleaning unit is used, exhaust air is generally abated. In other instances, all coating room air is vented directly to the air, as it is widely considered that the installation of abatement equipment is not a practical option, as air volumes, for occupational health reasons, are high with low emission concentrations. Compared with emissions from dryers/ovens, emissions from coating houses are considered to be insignificant.

Technical considerations relevant to applicability

The practicality of the retrofitting of localised extraction in coating rooms will be dependent upon the age, design and capacity of the combined curing (drying) and abatement equipment.

Economics

Costs will depend on the existing extraction system and on the capacity of the off-gas treatment technique. Retrofitting might, therefore, be very expensive.

Example plants

For automatic (machine) cleaning: Plants: #097, #098, #099 and #153 in [155, TWG 2016].

Reference literature

[22, ECCA 2004] [155, TWG 2016], [38, TWG 2004]

6.4.4 Drying

6.4.4.1 Convection drying or curing combined with heat recovery from off-gases

Description

Gas-fired, forced air recirculation ovens are commonly used throughout the coil coating industry for curing the different layers of primer and topcoat that are applied to the metallic strip. The ovens operate at air temperatures of around 350 °C (the strip generally needs to reach a temperature in the range of 200-280 °C depending on the paint supplier's specifications). The waste gas is extracted and routed to the abatement plant. Heat exchangers using the energy contained in the waste gases preheat the air to a maximum temperature of about 550 °C before it is reinjected into the oven. The units typically contain three to six independent zones and can be up to 50 metres long in total on the line. Their stable operational profile and reliability means that they are capable of providing high-quality, cured coatings in the wide range of textures and colours required by the coil coating market. See also Section 17.8.6.

Technical description

Hot air is circulated in the dryer or oven to transport heat to the strip by convection. The hot air is in direct contact with the surface of the strip to be dried. The drying time depends on the substrate, the type of coating and the thickness of the coating.

For the drying of water-based coatings or a pre-drying step of wet-on-wet layer combinations, dehumidified air is used; in these cases, the convection dryers operate with an additional dehumidification step. Due to the uptake of water, the drying times can be significantly reduced. The dryers are built as flat-line dryers, nozzle dryers, tray systems or tower dryers. The energy demand depends to a great extent on the heat losses of the dryer.

Normally, during the drying process, flammable substances are released by evaporation and curing.

The European Standard EN 1539[28] defines the permitted operating ranges with respect to the admissible drying temperature and the maximum admissible concentration of released flammable substances inside the dryer.

Achieved environmental benefits

The overall impact of the curing technique on environmental performance not only depends on the ovens themselves but also on the surrounding air treatment and air circulation devices. Most coil coating paints are solvent-based, so it is therefore necessary to dilute the VOC concentration in the ovens below the LEL with a significant input of air. The VOC-containing air then needs to be oxidised at high temperature. The energy balance of the curing section is then the result of the efficiency of the oxidiser and the reuse of the energy liberated at the oxidiser.

The optimal configuration and energy usage will depend on the kind of products the line is running, the way the line is programmed and the possibility to reuse the hot air or not.

Environmental performance and operational data

Hot air ovens are the most common curing technique of a coil coating line. The process window is large and the efficiency of the technique is not dependent on the substrate.

The simple hot air ovens are catenary ovens, with three to six independent zones that allow good control of the temperature profile. The overall length of such ovens depends on the line speed and generally lies in the range of 25-50 metres.

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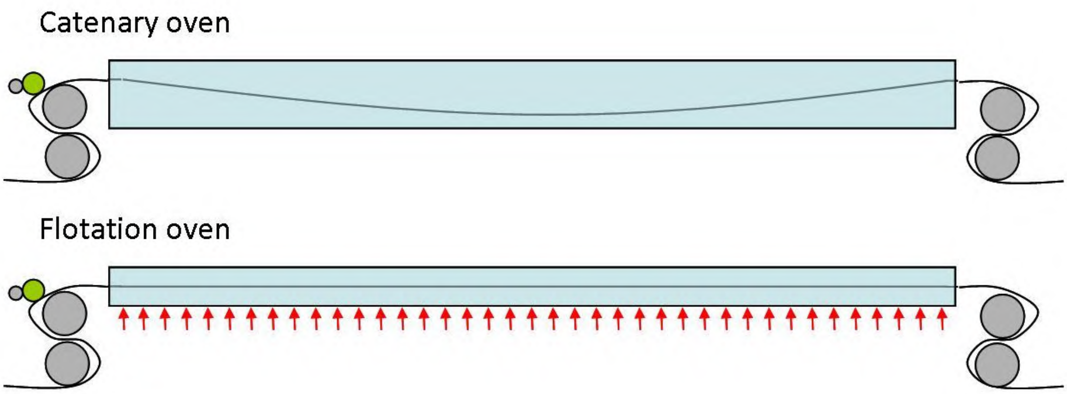
[28] EN 1539:2015: Dryers and ovens, in which flammable substances are released. Safety requirements.

Flotation ovens are an alternative technique based on hot air jets very close to the strip. Although the electricity consumption of these units is higher than catenary ovens, the flotation technique facilitates shorter curing times because of the efficient heat transfer to the strip. Moreover, there is no catenary of the strip in the oven. Therefore, the process window is larger than with normal convection ovens and the ovens are more compact [212, TWG, 2018]. See also Figure 6.19.



Source: [257, ECCA 2019]

Figure 6.19: **Schematic of catenary (convection) and flotation ovens**

Cross-media effects
Energy consumption.

Technical considerations relevant to applicability
Drying time and drying temperature influence the surface quality. There is a stronger risk of dust being incorporated into the wet layer with hot air ovens than with other curing techniques. Drying times are relatively long and the energy demand is high. However, a high level of automation is possible and there is high flexibility in employing this drying technique.

Compared to other curing techniques (induction ovens and NIR), the thermal inertia of a hot air oven is generally high. This is a constraint when it is necessary to change either the section of the strip or the paint, which usually happens several times per shift. The way the line is programmed is then very important because it can seriously affect the energy efficiency due changes in production. On the other hand, a high inertia and a long curing time reduces the risk of over-curing, even if short standstills of the conveyors occur.

With a hot air oven, the homogeneity of the temperature of the strip is excellent and the curing consistency along and across the strip is then generally better than with other techniques.

Convection dryers are commonly used in the coil coating process and, in addition to their use with solvent-based paints, they can be used for drying layers of water-based paints, for a pre-drying step or for wet-on-wet layer combinations.

Economics
In terms of investment cost, hot air ovens are cheaper than alterative curing techniques.

The operating cost strongly depends on the kind of products, the way the line is programmed and the general design of the curing-incinerating-recirculating system.

Driving force for implementation
There is no limit in the capability and it is considered the ‘normal’ curing technique.

Example plants
Commonly applied in the coil coating industry.

Reference literature
[4, Germany 2002] [5, DFIU et al. 2002] [27, VITO 2003] [38, TWG 2004] [78, TWG 2005] [155, TWG 2016] [212, TWG 2018] [257, ECCA 2019]

6.4.4.2 Induction curing processes

Description
For a general description, see Section 17.8.2.

Example plants
Plants #152, #172 and #173 in [155, TWG 2016].

6.4.4.3 Infrared radiation drying/curing

For a general description of radiation drying/curing techniques, see Section 17.8.5.

Description
For a general description of infrared radiation drying/curing, see Section 17.8.5.1.

Example plants
Plants #099 and #105 in [155, TWG 2016].

6.4.5 Off-gas extraction and treatment

6.4.5.1 Air extraction from conversion coatings station

Description
Emissions from the application of conversion coatings, i.e. the mist arising from the spray application and drying of the conversion coating, are extracted and routed to an off-gas treatment system, such as a wet scrubber (see Section 17.10.4.2). See also the STM BREF for details of the techniques.

Example plants
Plants #081, #082, #092, #093, #101, #102, #105, #106, #158 and #173 in [155, TWG 2016].

Reference literature
[78, TWG 2005] [155, TWG 2016]

6.4.5.2 Air seals on the entrance and the exit of the ovens/dryers

Description
For a general description, see Section 17.10.2.3. This technique is commonly applied in the coil coating industry and was reported by the majority of plants.

Reference literature
[22, ECCA 2004] [38, TWG 2004] [155, TWG 2016]

6.4.5.3 Sub-atmospheric (negative) pressure in drying

Description
The dryer is kept under sub-atmospheric pressure to minimise VOC emissions and heat losses. This technique is commonly applied in the coil coating industry and was reported by the majority of plants.

For a general description of air extraction from drying/curing processes, see Section 6.4.5.6 and Section 17.10.2.4.

Reference literature
[5, DFIU et al. 2002] [22, ECCA 2004] [38, TWG 2004] [155, TWG 2016]

6.4.5.4 Air extraction from coating preparation

Description
Before use, paint is prepared in an enclosed room referred to as a paint kitchen. The drum is opened and stirred, which generates solvent evaporation. Usually, air is extracted from the room to the oven/off-gas treatment system.

Technical description
For a general description, see Section 17.10.2.2.

Coatings are prepared by stirring to ensure that any settled pigments are thoroughly mixed and that the coating is at the correct viscosity for application. Solvent-based raw materials are mixed, e.g. for achieving a certain viscosity or colour. In coil coating plants, the mixing and stirring of paint takes place either in the coating house/room or in a separate room often referred to as a paint kitchen. Commonly, coating houses are equipped with localised extraction. The extracted air is directed into the oven/off-gas treatment system, with the balance vented to the air.

Achieved environmental benefits
Reduction of fugitive emissions of VOCs from the coating house/room/paint kitchen. Where the VOC-containing airflow is channelled to an abatement system, the overall VOC emissions to air are lowered.

Environmental performance and operational data
In some installations where air volumes are high with low emission concentrations, for occupational health reasons, all the coating room air is vented directly to the atmosphere. It is widely considered that installing abatement equipment may not be a practical option in these cases.

Compared with emissions from ovens/dryers, emissions from paint kitchens are considered to be insignificant. However, see Section 17.10.2.2.

Cross-media effects
To achieve safe working conditions and a low VOC content of the airstream, large quantities of energy (e.g. gas) are needed for treatment of extracted air.

Technical considerations relevant to applicability
The practicality of the retrofitting of localised extraction in coating rooms will be dependent on the age, design and capacity of the combined curing (drying) and abatement equipment.

Economics
On existing coil coating lines where additional abatement equipment capacity is required, the cost of retrofitting may be high.

Driving force for implementation
Occupational health reasons.

Example plants
Widely used in the coil coating industry and reported by the majority of plants.

Reference literature
[22, ECCA 2004] [38, TWG 2004] [155, TWG 2016] [175, ECCA 2016]

6.4.5.5 Air extraction from the paint application station

For a general description, see Section 17.10.2.1.

Description
The paint application station is enclosed (see Section 17.10.2.1) and part or all of the extracted air is drawn into the ovens, and hence to an off-gas treatment system.

Achieved environmental benefits
About 8 % of the processed solvents are released as VOC emissions in the paint application booths and, by applying this technique, they are extracted and treated.

Cross-media effects
Energy consumption for extraction and treatment.

Environmental performance and operational data
Reduction of VOC emissions. See also Section 17.10.2.1.

Technical considerations relevant to applicability
Applicability may be restricted where enclosure leads to difficult machinery access during operation or by the size and shape of the area to be enclosed.

Economics
See Section 17.10.2.1.

Driving force for implementation
Workplace health and safety.

Example plants
Widely applied and reported by all plants participating in the data collection.

Reference literature
[5, DFIU et al. 2002][22, ECCA 2004] [38, TWG 2004] [155, TWG 2016]

6.4.5.6 Air extraction from the oven/dryer

For a general description, see Section 17.10.2.4.

Description
The dryers and ovens are equipped with an air extraction system routing the solvent emissions to the off-gas treatment.

Technical description
Drying/curing of the coil coating is done in ovens/dryers which are connected to abatement equipment, e.g. thermal oxidiser (see Section 17.10.5.2).

In the case of a coil coating oven, the management of the solvent concentration is generally based on some FID measurements within the oven, in the zone where it appears relevant (i.e. the zone which is most likely to have the highest concentration). The oven is then run in such a way that air is used with the minimum required flow to keep it at acceptable levels for avoiding the risk of explosion. The solvent concentration in the extracted air is then as high as possible as long as it is safe.

The European Standard EN 1539:2015 defines the admissible operating ranges with respect to the admissible drying temperature and the maximum admissible concentration of released flammable substances.

Achieved environmental benefits

Most solvents are released during the curing/drying stages of production. Having an efficient extraction of the air from the oven and an efficient treatment later is the best way of significantly lowering overall emissions.

In the case of coil coating, the extraction and subsequent oxidation of solvent fumes from the oven results in very low values of emitted VOCs.

The use of FID for optimising the airflow in the oven makes it possible to lower the overall energy needed in the drying/curing step including VOC abatement.

The fugitive solvent emissions are reduced to the maximum possible extent by using an efficient extraction system.

Environmental performance and operational data

The quality control of the pre-painted product ensures that all solvents are released out of the paint and all solvents from the paints are then vaporised in the oven. An efficient air extraction system makes it possible to capture most of these solvents to send them to the oxidiser. A small amount of solvents can exit the oven with the strip (boundary air layer close to the strip), so other techniques are often used at the same time to prevent or capture this small flow.

The VOC content in the ovens of an example plant is in the range of 8.75-9.3 g/m^3, which is around 22 % of the LEL (40 g/m^3). The flow of fumes is continuously measured and the concentration of VOCs in the oven/dryer can also be measured. This is increasingly common for a number of reasons (e.g. safety, lower energy consumption, lower environmental impact).

Cross-media effects

- Extraction requires energy, primarily electrical energy for the operation of the extraction fan.
- Noise levels might increase.

Technical considerations relevant to applicability

Generally applicable.

Driving force for implementation

Workplace health and safety.

Example plants

Widely applied and reported by all plants participating in the data collection.

Reference literature

[5, DFIU et al. 2002] [22, ECCA 2004] [38, TWG 2004] [155, TWG 2016] [175, ECCA 2016] [212, TWG 2018]

6.4.5.7 Air extraction from the cooling zone

Description

After the curing step, it is necessary to cool the strip down, generally with water sprays or air cooling. In this zone, fumes or vapours can be extracted to further abatement or to a vent stack.

Technical description

For a general description, see Section 17.10.2.5.

The strip temperature at the exit of the oven lies in the range of 200-260 °C and requires cooling down before either coating a second layer (for the primary oven) or entering the accumulator tower before recoiling. This step needs to be short because the longer the cooling time, the more space needed. High cooling rates are achieved with sprays of cold water onto the strip or dipping the strip into a cold water bath.

A cooling section is then generally designed in such a way that the sprays (or the water bath) are in an enclosed zone. This makes it easy to extract air from the cooling zone. It is then possible to channel the extracted airflow to any air treatment device.

Achieved environmental benefits

There is no environmental benefit with such a technique in the case of coil coating:

- the quantity of VOCs at the exit of a cooling section of the coil coating oven is too low to consider capturing and abating these VOCs an environmental benefit;
- there is no direct impact of air extraction on the amount of water or on its quality.

The main driver for this technique is mostly related to health and safety and working conditions, and not an environmental benefit.

Environmental performance and operational data

Using an air extractor makes it possible to better identify the nature and the concentration of pollutants emitted from the cooling section in cases where it makes sense to do so. Without air extraction, these pollutants would be part of the fugitive emissions.

Cross-media effects

If the extracted air goes directly to the oxidiser, the energy consumption for treating this extra airflow is relatively high because the total mixture would deviate from the optimum concentration and composition for an efficient oxidation: the air temperature is low, the air does not contain solvent (i.e. there is little available fuel in the extracted air) and the extracted air contains water droplets that require energy to vaporise (i.e. latent heat is needed to vaporise water). Treating the extracted air in an oxidiser may significantly compromise the efficiency of the oxidiser, resulting in higher VOC emissions and significantly higher energy consumption.

Technical considerations relevant to applicability

All coil coating lines are equipped with a cooling section and extracting air from cooling sections is common.

Driving force for implementation

Depending on how the line is designed, it is likely that residual fumes or vapours at the exit of the ovens get trapped within the building if nothing is done to remove them. This accumulation over time makes the working area uncomfortable for workers. Most operators extract air from the cooling zone to improve the working conditions of the line crews.

Example plants

Reported by a significant number of plants.

Reference literature
[5, DFIU et al. 2002] [22, ECCA 2004] [38, TWG 2004] [155, TWG 2016] [175, ECCA 2016] [212, TWG 2018]

6.4.5.8 Recuperative thermal oxidation

For a general description, see Section 17.10.5.3. Recuperative thermal oxidation is commonly applied in the coil coating industry in Europe.
[22, ECCA 2004]

6.4.5.9 Regenerative thermal oxidation

For a general description, see Section 17.10.5.4. This technique is commonly applied in the coil coating industry in Europe.
[22, ECCA 2004] [212, TWG 2018]

6.4.6 Waste water treatment

For general descriptions of waste water treatment techniques, see Section 17.11.

6.4.6.1 Treatment of rinse water before discharge

Description
Process waters are usually treated in a waste water treatment plant with a sequence of process steps. Dissolved metals in rinse water are precipitated, e.g. by using lime or sodium hydroxide (see Section 6.4.6.3). The liquor is subsequently processed through a filter press to separate the solids from the liquids. Some chemicals are most effectively managed by treating them separately before mixing them with other effluents.

Achieved environmental benefits
For some substances, contaminant treatment and removal is only possible after separate treatment.

Cross-media effects
These are case-dependent.

Technical considerations relevant to applicability
Consideration should be given at every process discharge point as to whether treatment is better carried out on the separated stream, before mixing flows for subsequent treatment.

When using waste alkali flows to neutralise waste acids, additional chemicals may be required to achieve a suitable pH for discharge through a flocculation system.

Economics
Capital and treatment costs may be significantly reduced by treating individual waste water streams separately.

Driving force for implementation
The specific process chemistry will dictate which chemicals require separation. Separate treatment streams may be more efficient and cost-effective.

Example plants
Widely used, see also Section 6.3.2.4.

Reference literature
[22, ECCA 2004] [23, COM 2006] [155, TWG 2016]

6.4.6.2 Treatment of waste water containing chromate

Description
The use of Cr(VI) compounds within the industry has been significantly reduced over the past decade. Whilst the use of Cr(VI)-containing systems is authorised by the REACH legislation for a small, decreasing number of applications, it is still important for the industry to manage any waste waters containing chromate in an effective manner.

Hexavalent chromium compounds (chromates or dichromate) are difficult to precipitate and are normally reduced to trivalent chromium, which is subsequently precipitated as chromium(III) hydroxide on neutralisation. The chemical reduction is made at pH values under 2.5 (see also Section 17.11.2.1 and the CWW BREF [31, COM 2016]. The most common reducing agent is sodium hydrogen sulphite (bisulphite).

Achieved environmental benefits
Continued removal of chromium(VI). Commonly, values of < 0.1 mg Cr(VI)/l are achieved. See also Section 6.3.2.4.5.

Cross-media effects
Care should be taken with sodium hydrogen sulphite (bisulphite) as SO_X fumes are formed. Workspace ventilation may be required.

Environmental performance and operational data
If only a small amount of chromium(VI) is present at high pH values, the reaction can also be carried out in alkali solution with sodium dithionite or iron(II) compounds. The formation of salt by acidification is not necessary when using iron(II) compounds.

Technical considerations relevant to applicability
This technique is used in plants with Cr(VI)-containing coating systems. Flows containing chromate must be pretreated separately before being mixed together or mixed with other waste waters. The chromate reduction takes place at pH values < 2.5. In order to limit the use of additional chemicals, acid waste water can be neutralised with alkaline waste water.

Driving force for implementation
Water pollution legislation.

Example plants
Plant #100 in [155, TWG 2016].

Reference literature
[22, ECCA 2004] [23, COM 2006] [31, COM 2016] [155, TWG 2016] [212, TWG 2018]

6.4.6.3 Precipitation

Description
The transition metals are removed via neutralisation then precipitation at pH values of 9-11. A water-solid mixture results from the precipitation. Lower emission values can be achieved if fine filtration is also used. See also Section 17.11.2.4 and the CWW BREF [31, COM, 2016].

Achieved environmental benefits
Removal of transition metals from the effluent.

Environmental performance and operational data

Settlement tanks need space and may be costly to install. Caustic solution usually precipitates the heavy metals as hydroxides or phosphates. If several metals exist in the effluent at the same time, the precipitation of any metal that is more difficult to precipitate is facilitated.

The solubility of the metals increases with increased neutral salt concentrations. The metals partly precipitate in very fine particles, therefore the addition of flocculating agents (iron(III) chloride, lime) and/or flocculants (polyelectrolyte) is necessary for better separation and filtration.

Technical considerations relevant to applicability

This technique is widely used.

Economics

Investment costs might be significant.

Driving force for implementation

Water pollution legislation.

Example plants

Plants #081, #094, #095 and #106 in [155, TWG 2016]. See also Section 6.3.2.4.

Reference literature

[22, ECCA 2004] [23, COM 2006] [31, COM 2016] [155, TWG 2016]

7 MANUFACTURE OF ADHESIVE TAPE

[6, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005] [132, AFERA 2005] [148, COM 2009]

7.1 General information on the manufacture of adhesive tape

Adhesive tapes are used in many different industries such as packaging, vehicle production, electrical equipment, construction, furniture and paper industries as well as for the do-it-yourself market. Each industry has a wide range of different requirements for product applications and properties that have to be met. In the vehicle industry for example, adhesive tapes are used for attachment of parts onto outer surfaces of car bodies, for abrasion protection, for caulking small openings, for wrapping cables, for masking during painting and for supporting functions during assembly. Modern cars contain between 15 kg and 18 kg of adhesives (solvent-based but also hot-melt) used for coating of insulation materials, assembly bonding of car interiors and exteriors, seating manufacture, etc. [148, COM 2009].

Depending on the use, widely different requirements concerning product properties have to be met, such as adhesive strength, resistance against temperature, mechanical rigidity, tensile strength, shear adhesion, etc. VOC emissions in the production of adhesive tapes originate from the application of solvent-based adhesive systems and the application of auxiliary material containing solvent such as release agents and primers.

Due to the range of products and production techniques, installations usually specialise in certain types of products. Some installations specialise in using adhesive systems based on solvents. In these installations, significant amounts of VOCs are used as solvents in the adhesive systems, in auxiliary materials such as release agents and primers and as cleaning agents. In most cases, the amount of solvents used exceeds the threshold of 200 t/yr.

In 2003, 45 installations in Europe produced about 3 300 million m^2 of these solvent-based adhesive tapes. They share a proportion of about 40 % in the total European adhesive tape production.

The other part of the European adhesive tape market is covered by product groups for other purposes or with other properties. They are produced in installations using adhesives based on hot melt, water-based dispersions and UV cross-linking adhesives. These installations use no or only very small amounts of VOCs (usually for cleaning).

Recent data show that the adhesive tape production in western European countries was of the order of 6 300 million m^2 in 2018[29].

7.1.1 Applications of pressure-sensitive adhesives

The selection of the solvent-based adhesive system depends on the technical application of the adhesive tapes. Table 7.1 gives an overview of different applications of adhesive tapes and the adhesives most commonly used.

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[29] Data from AFERA website: www.afera.com (2018).

Table 7.1: Applications of solvent-based pressure-sensitive adhesives for adhesive tapes

Tape use	Application (end use)	Solvent-based pressure-sensitive adhesive type
Packaging	Adhesive labels, adhesive tapes for packaging	Natural rubber adhesives, (SB)
Automotive industry	Transfer adhesive tapes for decorative strips and flank protection strips, insulating slabs, assembly aids for wheel case covers and skirt side panels, adhesive tapes for winding wire harnesses	Natural rubber adhesives, esters of acrylic acid and acrylates
Construction industry	Foamed plastic adhesive tapes for sealing of windows, caulking of construction splices and expansion joints, carpeting adhesive tapes, etc.	Acrylate dispersions
Medicine	Medical tapes, adhesive plasters	Pure acrylates, polyacrylates
Furniture industry	Transfer adhesive tapes for mirrors, etc.	Acrylate adhesives
Source: [6, DFIU et al. 2002] [78, TWG 2005]		

7.2 Applied processes and techniques in adhesive tape manufacturing

7.2.1 Manufacturing of adhesive tapes

Solvent-based adhesive tapes consist of a substrate (backing), a coupling agent, a pressure-sensitive adhesive and releasing agents. The substrates used are: paper (widely used), fabrics, film, polyvinyl chloride foils, polyester, polyamide and aluminium. Products can be classified as transfer adhesive tapes (double-sided adhesive tapes), adhesive tapes for packaging purposes and adhesive tapes for coating purposes.

For the production of one-sided adhesive tapes, a pressure-sensitive adhesive is applied onto a substrate. Adhesion of the adhesive layer onto the substrate is improved by physical surface preparation or application of primers. For the production of double-sided adhesive tapes, a pressure-sensitive adhesive is applied onto both sides of the substrate. A releasing agent is applied onto one of the adhesive layers in order to avoid contact between the adhesive layers.

7.2.2 Materials for the production of adhesive tapes

Pressure-sensitive adhesives are organic compounds that have a high adhesive strength with different surfaces at the same time. Unlike other adhesive systems, the plastic adhesive film is also active in dry conditions. The adhesive shows visco-elastic behaviour and can be considered a fluid with a very high viscosity. A classification of pressure-sensitive adhesives is shown in Table 7.2.

Table 7.2: Pressure-sensitive adhesives for the production of adhesive tapes

Type of adhesive	Caoutchouc adhesive	Acrylate adhesive	Other pressure-sensitive adhesives
Adhesives using solvents in production			
Dissolution in organic solvents	Natural rubber (NR), butadiene styrene (SBR), styrene isoprene styrene block copolymer (SIS)	Pure acrylate, polyacrylate	Polyurethane, neoprene
Adhesives not using solvents in production			
Dispersion in water	Styrene butadiene styrene block copolymer (SBS), SBR latex, carboxylated (CSBR)	Pure acrylate, polyacrylate	Polyvinyl acetate, acrylate, ethylene vinyl acetate (EVA)
Hot melt	Styrene isoprene styrene block copolymer (SIS), butadiene styrene copolymer (SBR), styrene butadiene styrene block copolymer (SBS)	Polyacrylate	No application
Systems with 100 % solids content, radiation curing or as two part system	Natural rubber (NR), butadiene styrene copolymer (SBR), styrene isoprene styrene block copolymer (SIS)	Pure acrylate, polyacrylate	Polyurethane, polyester, two-part polyurethane
Source: [6, DFIU et al. 2002]			

Caoutchouc adhesives and resins
Caoutchouc adhesives that are technically processed are natural rubber (NR) and synthetic caoutchouc adhesives such as butadiene styrene (SBR), styrene isoprene styrene (SIS).

For the production of natural caoutchouc systems, caoutchouc is dissolved in organic solvents together with resins influencing cohesiveness and adhesion (‘tackifiers’). Other additives, such as agents preventing the ageing processes, are also added. These adhesives are mainly used for plasters, but also for double-sided adhesive tapes, adhesive tapes for packaging and coating adhesive tapes.

Acrylate adhesives

Adhesive tapes are coated with acrylate adhesives especially for long-term or exterior use. Acrylate adhesives dominate the field of assembly application due to their higher thermal and chemical resistance as well as higher cohesion compared to caoutchouc adhesives. Solvent-based adhesives are dissolved in organic solvents (e.g. benzene, ethyl acetate or toluene). The solvent-based acrylate adhesives possess higher cohesiveness than water-based ones.

Other pressure-sensitive adhesives

Thermoplastic elastomers, polyurethanes and neoprene are also used for the production of adhesive tapes for special applications.

Solvents

Solvents for pressure-sensitive adhesives are aromatic and aliphatic solvents with a boiling point of between 60 °C and 120 °C as well as mixtures of these components. Solvent proportions in adhesives ready for application range between 60 % and 75 %. High-solids systems with solids proportions over about 60 % are used in some cases.

Non-solvent adhesive tapes

Synthetic caoutchoucs are applied as hot melts without solvents. For the production of such synthetic caoutchoucs, resins and other auxiliary materials are mixed in the melt, for example in continuously working extruders, and then coated as a melt. The thermoplastic behaviour of the compound is reversible.

Acrylate adhesives can also be applied as water-based dispersions, as 100 % solids systems (as UV cross-linking compounds).

Auxiliary materials

Coupling agents allow a failure-free unwinding and restripping of the adhesive tape by increasing the adhesion between the pressure-sensitive adhesive and the substrate. The coupling can be realised by application of a primer layer. Primers are applied dissolved in organic solvents. Common low-emission techniques for surface treatment are corona discharge, flaming and low-pressure plasma surface preparation.

Releasing agents

Releasing agents are used to prevent adhesion of the pressure-sensitive adhesive to the surface of the adhesive tape. Silicones are applied as releasing agents for acrylate adhesives and synthetic caoutchoucs. For natural caoutchouc adhesives, systems containing stearyl groups are also in use. Most of the releasing agents are applied as solutions.

Impregnating agents

Impregnating agents are applied for surface refinement of smooth, absorbent papers in order to increase the wet strength and mechanical rigidity. For this process, polymer dispersions containing water are used based on SBR acrylate, acrylate and acrylate-natural caoutchouc systems for special applications.

Cleaning agents

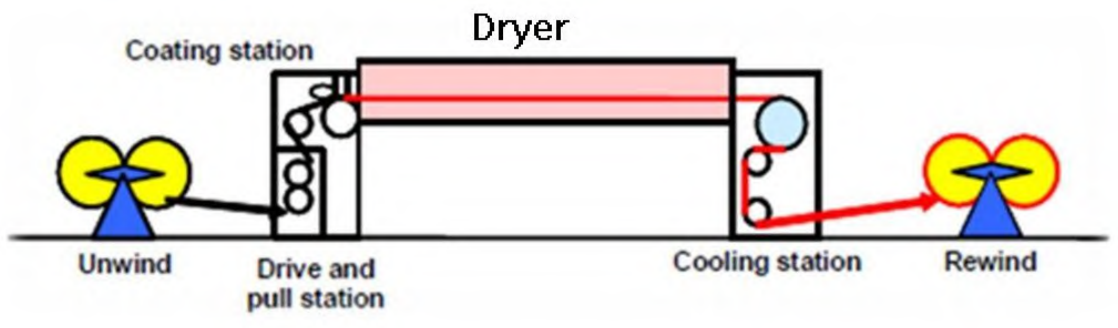
Usually, the same solvents are used for the different cleaning activities as are used in the adhesive systems, both for cleaning during production and for maintenance.

7.2.3 Adhesive tape production process

[78, TWG 2005] [132, AFERA 2005]

The production process can be subdivided into three main steps:

- coating: surface treatment of the substrate and the coating of the sheet-like substrate with the adhesive;
- drying (cross-linking) of the adhesive;
- winding.



Source: [132, AFERA 2005]

Figure 7.1: Schematic layout of an adhesive tape production line

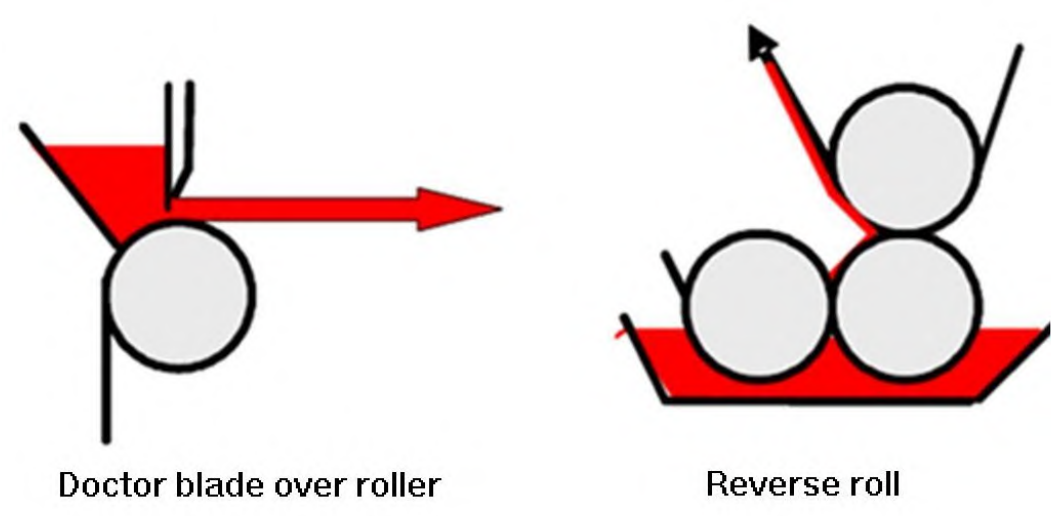
In addition, in (nearly) all solvent-based installations, the following auxiliary processes are installed:

- storing the adhesive components;
- adhesive mixing;
- off-gas treatment (from the dryer);
- slitting the rewound tape.

This section describes the production steps of adhesive tape manufacturing which may have an impact on the environment.

Coating

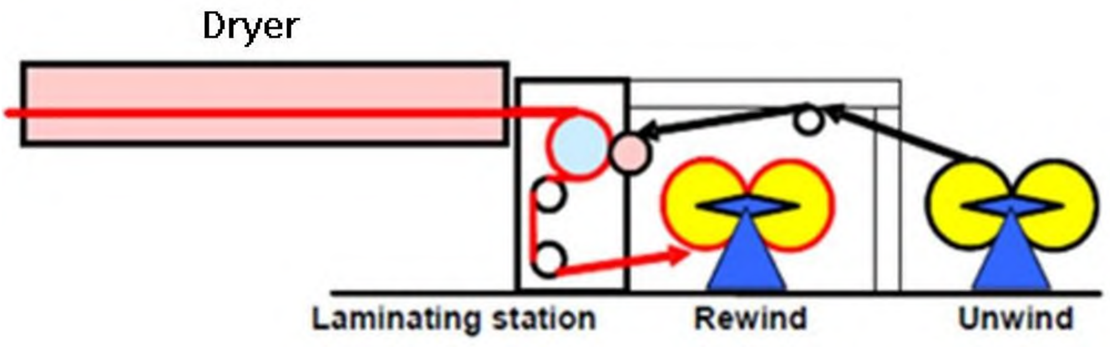
The application of a solvent-based pressure-sensitive adhesive can be carried out by different application techniques. Doctor blade (knife) systems or reverse-roll-coat systems as shown in Figure 7.2 are commonly used.



Source: [132, AFERA 2005]

Figure 7.2: Different types of adhesive application units

The adhesive material can be applied directly onto the substrate. An alternative is the transfer technique, where the pressure-sensitive adhesive is dried onto the releasing material and cross-linked. Afterwards, the adhesive film is transferred onto the substrate by lamination; therefore the substrate has to be protected from damage during the drying process. Lamination can be carried out with coating directly to a transfer release liner and laminating with a backing as shown in Figure 7.3.



Source: [132, AFERA 2005]

Figure 7.3: Lamination unit

The formulation of the adhesives is often situated close to the application process. Different mixing facilities are used for different types of adhesives:

- Granulated rubber, resins and other additives are put into a kneader filled with solvent. This is a slow batch process for adhesives with a high viscosity.
- Granulated rubber, resins and other additives are put into a high-speed mixer filled with solvent. The mixer has different mixing blades inside. This is a short batch process for a lower-viscosity adhesive.
- Acrylic adhesive is made in batches in polymerisation stations. The reaction is based on a catalyst in the mixer and is controlled by temperature and pressure.

Fugitive emissions of VOCs in these first production steps may arise from the following processes or units:

- storing of solvents or pre-products containing solvent;
- formulation of the adhesives in the mixing units;
- leading the adhesives to the application machine;
- the application unit of the primer;
- the adhesives application unit.

Some of the fugitive emissions from these sources are captured and led to an off-gas treatment unit.

Waste results from mixed but not used adhesives and from cleaning of the mixing facilities.

Normally there is no waste water from these processes.

Drying
Solvent-based adhesives are dried thermally by convection dryers and infrared dryers. Any cross-linking can be carried out chemically or by UV radiation in order to improve technical properties. The air of the convection dryers is heated with gas, oil or steam via heat exchangers.

The main dryer equipment for solvent-based systems is differentiated by airflow and material transportation:

- in a tangential airflow dryer, the material is transported by rolls;
- in a single side dryer with nozzles over rolls, the material is transported by driven rolls;
- in a transport belt dryer, the material is transported by a belt;
- in an air floating dryer, the material is transported by specially designed air nozzles;
- in a festoon dryer, long loops are hung on poles which move slowly through a sealed room.

The VOCs evaporating from the adhesive layer during drying are captured with part of the exhaust air from dryer. For safety reasons, a maximum solvent concentration is maintained in the exhaust air, according to EN 1539. The safe working level maintained is 50 % of the lower explosive limit (LEL). A reduction of the solvent concentration of the dryer's air is controlled by the airflow rate. If gas-tight inert gas dryers are used, higher solvent loads are possible. The load depends on the solvents used and the drying temperature.

The exhaust air of the dryers is usually treated by solvent recovery. This is carried out by condensation in the pre-drying stage (captured fugitive emissions from the mixing and application units) and by adsorption on activated carbon in the drying stage. Solvents are recaptured by steam desorption and trapping. In the case of recycled solvent that cannot be reused, regenerative thermal oxidation is usually applied.

There is no waste from the processes of drying and off-gas treatment. Minor amounts of waste water result from the desorption process in the case of adsorptive off-gas treatment.

Winding
Before rewinding, the tape has to be cooled down in a cooling unit with cooling rolls. The cooling is done by the use of cooling water.

After cooling, the tape is rewound on large rolls ready for transport to the slitting process.

The solvent proportions remaining in finished double-sided adhesive tapes produced with solvent-based adhesives account for between 0.1 % and 2 % depending on the amount of solvent used. Solvents remaining in the products are either slowly lost due to diffusion processes or they remain in the adhesive layer functioning as a plasticiser.

At this stage of the production process, waste may result from faulty charges and as slitting remains. The amount of waste normally remains below 10 % of the material input.

There is no waste water generation.

7.3 Current consumption and emission levels in adhesive tape manufacturing

[78, TWG 2005] [132, AFERA 2005] [155, TWG 2016]

Data for three adhesive tape manufacturing plants were received in the data collection and they are analysed in the following sections.

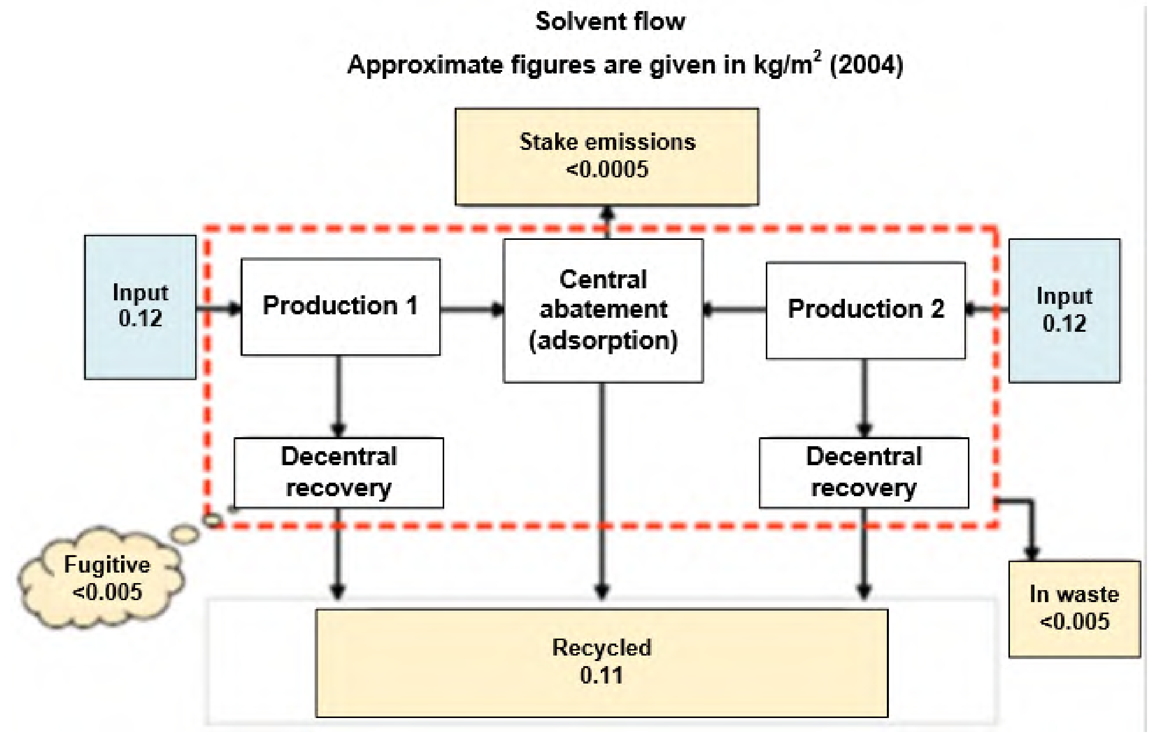
7.3.1 Consumption

7.3.1.1 Consumption of raw materials

The adhesive material is usually produced in-house and has a solids content which could vary from < 1 % up to 80 % depending on the product type, the substrate (backing) material and the production process. The adhesive-material-specific consumption value could vary from 10 g/m^2 to 300 g/m^2 of produced tape and the corresponding specific solvent consumption could vary from 0.05 g/m^2 up to 5 g/m^2.

For the production of plastic films used for temporary surface protection, applied average coat weights are 5 to 20 times lower than tapes [255, France 2018].

Information on average solvent flow (data from 2004) for a reference plant producing high-quality solvent-based adhesive tapes for very specific industrial uses is presented in Figure 7.4.



Source: [132, AFERA 2005]

Figure 7.4: Solvent flow (2004 data)

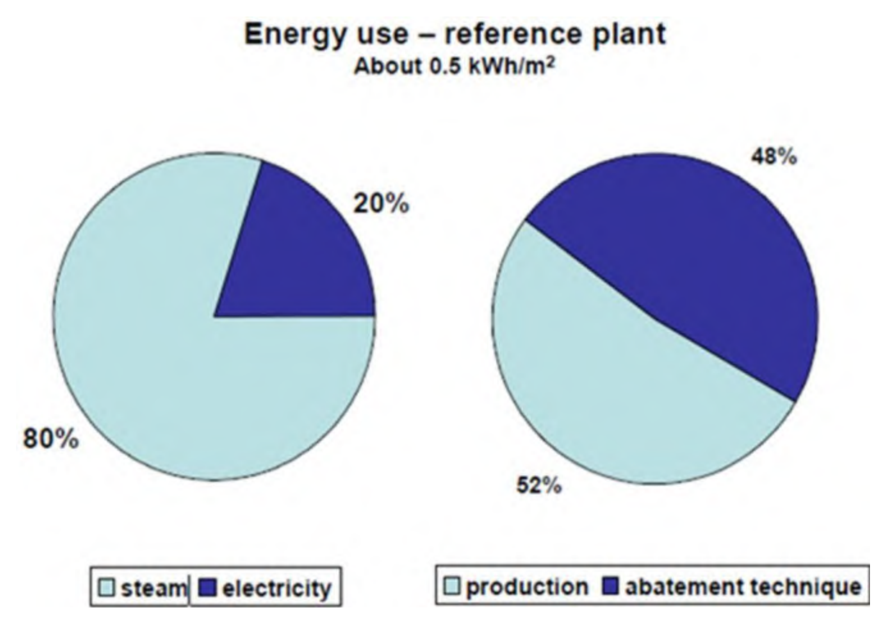
7.3.1.2 Energy consumption

Data from two reference plants show that the specific energy consumption varies from 0.2 kWh/m^2 up to 1 kWh/m^2. Of the total energy usage, 60-80 % relates to fossil fuel consumption for steam generation and the rest to electricity which also covers heating, ventilation and air conditioning (HVAC) needs.

Energy consumption data (from 2004) for the reference plant of Figure 7.4 are presented in Figure 7.5.

A reduction of the energy consumption is gained by:

- the use of heat exchangers in the dryers;
- optimised insulation of the dryers.



Source: [132, AFERA 2005]

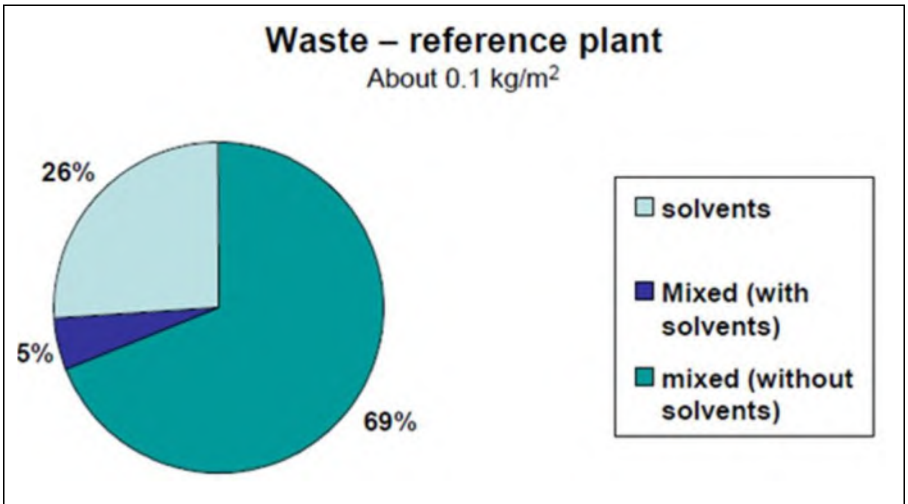
Figure 7.5: Energy consumption (2004 data)

For the production of plastic films used for temporary surface protection, a specific energy consumption value of the order of 0.072 kWh/m^2 is reported [255, France 2018].

7.3.1.3 Waste generation

Data from one installation show a specific waste generation value of the order of 0.1 kg/m^2 of produced tape [155, TWG 2016].

Waste generation data (from 2004) for the reference plant of Figure 7.4 are presented in Figure 7.6.



Source: [132, AFERA 2005]

Figure 7.6: Waste generation (2004 data)

The amount of waste is reduced by:

- process optimisation by risk analysis (the FMEA process: failure mode and effects analysis) avoiding quality problems;
- continuous process control to avoid non-conforming products;
- optimisation of adhesive mixing to avoid excess materials with limited shelf life;
- an efficient solvent recovery system.

The specific consumption and emission values are significantly dependent on the types of manufactured tapes (type of solvent, substrate, coating weight) and will decrease with:

- a decreasing number of different products during the production period (longer campaigns);
- a lower share of double-sided tapes in the production.

Table 7.3 shows the specific consumption figures of the reference plant of Figure 7.4 in comparison with average data from other solvent-based production plants.

Table 7.3: Benchmark comparison for solvent and energy used and waste generated

	Solvent used (kg/m^2)	**Energy used (kWh/m^2)**	**Waste generated (kg/m^2)**
Average data (Min.-Max.) (normal production)	0.04 (0.02-0.12)	0.5 (0.25-1.1)	0.03 (0.005-0.1)
Reference plant (special production)	0.12	0.5	0.10

NB: This table very clearly expresses the higher specific consumption of specialised production (as in the reference plant) compared with the average level of commodities produced in other solvent-based plants.
Source: [132, AFERA 2005]

For the production of plastic films used for temporary surface protection, a specific waste generation value of the order of 0.008 kg/m^2 is reported [255, France 2018].

7.3.2 Emissions

7.3.2.1 Total and fugitive emissions of VOCs

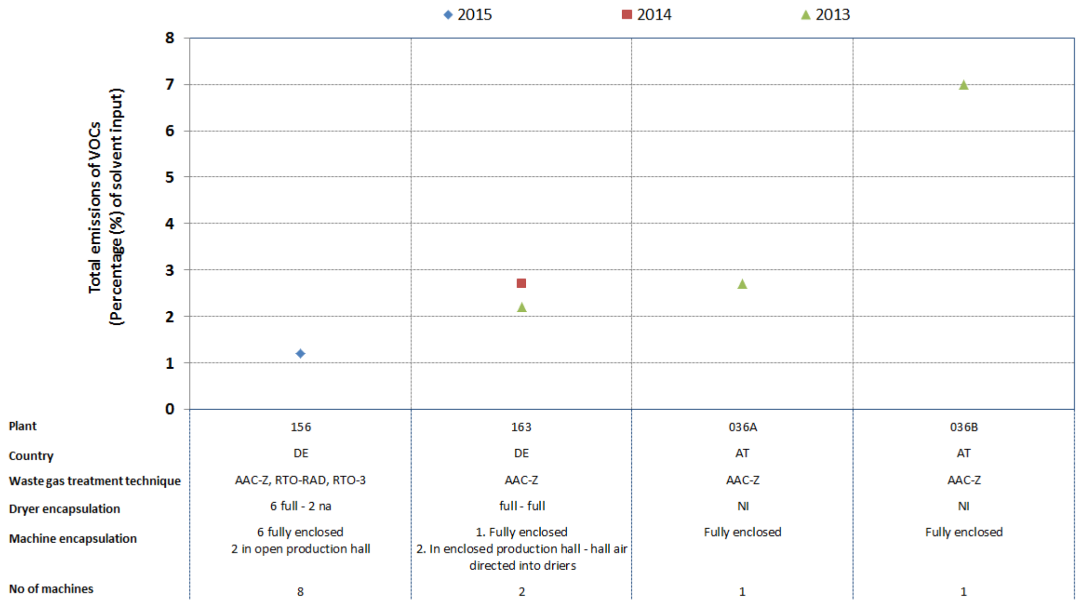
[155, TWG 2016] [212, TWG 2018]

In general, total emissions of VOCs expressed as a percentage of the solvent input are low.

Elevated total emissions may occur in the following cases:

1) Products which require coatings with highly volatile components (e.g. benzine 60/95) and/or high coating weights can have a considerable residual solvent content. Because this is part of the fugitive emissions (and therefore counted under total emissions), it can result in total emission levels higher than 1 % of the solvent input.
2) Ancillary activities (e.g. cleaning, transferring) which are characterised by erratic intervals and often by short peaks with high concentrations, so exhaust air treatment may have an unfavourable cost-benefit ratio [AFERA comment #5 in [212, TWG 2018]].

The reported total emissions of VOCs expressed as a percentage of the solvent input are presented in Figure 7.7.



Source: [155, TWG 2016]

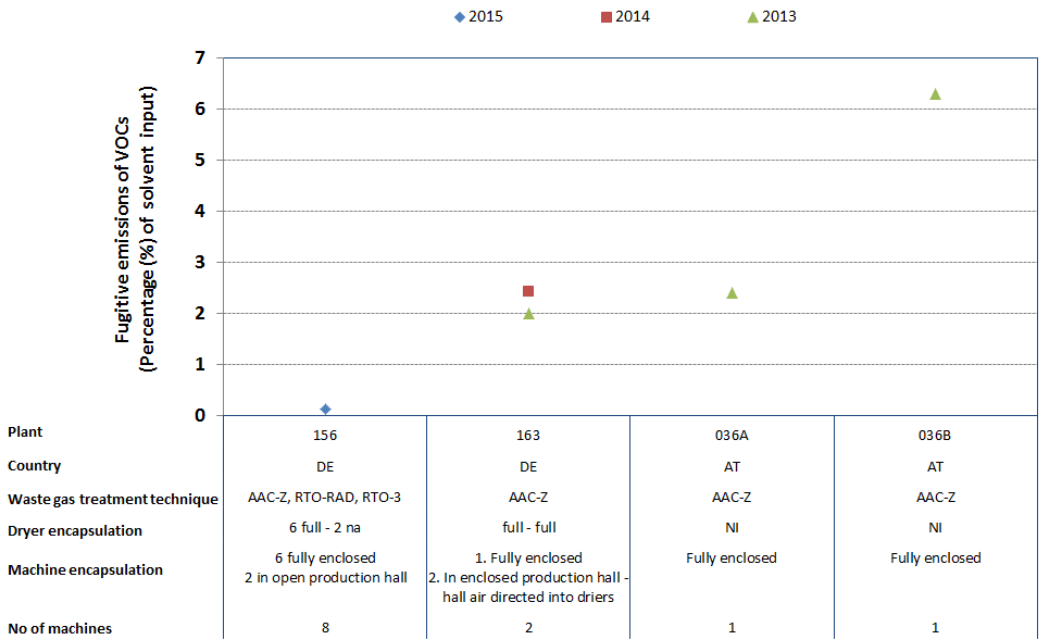
Figure 7.7: Total emissions of VOCs expressed as percentage of the solvent input for the period 2013-2015

Data show that all but one values for total VOC emissions are below 3 % of the solvent input. The deviated figure for one plant is mainly attributed to the relatively high percentage of fugitive emissions compared to the corresponding values for the other plants, as can be seen in Figure 7.8.

In terms of total emissions expressed as g VOCs per m^2 of coated surface, data from two plants show a range from 0.6 g VOCs/m^2 to 1.5 g VOCs/m^2.

For the production of plastic films used for temporary surface protection, a specific emissions value in the order of 1.2 g VOCs/m^2 is reported [255, France 2018].

All plants reported either full encapsulation of coating machines or enclosure of the production hall and full dryer encapsulation with extraction and subsequent treatment using activated carbon adsorption and recovery.



Source: [155, TWG 2016]

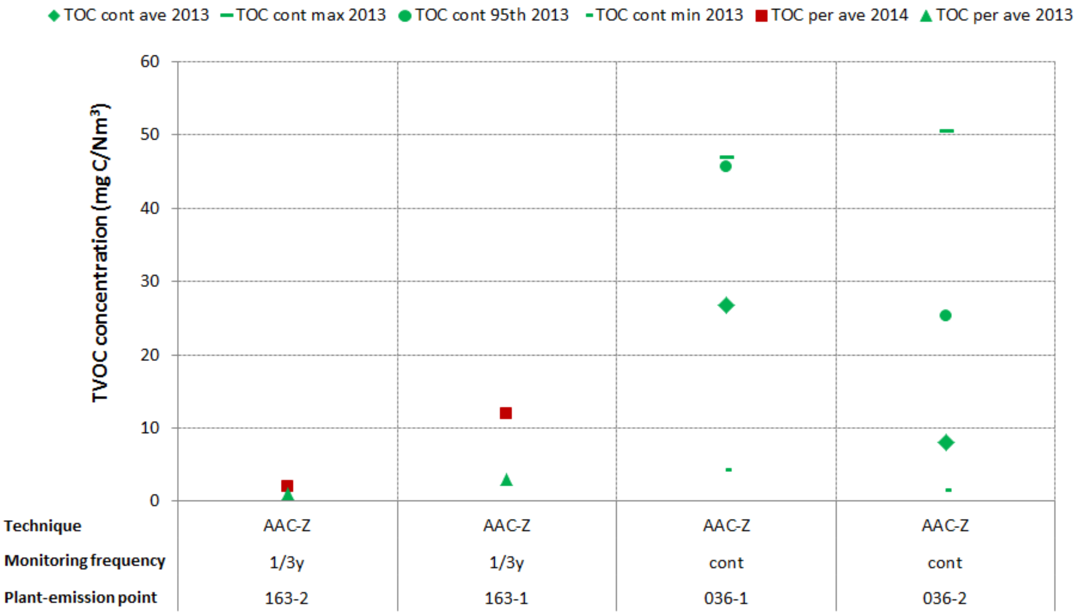
Figure 7.8: Fugitive emissions of VOCs expressed as percentage of the solvent input for the period 2013-2015

In Plant #036A, rubber, solvent (hexane) and resins are used for the adhesion, while Plant #036B uses a hot-melt process. In both lines, a release coat is applied by using toluene. Therefore, the differences in the achieved total (and fugitive) emission values between the two lines of the same installation could be explained on the basis of higher fugitive emissions of the release coat application in comparison to the hexane-based adhesive coating.

7.3.2.2 TVOC emissions in waste gases

[155, TWG 2016]

TVOC emissions in waste gases were reported for only four out of the nine monitoring points from three adhesive tape manufacturing plants. At eight of the nine waste gas emission streams the applied abatement technique is activated carbon adsorption and at one RTO is applied. All reported maximum values from continuous monitoring of adsorption systems are below 50 mg/Nm^3 while the 95th percentiles are below 45 mg/Nm^3 (see Figure 7.9).

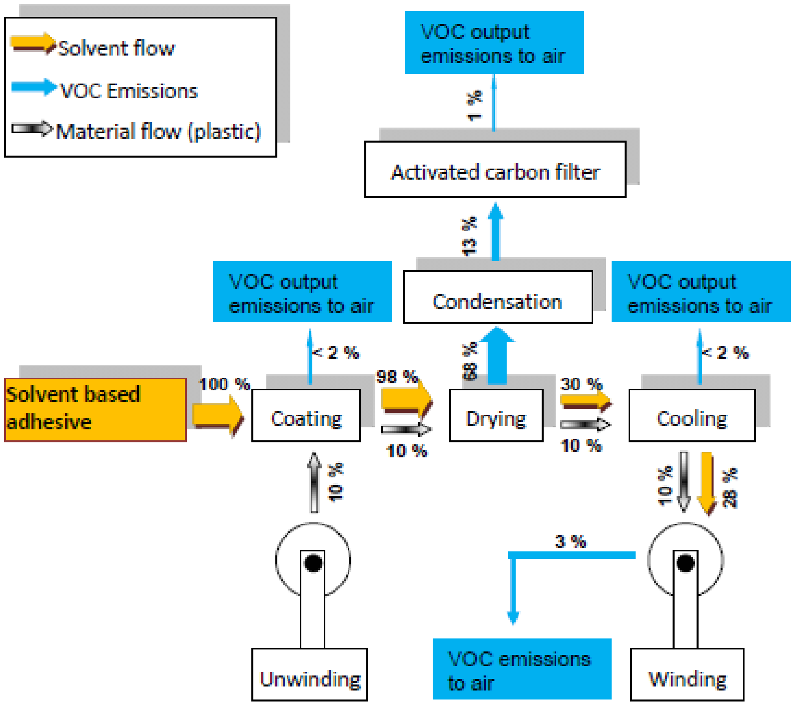


NB: For plant #163, data for 2011 instead of 2013.

Source: [155, TWG 2016]

Figure 7.9: TVOC emissions in waste gases for the period 2013-2015

A general diagram presenting the solvent flows and main sources of VOC emissions is presented in Figure 7.10.



Source: [148, COM 2009]

Figure 7.10: Solvent input and main VOC outputs for adhesive tape coating

As can be seen from Figure 7.10, channelled VOC emissions are kept low and minimisation of fugitive emissions (e.g. from coating application) would result in low total VOC emissions as confirmed by the collected data (see Figure 7.7).

Important elements for achieving low emission levels are:

- using solvent-free techniques for manufacturing suitable products (currently lower-quality ranges of packaging and masking tapes, and double-sided tapes);
- capturing of emissions from solvent storing and adhesive mixing;
- encapsulation of the whole coating machine and leading all emissions from all fugitive sources to the off-gas treatment; off-gas treatment can be one or a combination of:
    - condensation, after a pre-drying step (see Sections 7.4.2.1 and 17.8.1);
    - adsorption with recovery of > 90 % and emissions of < 1 % (see Section 17.10.6.2);
    - thermal oxidation with energy recovery (see Section 17.10.5);
    - additional specific capturing of VOC emissions directly from the coating units (see Section 17.10.2);
- decreasing the number of different products during the production period (longer campaigns), avoiding the need for interim cleaning.

7.4 Techniques to consider in the determination of BAT for the manufacturing of adhesive tape

In Chapter 17, techniques are discussed which might also be applicable to the manufacturing of adhesive tape. In Table 7.4, the general techniques relevant for the manufacturing of adhesive tape are shown. These techniques are not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 17.1.

The EGTEI background document for the industrial application of adhesives (see Annex 21.3.1) gives some data on the costs and benefits at the European level of some techniques to reduce VOC emissions. However, the EGTEI approach necessarily has to limit its complexity, and only key techniques are given without consideration of the other BAT factors, such as cross-media effects, or of the technical characteristics of individual installations and products [83, EGTEI 2005].

Table 7.4: Reference to techniques generally applicable to the sector

Technique	Section number
Environmental management techniques	17.1
Storage and handling of raw materials	17.2
Monitoring	17.3
Water use and waste water generation	17.4
Energy management and energy efficiency	17.5
Raw material management (including substitution)	17.6
Coating processes and equipment	17.7
Drying and/or curing techniques	17.8
Cleaning techniques	17.9
Off-gas extraction and treatment	17.10
Waste water treatment techniques	17.11
Waste management techniques	17.12
Odour emissions	17.13

7.4.1 Material-based techniques

7.4.1.1 Hot-melt adhesives

Description
Use of coating with adhesives made from the hot extrusion of synthetic rubbers, hydrocarbon resins and various additives. No solvents are used.

Technical description
Hot melts are solid at room temperature, and must be heated to 100-250 °C before being used. In practice, the liquid hot melt is applied to a substrate and the parts to be glued are brought together promptly. Hot melts bond efficiently on cooling and solidifying; the working time ranges from a few seconds to several minutes.

Hot melts are available in sheet foil, granular material, pillows or block form. The adhesive is then processed with a melting appliance and custom-made nozzles.

Achieved environmental benefits
Solvent emissions are eliminated.

Environmental performance and operational data

Hot-melt adhesives are 100 % solvent-free. They cannot be used over the same wide temperature ranges as solvent-based adhesives and do not have the same high quality. On the other hand, a major advantage of hot melts is that almost any substrate can be bonded. In addition, use of hot-melt adhesives compared to solvent-based systems results in low odour emissions, good solubility and excellent heat stability.

Cross-media effects

There is a necessity for heating equipment and the associated energy costs; the extra energy needed depends on the size of the production line. For small applications, this starts with a capacity need of ~ 2 kW.

Technical considerations relevant to applicability

The technique is applicable in new and existing plants and installations. In the manufacturing of adhesive tapes, hot melts are suitable for the lower quality range of packaging and masking tapes as well as for double-sided tapes. They cannot substitute solvent-based adhesives entirely.

Hot-melt adhesives are not currently used for the production of plastic films used for temporary surface protection [255, France 2018].

Economics

They are around 80 % less expensive per dry kg than solvent-based adhesives and the corresponding equipment costs are 50-70 % lower – because there is no need either for dryers or abatement technology. Due to the lack of an energy-intensive dryer and abatement technology, the overall energy consumption of hot-melt coating is about 33 % less compared to solvent-based coating [148, COM 2009].

Example plants

Plant #36B in [155, TWG 2016].

Reference literature

[6, DFIU et al. 2002] [148, COM 2009] [155, TWG 2016] [255, France 2018]

7.4.1.2 Water-based adhesives

Description

For a general description, see Section 17.7.2.2. Water-based adhesives do not contain organic solvents or contain about 0.5 % solvent as a softener to keep the glued joint flexible.

Technical description

Water-based polymers alone are not sufficient to impart optimum adhesion to the adhesive, and tackifier resins are necessary to improve adhesion to different materials. In many cases, the same elastomers and tackifiers can be used as those used in solvent-based systems.

The amounts of solids in both adhesives (solvent-based and water-based) are about the same.

Achieved environmental benefits

Solvent emissions are eliminated.

Environmental performance and operational data

Water-based adhesives' raw materials are available in dry and wet form. Adhesive in dry form has about 65 % less volume and 75 % less weight than solvent-based adhesive – consequently transport costs are relatively low. The disadvantage of transporting it in dry form is that it has to be formulated on site - which requires large water-resistant mixing tanks with non-corrosive piping, fittings and stainless steel mixers and pumps. This increases the capital cost of operation. Ready mixed water-based adhesives have roughly the same volume and weight as solvent-based adhesives and transport costs are similar. They suffer from mould growth and should be stored above freezing point (multiple freeze-thaw cycles should be avoided) [148, COM 2009].

Cross-media effects
More energy is required for drying.

Technical considerations relevant to applicability
The technique is applicable in new and existing plants and installations. Water-based adhesives are not as widely applicable as solvent-based adhesives due to their lower performance; for instance, they have a more restricted operational temperature range [148, COM 2009].

Water-based adhesives are suitable for the lower quality range of packaging and masking tapes as well as for double-sided tapes.

For the production of plastic films used for temporary surface protection, water-based adhesives with low solvent content are used [255, France 2018].

Economics
Compared to solvent-based adhesives, the most important difference is their lower price - approximately 15-20 % of that of conventional products.

Investment costs for water-based adhesive applications are estimated to be ~ 8 % lower than for conventional solvent-based systems. The higher costs for solvent-based systems result from the need for explosion-proof electrical equipment and emission control systems and waste disposal charges [148, COM 2009].

The operating costs for both water-based and solvent-based systems are about the same - apart from the lower energy costs due to abatement technologies not being necessary for water-based systems.

Example plants
Plant #156 (used as dispersions for specific types of products) in [155, TWG 2016].

Reference literature
[6, DFIU et al. 2002] [148, COM 2009] [155, TWG 2016] [255, France 2018]

7.4.1.3 UV-cured adhesives

Description
For a general description, see Section 17.7.2.3. UV-cured adhesives do not contain solvents.

Technical description
Most UV-cured adhesives are completely solvent-free but for some applications UV-cured adhesives can still contain solvents to reduce viscosity. They consist of two compounds: one is the adhesive resin itself and the second is the photoinitiator. Once the photoinitiator is exposed to ultraviolet light it undergoes a chemical reaction and produces by-products, causing the adhesive to harden. Heating is not required.

Achieved environmental benefits
Solvent emissions are eliminated or significantly reduced.

Environmental performance and operational data
UV-cured adhesives have a high cohesiveness and high adhesion strength but are difficult to use if the materials to be combined are not UV-light-transparent. UV light can be exposed to the edge of a connection and the reaction can progress through the full volume of adhesive, but this

may take hours or days. Other options include delayed curing products that can be activated by UV light to initiate the curing before the pieces to be joined are positioned.

Technical considerations relevant to applicability
The technique is applicable in new and existing plants and installations. In the manufacturing of adhesive tapes, UV-cured adhesives are suitable for the lower quality range of transfer and packaging as well as for masking tapes. UV-cured adhesives can be used with a wide range of materials such as ceramic, composite materials, concrete, fabric, glass, metal, paper, plastic rubber or wool.

In general, UV-cured adhesives cannot be used to cure through opaque materials. Some UV-cured adhesives (particular epoxy adhesives), however, only need an initial UV beam to start the reaction. Once the curing reaction has started, a catalyst - included in the coating - promotes the further curing of the adhesive. Therefore opaque materials can be glued together if only a part is exposed to UV light - even so, the curing time can take hours or days. The process is known as ‘shadow’ curing [148, COM 2009].

Reference literature
[6, DFIU et al. 2002] [148, COM 2009]

7.4.2 Drying/curing

7.4.2.1 Inert gas convection drying

For a general description, see Section 17.8.1. This technique is commonly applied as a pre-drying step in adhesive tape manufacturing.

Example plants
Plant #156 (applied either in combination with convection drying or as a stand-alone technique) in [155, TWG 2016].

Reference literature
[6, DFIU et al. 2002] [155, TWG 2016]

7.4.2.2 Infrared radiation curing

For a general description, see Section 17.8.5.1. This curing dryer is commonly used in adhesive tape manufacturing and is suitable for dispersions and also for solvent-based adhesives if explosion protection is needed.

Reference literature
[5, DFIU et al. 2002] [6, DFIU et al. 2002]

7.4.2.3 Ultraviolet (UV) curing

For a general description, see Section 17.8.5.4. UV curing is increasingly applied in the production of adhesive tapes. It is used especially for newer acrylate hot melts. It is also used for radiation curing adhesives, where the final reticulation and the adjustment of the technically required cohesiveness and adhesive strength are initiated by UV radiation.

Reference literature
[5, DFIU et al. 2002] [6, DFIU et al. 2002]

7.4.2.4 Electron beam (EB) curing

For a general description, see Section 17.8.5.5. EB curing is increasingly applied in the production of adhesive tapes, however less than UV curing (see Section 7.4.2.3) due to the higher investment costs. Also, compared to UV curing, changes in substrate properties are possible.

Example plants
Plant #156 in [155, TWG 2016].

Reference literature
[5, DFIU et al. 2002] [6, DFIU et al. 2002] [155, TWG 2016]

7.4.3 Off-gas extraction and treatment

Available techniques for the extraction of off-gases and minimisation of fugitive emissions are discussed in Section 17.10.2.

7.4.3.1 Condensation (refrigeration)

For a general description, see Section 17.10.6.1. Used solvents can be recovered by applying condensation in a recuperative heat exchanging device and cooling (5 ºC to -30 ºC) by a refrigerant compressor. In adhesive tape manufacturing, condensation is applied after a pre-drying step using an inert gas nozzle dryer (see Sections 7.4.2.1 and 17.8.1) and before the main drying process. This is followed by an adsorption step for the exhaust gas.

Reference literature
[6, DFIU et al. 2002]

7.4.3.2 Activated carbon adsorption and recovery on site

For a general description, see Section 17.10.6.2. The off-gas loaded with solvents flows through adsorbers that are generally constructed as several parallel connected tanks. The tanks are filled with activated carbon. If one adsorber is saturated, the waste gas is routed to the adjacent adsorber. For regeneration, the adsorbed solvents are first desorbed due to a rise in temperature initiated by steam supply. The water-solvent mixture being formed is then condensed and separated by phase separation. Maximum emission concentrations < 50 mg/m^3 are achieved in the cleaned gas (see also Section 7.3.2.2).

Example plants
Plants #036, #156 and #163 in [155, TWG 2016].

Reference literature
[6, DFIU et al. 2002] [155, TWG 2016]

7.4.3.3 Regenerative thermal oxidation (RTO)

For a general description, see Section 17.10.5.4.

Example plants
Plant #156 in [155, TWG 2016].

8 COATING OF TEXTILES, FOILS AND PAPER

8.1 General information on the coating of textiles, foils and paper

[161, TWG 2015] [163, Kovacevic et al. 2010] [164, Singha 2012] [165, EURATEX 2018]

This chapter covers the sector of coating of various substrates (textiles, foils, paper) with different end uses and similar application techniques.

Coating and laminating are increasingly important techniques for adding value to technical textiles. Coating and lamination enhance and extend the range of functional performance properties of textiles and the use of these techniques is growing rapidly as the applications for technical textiles become more diverse.

Textile and apparel manufacturing is an essential pillar of the local economy across the EU regions. One federation alone represents some 174 000 companies with a turnover of EUR 162 billion, employing 1.66 million workers. The EU is the second world exporter of textiles and clothing with 22 % and 25 % of world sales respectively in 2017 [165, EURATEX 2018].

The total number of plants in Europe for the coating of textiles, foils and paper above the IED Annex I 6.7 threshold is estimated to be more than 25 [161, TWG 2015].

8.2 Applied processes and techniques

8.2.1 Polyurethane (PU) coating

[163, Kovacevic et al. 2010] [164, Singha 2012]

Coating is a process in which a polymeric layer is applied directly to one or both surfaces of the fabric. The polymer coating must adhere to the textile and a blade or similar device controls the thickness of the viscous polymer. The coated fabric is heated and the polymer is cured (polymerised). Where a thick coating is required, this may be built up by applying successive coating layers, layer on layer.

The selection of polymers is very important to obtain the desirable properties of the finished product, and the coating composition is determined according to the application of the finished product.

The coating consists of the basic polymer and additives. In the selection of the basic polymer, the properties are as follows: thermoplasticity, weldability, impermeability to liquids, mechanical properties of polymers, possibility of film formation, stiffness, good adhesion, abrasion resistance, heat, water and air permeability, resistance to solvents and hydrolysis, resistance to UV radiation, melting point, etc.

The basic polymer is mostly polyurethane which may be strong and rigid or soft and elastic. Polyurethanes belong to the group of very durable plastic materials. The main property of polyurethane is its wide-ranging application. It can be used to coat textiles, leather, in solution, dispersion, with a low solvent content or without it, as granules or powder. Softness or hardness can be obtained by varying polymer structures.

Polyurethane has good washing and cleaning resistance, good adhesion to fabric, good durability at low temperatures, good viscosity and abrasion resistance, and it is possible to use it without softeners. At the same time, it has a pleasant and soft touch, a low specific mass, and resistance to oils and fats. Polyurethane can be used to coat textile materials in more ways:

- as a two-component polyurethane with isocyanate cross-linking;
- as one-component aromatic or aliphatic polyurethanes with chemical reactions;
- as a one-component product that enables dispersion in water and is environmentally friendly;
- as a solid product with possible coating of greater quantities in each coating passage.

It is of special environmental importance when the organic solvents used for the preparation of polyurethane coating mixture are characterised as CMR. A typical example is the use of DMF (N,N-dimethylformamide, CAS number 68-12-2), which according to the harmonised classification and labelling of hazardous substances carries the following hazard statement codes: H360D, H332, H312, H319.

8.2.1.1 Coating methods

[164, Singha 2012] [166, FEDUSTRIA 2016] [167, FEDUSTRIA 2016] [168, United Kingdom 2016]

There are several processes for the application of coating to the textile material depending upon the requirements for the end product. The most frequently used are the following:

- **Direct coating**: The fabric is stretched flat to form a uniform surface and is transported under a stationary doctor blade. The direct coating process of polyurethane involves the application of multiple coating layers on a textile substrate. Every coating step is followed by a passage through a drying unit to remove the solvent (such as DMF). A range of solvents are involved, depending on the coating polymer type specified, including DMF as well as MEK (methyl ethyl ketone) or toluene. In at least one case, the specialised coated fabric can be passed through the dryer again to reduce the residual quantity of DMF otherwise remaining in the product. As DMF is a CMR substance, a high standard of collection and destruction is needed to meet permit limits (see also Section 8.2.1.1.1).

- **Foamed and crushed foam coating**: This can be used to apply polymer to woven fabrics and knitted fabrics and also to fabric produced from spun yarns or fabrics of a general open construction which cannot generally be directly coated.

- **Transfer coating**: The principle of transfer coating is first to spread the polymer onto release paper to form a film and then to laminate this film to the fabric. Multiple coating layers are applied on release paper and transferred to a textile substrate by means of a polyurethane (PU) adhesive layer. Every coating step is followed by a passage through a dryer to remove the solvent (such as DMF). After drying of the adhesive layer, the paper is released from the coating (see also Section 8.2.1.1.2).

- **Hot-melt extrusion coating**: This method is used for thermoplastic polymers such as polyurethane, polyolefins and polyvinyl chloride (PVC), which are applied by feeding granules of the material into the nip between moving heated rollers.

- **Calender coating**: Calenders are primarily used to produce unsupported films of PVC and rubbers from compounded polymer ‘dough’.

- **Rotary screen coating**: The application of a compound to a fabric by forcing it through a cylindrical screen, it is used mainly for textile printing.

8.2.1.1.1 Direct coating

[167, FEDUSTRIA 2016] [168, United Kingdom 2016]

Within individual mixing booths equipped with air extraction, the supplied polyurethane, chemical auxiliaries and organic solvent, as required for viscosity adjustment, are mixed according to the technical specification. Extracted air is directed to the thermal oxidiser.

The coating machines are comprised of three separate contained individual coating heads and associated thermal oil-heated dryers with extraction. Individual doctor blades control the coating weight.

Visibly open areas of the machine are the web inlet before the liquid coating is applied and the web outlet after the dryer. The drums containing the coating mix(es), at each individual coating head, are located at the appropriate coating station.

The polyurethane direct coating process involves coating directly onto a specified textile fabric substrate. This may involve a single machine pass for up to the three coating heads installed in sequence, with additional machine passes as required for additional coats and/or coating weight. Each of these runs through the coating machines adds solvent at the coater, followed by evaporation within the dryer. If necessary, to reduce the high-boiling-point solvents (e.g. toluene and DMF) content of the final product, the product can be run through the coater-dryer working just as a dryer.

Solvent-laden exhaust air is directed from the mixing booths, the open coating area of the coating machine and the dryers to a RTO (regenerative thermal oxidiser). Solvents involved are generally predominantly MEK, isopropyl alcohol (IPA), toluene, DMF and SBP 60/95 (light-hydrotreated naphtha). More information on DMF is available on the ECHA website[30].

The number of installations in Europe is estimated at more than 10, three of them in Belgium which produce protective clothing, technical textiles, automotive-related textiles like tarpaulins etc.

8.2.1.1.2 Transfer coating

[167, FEDUSTRIA 2016] [168, United Kingdom 2016]

Within booths equipped with air extraction, the supplied mixture of polyurethane and solvents (i.e. DMF) is diluted in drums using more DMF to adjust the viscosity. Extracted air goes to the thermal oxidiser or scrubber-distillation column. In the latter case, the solvents are recovered.

The coating machines are contained, gas-fired coater-dryers, with extraction. A doctor blade controls the coating thickness.

Visibly open areas of the machine are the web inlet before the liquid coating is applied and the web outlet after the dryer. The closed drum containing the coating mix stands beside the coating line and the coating mix is pumped to the coating unit.

Transfer coating is mostly applied on elastic fabrics, the polyurethane coating is indirect. The coating is built up on a release paper in more than one coat, then stuck to the substrate using the polyurethane/DMF mix, and finally the transfer paper is removed. Each of these runs through the coating machines adds DMF in the coater, followed by driving off the DMF in the dryer. If necessary, to reduce the DMF content of the final product, the product can be run through the coater-dryer working just as a dryer.

Air containing DMF goes to a thermal oxidiser or distillation unit from: the dilution booths, the open coating area of the machine, the area where the liquid coating is applied on the paper, and the dryers.

There are four installations in Belgium applying transfer coating using DMF which produce mainly medical textiles, protective clothing, mattress covers, artificial leather, etc.

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[30] http://echa.europa.eu/documents/10162/13640/axiv_5th_recommendation_dmf_rcom_en.pdf

8.3 Current consumption and emission levels in PU and PVC coating

[155, TWG 2016]

Data were submitted for 10 plants, 8 of which are textile coating plants (woven and non-woven, knitwear), one a paper and foil coating plant and one a paper, plastic and other substrates coating plant.

Table 8.1: List of plants that submitted data for the coating of textiles, foils and paper

Plant number	Substrate	Coating method
134	Woven textile polyester	PVC direct coating followed by varnish, no PU coating
135	Textile non-woven knitted	Transfer coating using transfer paper
136	Textile	Both direct and transfer coating
137	Foil and paper laminates, metallised paper and pure paper	Indirect
138	Textile	PU line and PVC line
139	Paper, plastic and other	Direct
140	Knitted textile	Indirect - coating line + lamination line
151	Woven textile	Direct
166	Knitwear	Transfer coating of knitwear with solvent-based PU
171	Woven textile for the production of conveyor and process belts	4 direct coating lines + 2 calenders with PU

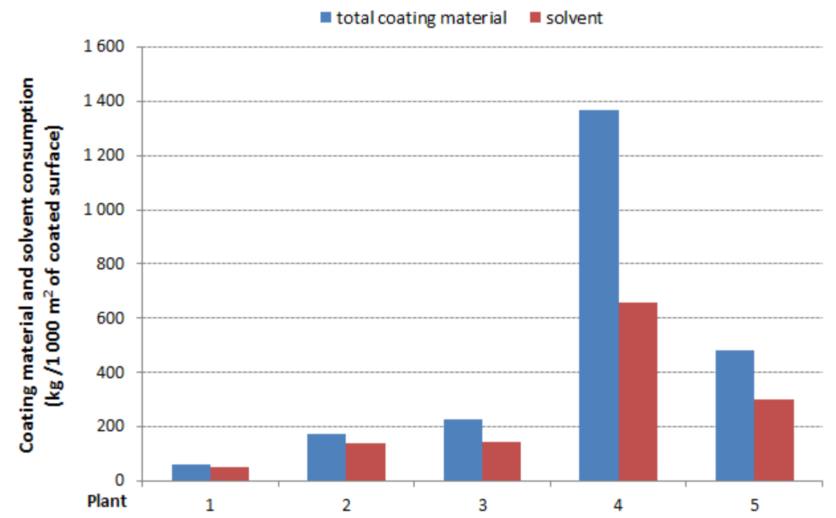
Source: [155, TWG 2016]

8.3.1 Consumption

[155, TWG 2016]

8.3.1.1 Coating material and solvent consumption

Available data for textile coating plants on total material (including coating adhesive and cleaning materials) and solvent consumption are presented in Figure 8.1.



Source: [155, TWG 2016]

Figure 8.1: Average values of total material (including coating adhesive and cleaning materials) and solvent consumption (per 1 000 m^2 of coated surface) for the period 2013-2015

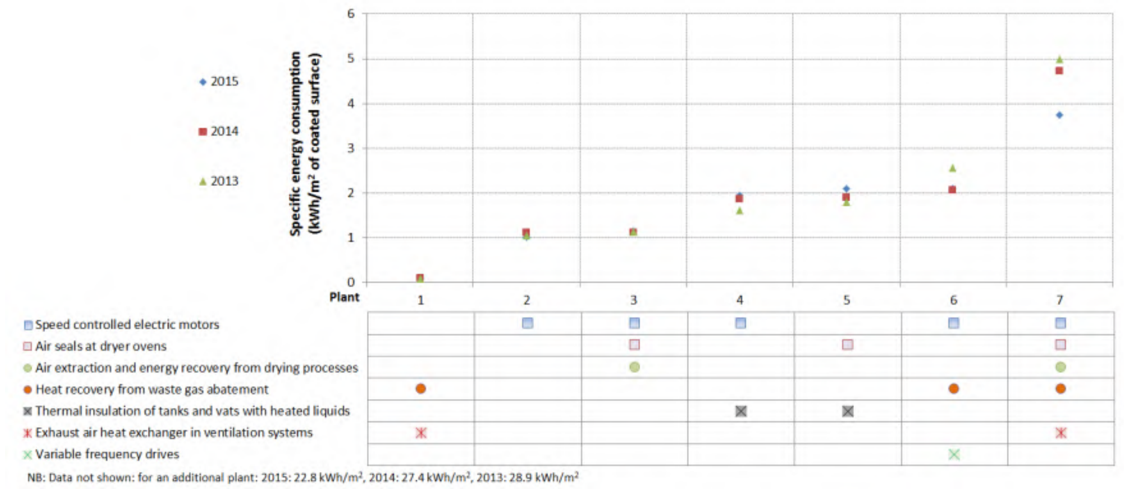
For paper coating, the coating material and solvent consumption are of the order of 1.1-1.5 kg/1 000 m^2 and 0.8-1.1 kg/1 000 m^2, respectively, as averages over the 3-year reference period (2013-2015).

8.3.1.1.1 Dimethylformamide (DMF) consumption

The reported figures for DMF use show that DMF represents a percentage share of solvent input that varies from 15 % up to 98 % depending on the process, the materials and the end-product specifications.

8.3.1.2 Energy consumption

The reported figures for specific energy consumption for textile coating vary from 1 kWh/m^2 up to 29 kWh/m^2 depending on the process and the substrate. For paper and/or foil coating, specific energy consumption values are in the range 0.1-2.6 kWh/m^2.



Plant	1	2	3	4	5	6	7
▢ Speed controlled electric motors		▢	▢	▢		▢	▢
☐ Air seals at dryer ovens			☐		☐		☐
● Air extraction and energy recovery from drying processes			●				●
● Heat recovery from waste gas abatement	●					●	●
☒ Thermal insulation of tanks and vats with heated liquids				☒	☒		
✳ Exhaust air heat exchanger in ventilation systems	✳						✳
× Variable frequency drives						×	

NB: Data not shown: for an additional plant: 2015: 22.8 kWh/m², 2014: 27.4 kWh/m², 2013: 28.9 kWh/m²

Source: [155, TWG 2016]

Figure 8.2: Specific energy consumption expressed in kWh per m^2 of coated surface for the period 2013-2015

8.3.2 Emissions

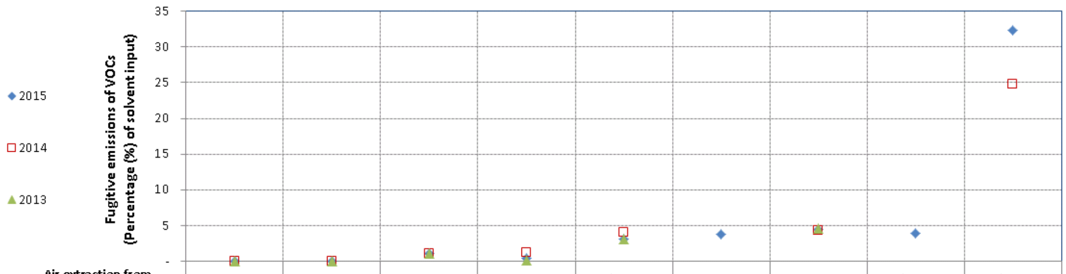
[155, TWG 2016]

8.3.2.1 Fugitive and total emissions of VOCs

In general, coating processes are well enclosed with air extraction and subsequent treatment via adsorption and/or regenerative thermal oxidation. As a result, submitted data show that fugitive emissions are kept below 5 % of the solvent input in all but one case (see Figure 8.3). The high value for only one installation is mainly related to the uncertainty on the calculation of the mass flow to the thermal treatment.

The main reported techniques for the limitation of total and fugitive emissions of VOCs are:

- air extraction from cleaning areas (pumps and doctor blades);
- increase of the VOC concentration of low concentrated off-gases by a rotor concentrator and treatment of concentrated off-gases by a RTO;
- safe storage of hazardous substances and measures to prevent unplanned releases;
- handling and use of hazardous materials;
- air extraction from drying processes and subsequent treatment;
- air extraction from the cooling zone and subsequent treatment;
- air extraction of tank breathing from mass storage tanks, benzene tanks and the distillation plant; extracted air is conducted to the off-gas treatment;
- air extraction from mixing tanks and the mixing area in general, and the container for distillation residue is conducted to the off-gas treatment;
- air extraction from the cleaning materials (cloths etc.) container and subsequent treatment;
- enclosed application zones with air extraction;
- maintenance of production hall (building) underpressure and air extraction and treatment;
- use of water-based coatings;
- use of alkaline-based washing machines for both rolls and parts cleaning.



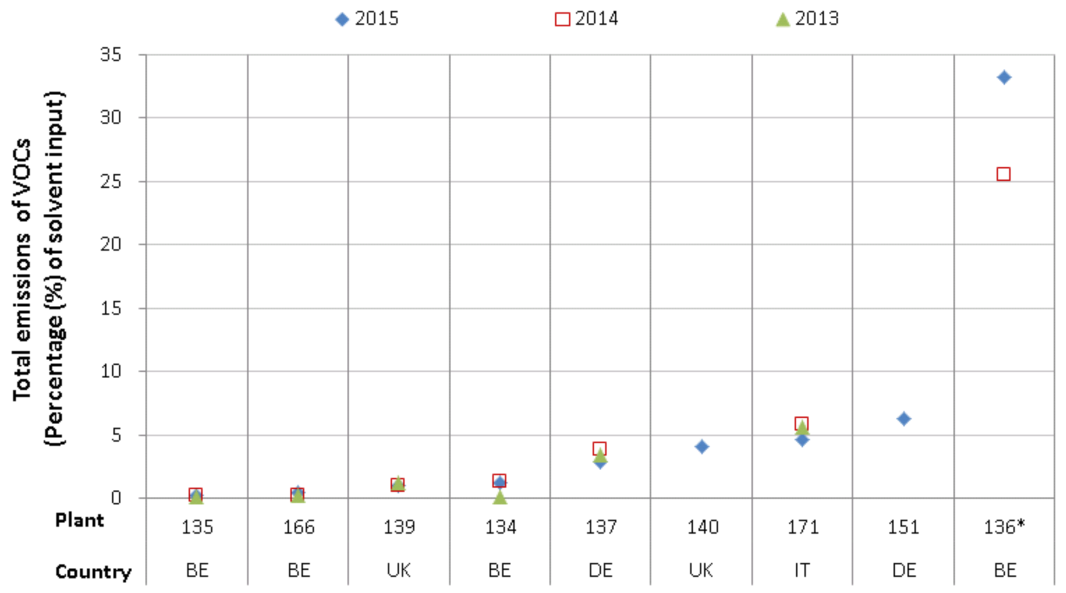
Air extraction from	Drying	Preparation - application	Preparation - application - drying	Drying	Application - drying - cleaning	Mixing - application - drying	Preparation - application - drying - cooling	Application - tanks - transfer	Application - drying
Machine encapsulation	Open	Open	Fully 4/4	Open	Half-closed	Partly	Fully(4) - open(2)	Fully 4/4	Open
Number of machines	2	2	4	1	1	2	6	4	2
Year of current layout	2013	2011	1985-2004	1998	2013	2000	2006	2014	2015
Plant	135	166	139	134	137	140	171	151	136*
Country	BE	BE	UK	BE	DE	UK	IT	DE	BE

* For #136, it was reported that F percentage is in reality below 20%, but there are not enough data to calculate in correct way due to uncertain mass flow to after burner.

NB:
Machine encapsulation - Open: in open production hall; Fully: fully enclosed; Partly: partially enclosed.
Source: [155, TWG 2016]

Figure 8.3: Fugitive emissions of VOCs expressed as percentage of the solvent input for the period 2013-2015

As a result of the proper enclosure of the process, the air extraction from the solvent-related processes and subsequent treatment, total emissions of VOCs (which are presented in Figure 8.4) are only slightly higher than fugitive ones. With only one exception, all reported percentage values are below 6 %.



* For #136, it was reported that F percentage is in reality below 20%, but there are not enough data to calculate in correct way due to uncertain mass flow to after burner.

Source: [155, TWG 2016]

Figure 8.4: Total emissions of VOCs expressed as percentage of the solvent input for the period 2013-2015

8.3.2.2 TVOC emissions in waste gases

The reported values of TVOC emissions in waste gases expressed in mg C/Nm^3 are presented in Figure 8.5. The abbreviations used in this figure are explained in Table 8.2.

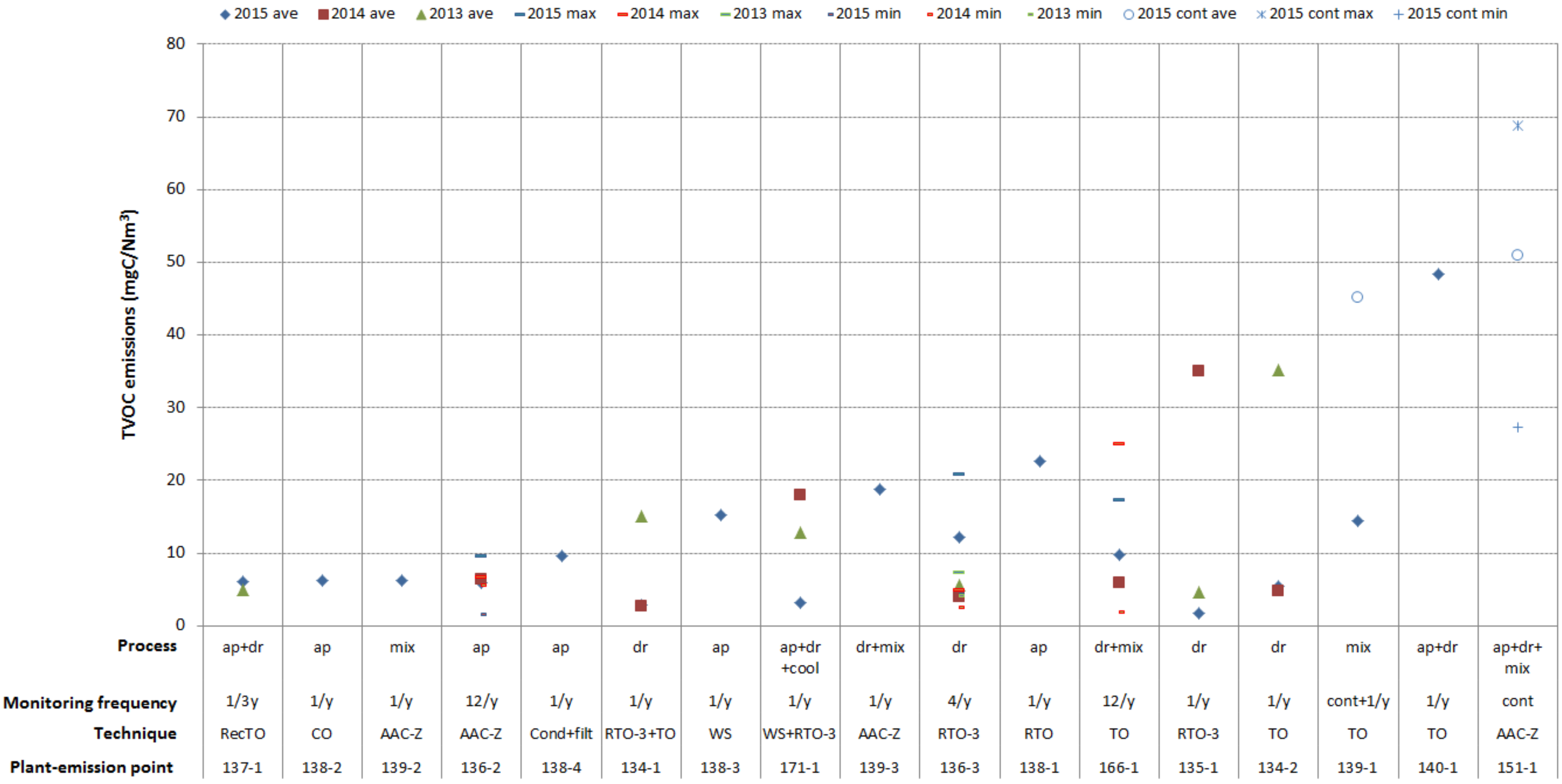
Only two values for continuous monitoring of TVOC emissions were reported. For periodic monitoring, the monitoring frequency varies from once a month up to once every 3 years.

In general, most of the reported maximum values are below 25 mg C/Nm^3.

Table 8.2: Explanation of abbreviations used for type of process

Term	Definition
ap	Application
dr	Drying
mix	Mixing process and area extraction
cool	Extraction from the cooling area

.



NB: #136-2: data for 2016 instead of 2014 / #136-3, #134-1 and #134-2: data for 2016 instead of 2013

Source: [155, TWG 2016]

Figure 8.5: TVOC emissions in waste gases for the period 2013-2015

The basic statistical parameters of the reported data for monitoring of TVOC emissions in waste gases for the reference period 2013-2015 are presented in Table 8.3.

Table 8.3: Statistical parameters of reported data for periodic monitoring of TVOC emissions in waste gases for the period 2013-2015

Applied technique	2015				2014				2013			
	No of values	Average	Max.	Min.	No of values	Average	Max.	Min.	No of values	Average	Max.	Min.
		mg C/Nm^3				mg C/Nm^3				mg C/Nm^3		
TO	4	19.5	48.4	5.5	2	5.4	6.0	4.8	1	35.2	NA	NA
RecTO	1	6.1	NA	NA	NA	NA	NA	NA	1	5.0	NA	NA
RTO	1	22.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
RTO-3	2	6.9	12.1	1.7	2	19.5	35.1	4.0	2	5.2	5.6	4.7
RTO-3+ TO	1	2.9	NA	NA	1	2.7	NA	NA	1	15.1	NA	NA
WS+ RTO-3	1	3.1	NA	NA	1	17.9	NA	NA	1	12.9	NA	NA
WS	1	15.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CO	1	6.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AAC-Z	4	20.5	51.0	5.9	1	6.4	NA	NA	NA	NA	NA	NA
Cond+filt	1	9.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NB:
NA: Not applicable/available.
Source: [155, TWG 2016]

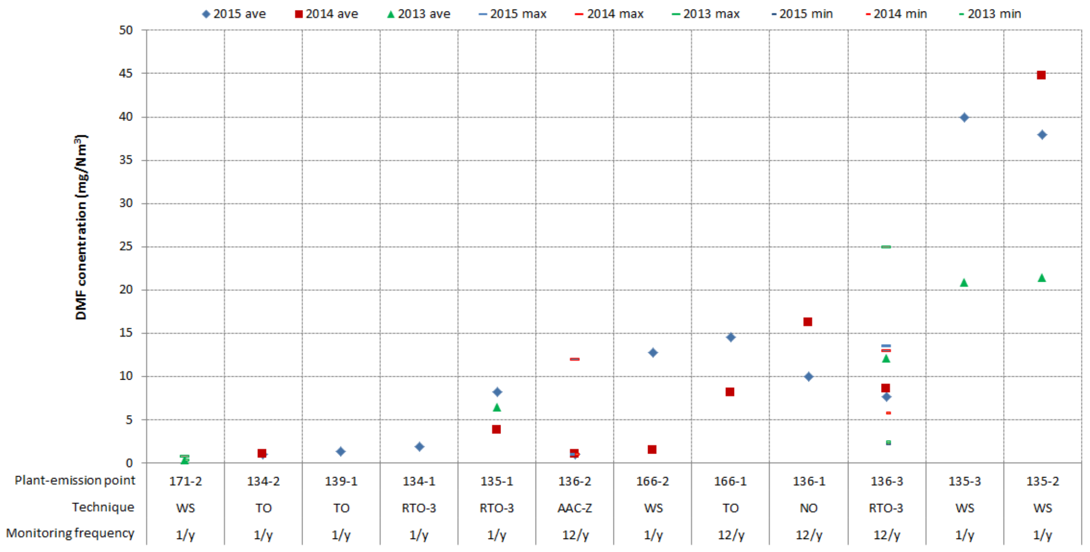
8.3.2.3 DMF emissions in waste gases

[155, TWG 2016] [212, TWG 2018] [220, Belgium 2018]

The reported values for DMF emissions in waste gases are presented in Figure 8.6.

From the analysis of submitted data and the contextual information, the following aspects may be considered:

- high values of DMF emissions are measured at installations in Flanders, Belgium at which, since 2015, a new monitoring standard prescribed by the regional competent authority (see following paragraph) is applied;
- different interpretation of the monitoring standard as well as different monitoring frequencies apply in various countries.



NB: #136-1 & #136-2: instead of 2014, data for 2016, #136-3: instead of 2013, data for 2016, #171-2: instead of 2013, data for 2012

Source: [155, TWG 2016]

Figure 8.6: DMF emissions in waste gases for the period 2013-2015

The reported DMF emission values and contextual information on DMF monitoring are presented in Table 8.4.

Table 8.4: DMF emission values and contextual information on DMF monitoring

Plant-Emission point	**Related process**	**Applied technique**	**Monitoring method**	**Monitoring frequency**	**DMF concentration (mg/Nm^3) - Periodic monitoring**								
					2015			**2014**			**2013**		
					Ave.	**Max.**	**Min.**	**Ave.**	**Max.**	**Min.**	**Ave.**	**Max.**	**Min.**
171-2	Coating line (application area, ovens, cooling area)	WS	Internal method 065:2010 Rev.0	1/yr	NA	NA	NA	NA	NA	NA	0.4	0.8	0.4
134-2	Dryer oven's varnish unit	TO	LUC/IV/010	1/yr	1	NA	NA	1	NA	NA	NA	NA	NA
139-1	All process emissions (solvent-based)	TO	TGN M22	1/yr	1.4	2	1	NA	NA	NA	NA	NA	NA
134-1	Dryer ovens direct coating	RTO-3	LUC/IV/010	1/yr	1.93	NA	NA	NA	NA	NA	NA	NA	NA
135-1	Dryer ovens transfer coating	RTO-3	NI	1/yr	8.18	NA	NA	3.77	NA	NA	6.46	NA	NA
136-2	Extraction application zone	AAC-Z	LUC/IV/010	12/yr	1	1	1	1	12	1	NA	NA	NA
166-2	2x2 ovens	WS	LUC/IV/010	1/yr	12.8	NA	NA	1.5	NA	NA	NA	NA	NA
166-1	2x1 ovens / air of the production room and kitchen	TO	LUC/IV/010	12/yr	14.6	NA	NA	8.13	NA	NA	NA	NA	NA
136-1	Paste preparation and mixing	NO	LUC/IV/010	12/yr	10	NA	NA	16.2	NA	NA	NA	NA	NA
136-3	Ovens, transfer coating and direct coating	RTO-3	LUC/IV/010	12/yr	7.63	13.6	2.28	8.61	13	5.73	12.1	25	2.5
135-3	Wet scrubber 2	WS	NI	1/yr	40	NA	NA	0	NA	NA	20.9	NA	NA
135-2	Wet scrubber 1	WS	NI	1/yr	38	NA	NA	44.7	NA	NA	21.4	NA	NA

NB:
NA: Not applicable/available.
NI: No information (contextual) provided.
Source: [155, TWG 2016]

Flemish measurement method for DMF

The Flemish measurement method for DMF (LUC/IV/010) is based on the European TS 13649, but elaborates further on the risk of condensation. TS 13649 states that in case of risk of condensation (i.e. 'when the concentration of water or solvent is high enough to cause the risk of condensation'), either dilution or a condensate trap should be used. In the case of DMF, due to its high solubility in water, the concentration of water or solvent is high enough to cause the risk of condensation. Additional monitoring data from installations in Belgium show that, in order to capture the component sufficiently, either dilution or a condensate trap may be necessary. The Flemish measurement method (LUC_IV_010) prescribes specific criteria for the water content; in the event that these criteria are exceeded, one of both methods (dilution or a condensate trap) need to be used[31].

Information on the results of a technical test that was performed at the request of the Flemish environmental inspection agency where both methods were used (either based on dilution or based on a condensate trap) showed that the results were comparable. For the condensate trap method, the total DMF emission is the sum of the concentrations that are present in the respective partial samples (being carboxen trap and condensate trap).

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[31] Due to solubility of DMF in water, either a dilution or a removal of water via condensation in a cooled washbottle must be performed when the following criteria are not met: [T_{dew} off-gas < T environment – 2 °C] and [T_{dew} off-gas < 18 °C].

Additional information from Belgium on recent DMF monitoring campaigns (anonymised data) indicates that the share of DMF that could be found in the condensate phase is on average 68 % of the total DMF concentration while for individual measurements it could be as high as 99 % of the total [BE comment #85 in [212, TWG 2018]].

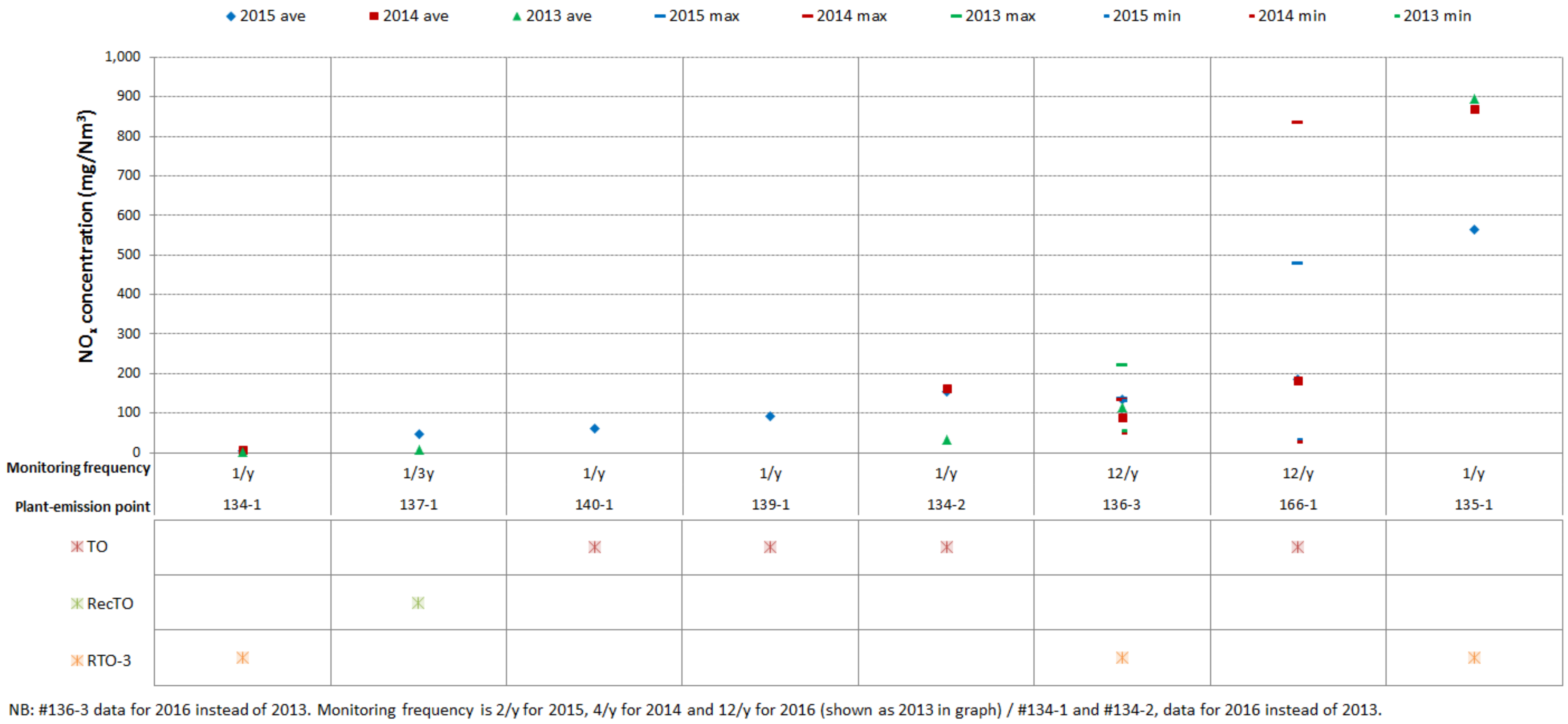
8.3.2.4 NO_X and CO emissions in waste gases

Nitrogen oxides (NO_X) and carbon monoxide (CO) emissions result from the thermal oxidation of off-gases. In addition, when nitrogen-containing solvents are used (e.g. DMF), the NO_X level may be elevated due to the chemical NO_X production.

Data for eight monitoring points (from seven plants) were reported for NO_X and CO emissions in waste gases with monitoring frequencies varying between once every month and once every 3 years.

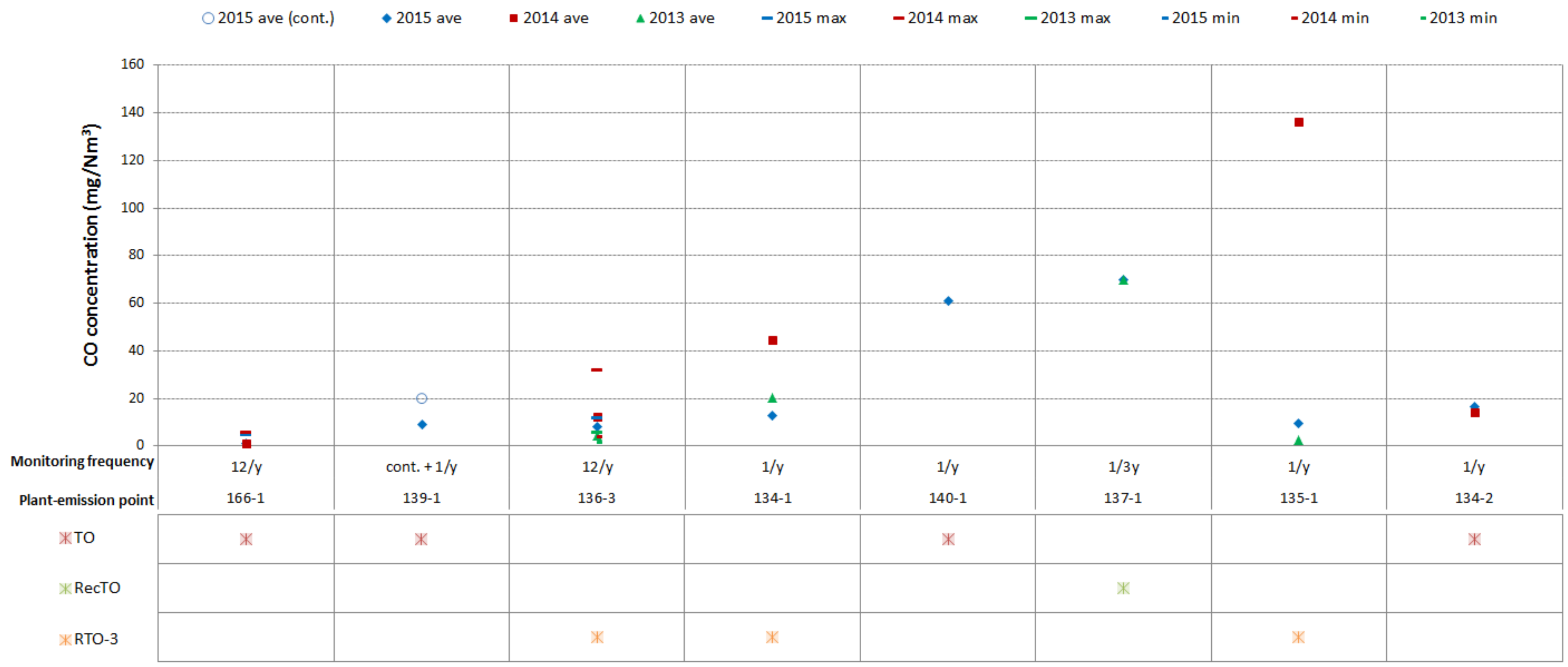
The reported values for periodic monitoring of NO_X and CO emissions in waste gases are presented in Figure 8.7 and Figure 8.8.

Additional anonymised data (93 data sets) for five plants from Belgium covering the period 2012-2017 show a maximum NO_X level of 837 mg/Nm^3 and an average of 157 mg/Nm^3. For CO, 30 data sets for five plants from Belgium covering the period 2012-2017 show a maximum CO level of 16 mg/Nm^3 and an average of 7 mg/Nm^3 [220, Belgium 2018].



Source: [155, TWG 2016]

Figure 8.7: NO_X emissions in waste gases for the period 2013-2015 (periodic monitoring)



NB: #136-3 data for 2016 instead of 2013. Monitoring frequency is 2/y for 2015, 4/y for 2014 and 12/y for 2016 (shown as 2013 in graph) / #134-1 and #134-2, data for 2016 instead of 2013.
Data not shown for #134-2: 831 mg/Nm³

Source: [155, TWG 2016]

Figure 8.8: CO emissions in waste gases for the period 2013-2015 (periodic monitoring)

8.4 Techniques to consider in the determination of BAT for the coating of textiles, foils and paper

In Chapter 17, techniques are discussed which might also be applicable to coating of textiles, foils and paper. In Table 8.5, the general techniques relevant for textile, foil and paper coating that are described in Chapter 17 are shown. These techniques are not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 17.1.

The EGTEI background document for other coating sectors (see Annex 21.3.1) gives some data on the costs and benefits of some techniques to reduce VOC emissions at the European level. However, the EGTEI approach necessarily has to limit its complexity, and only key techniques are given without consideration of the other BAT factors, such as cross-media effects, or of the technical characteristics of individual installations.

Table 8.5: Reference to techniques generally applicable to the sector

Technique	Section number
Environmental management techniques	17.1
Storage and handling of raw materials	17.2
Monitoring	17.3
Water use and waste water generation	17.4
Energy management and energy efficiency	17.5
Raw material management (including substitution)	17.6
Coating processes and equipment	17.7
Drying and/or curing techniques	17.8
Cleaning techniques	17.9
Off-gas extraction and treatment	17.10
Waste water treatment techniques	17.11
Waste management techniques	17.12
Odour emissions	17.13

8.4.1 Material-based techniques

8.4.1.1 Substitution of CMR substances

For general information, see Section 17.6.1.

Description
High-solids, fine-particle polyurethane (PU) dispersions (water-based with a solids content up to 60 %) can be used as polyurethane dispersions for synthetic leather manufacturing.

Technical description
During this process, air is intensively incorporated into a water-based PU dispersion to produce foam. Foams are produced at various densities (200-800 g/l) depending on the amount of air entrapped. Stabilisers, thickeners, cross-linking agents and pigments are added to the foam as needed.

Achieved environmental benefits

- No use of CMR, VOC substances and of solvents in general.
- Reduced energy and water consumption as smaller amounts of water have to be evaporated.

Technical considerations relevant to applicability
At present, this technique has only been used for artificial leather production. In terms of the properties of the resulting synthetic leather, water-based formulations have been tested as polyurethane dispersions for synthetic leather manufacturing but the products did not fulfil mechanical and chemical resistance requirements.

Tests carried out for the production of other textile types showed that products did not fulfil the relevant specifications, e.g. chemical resistance to cleaning and disinfection, thermoplastic behaviour.

Reference literature
Substitution support portal: http://www.subsport.eu/

8.4.1.2 Use of water-based coatings

For general information, see Section 17.7.2.2.

Example plants
Plant #137 in [155, TWG 2016].

8.4.2 Off-gas extraction and treatment

Available techniques for the extraction of off-gases and minimisation of fugitive emissions are discussed in Section 17.10.2.

Extraction and treatment of air from the coating application point, oven/dryer, mixing room and cooling area is commonly applied.

The following off-gas treatment techniques are commonly applied:

- oxidation: recuperative, regenerative and catalytic oxidation, see Section 17.10.5;
- adsorption using activated carbon or zeolites, see Section 17.10.6.2;
- wet scrubbing, see Section 17.10.6.3;
- condensation, see Section 17.10.6.1.

Example plants
Widely applied. All plants that submitted information reported using one or a combination of those techniques (see Section 8.3.2.2).

9 MANUFACTURE OF WINDING WIRE

[82, EGTEI 2005] [148, COM 2009] [155, TWG 2016] [173, EWWG 2017] [212, TWG 2018]

9.1 General information on the winding wire industry

The manufacturing of winding wires involves a unique type of surface treatment using solvents; it basically involves the application of electrical insulation layers (enamels) onto the surface of a copper wire, although in some cases the conductor material may be a different metal like aluminium, copper-clad aluminium or brass. These insulation layers are applied for a variety of functional purposes, including a high and prolonged dielectric strength throughout the whole lifetime of the wire. The surface of round wires also needs a well-defined lubricant covering to ensure a good coiling performance and a smooth laying of the wire.

It should be noted that all information and emission values in all specific winding wire sections are given for copper winding wires, because of their predominant market share. In the case of aluminium wire manufacturing, all specific emission limits and achievable emission figures need to be adapted according to the smaller specific weight of the product using a conversion factor according to the ratio of the specific weights of copper and aluminium.

Table 9.1 gives figures for the production of enamelled wires in Europe over the period 1970 to 2010 and the correlated use of organic solvents.

Table 9.1: European production figures for enamelled wires and the correlated consumption of organic solvents from 1970 to 2010

Year	Production (t)	Consumption of organic solvents (t)	Specific consumption of organic solvents (t/t)
1970	150 000	11 250	0.075
1990	286 000	20 020	0.070
2000	390 000	25 350	0.065
2006	420 000	21 000	0.050
2010	350 000	17 500	0.050

Source: [173, EWWG 2017]

According to ESIG[32], the total consumption of hydrocarbon solvents in Europe was about 2.3 million t/yr for the EU-27 in 2009. From Table 9.1, it can be estimated that the share of the winding wire industry is about 0.8 % of this.

The European winding wire industry comprises about 20 installations and nearly 3 000 workers. A typical installation falling under IED Annex I has 50 to 250 employees, with most being family-owned.

As electric and electronic products are manufactured and sold worldwide, the winding wires used in these products are manufactured according to international standards. Insulating materials are classified in the technical terms of delivery in the EN 60317 standard series. As a consequence, the wires are manufactured to the customer's specifications for their approved type of product, and the manufacturer is not free to select the type of coating. Winding wires can be produced in many hundreds of dimensions, but they are generally grouped as follows.

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[32] ESIG - European Solvents Industry Group, Solvent VOC inventories for EU (2013).

Table 9.2: Groupings of round winding wire types in respect to diameters

Wire type	Diameter above (mm)	Diameter up to and including (mm)
Ultrafine wires	-	0.040
Fine wires	0.040	0.10
Medium wires	0.10	1.0
Thick wires	1.0	6.0
Source: [173, EWWG 2017]		

Additionally there are rectangular shaped winding wires which range from small sizes to big sizes of about 80 mm^2.

Apart from the diameter of the produced round wires and the shape/cross-section of flat wires, there are other factors influencing emission data. The most important of these factors are: the grade of the wire; the thickness of enamels; conductor materials; round or flat wire geometry; the wire quality such as solderable wires, self-bonding wires; the lubrication amount and its application process; the enamel application method such as dies or felts; the solids content of different enamels; the types of solvent contained in enamels; oven temperatures and geometries; machine technology; enamel types; usage of primers; specific product properties, such as tanDelta; the number of product changes, size of lots, type of enamelling machine, i.e. horizontal vs vertical.

9.1.1 Product characteristics and end use applications

The enamelled wire is useful for its very thin, high-specification insulating film, which allows close-packed and energy-efficient winding wires to be produced, which can operate at high temperatures. The insulation consists of one or more layers of enamel or tape(s) or a combination of both. The choice of the insulation material and its thickness results in typical electrical properties like breakdown voltage, loss factor, corona resistance, partial discharge behaviour. The thermal stability of the wire coating materials is characterised by a temperature index. Other specific requirements for insulating coating systems for wires are mechanical strength, chemical resistance, and overload current stability. Contemporary electrical insulating systems already meet these requirements with thin layers (see CENELEC Standard EN 60317 series for details). Electrical properties especially make winding wires a unique product not comparable with other products within the scope of this document.

The main use of winding wire is in magnetic wires in windings and coils. These are used in a wide range of applications such as miniature coils for medical devices, entertainment electronics (microphones, audio and video heads, etc.), ultrafine wires in watches, and as windings for electrical motors, relays and power transformers. In electrical equipment, the winding wires operate under voltage and conduct currents. The electrical insulation directly affects the functionality and also the safety of the equipment. The electrical properties of the insulation material and the application systems is an essential point to consider when discussing BAT.

During the last few years, many attempts have been made to introduce alternative insulating materials and application systems in order to reduce the use of solvents. Many of these have failed because of insufficient insulation properties, although there are some semi-successful niche products, e.g. using cresol-free enamels and extrusion coating. However, these have not yet been taken up as standard practice.

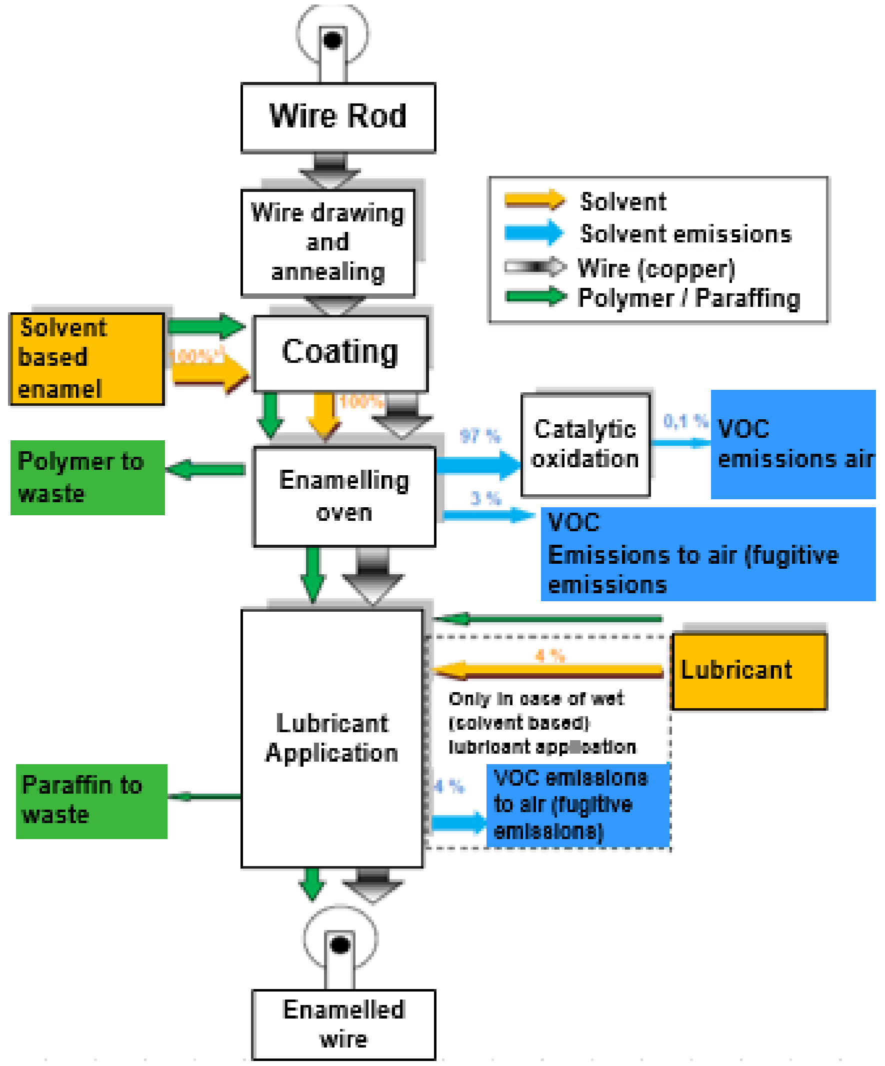
9.2 Applied processes and techniques in winding wire manufacturing

[82, EGTEI 2005] [148, COM 2009] [155, TWG 2016] [173, EWWG 2017]

This is a small industry and in Europe there are only about four producers of the machines used to make winding wires. The same technology will therefore be found in nearly all installations. The manufacturing process for enamelled wires is generally linear: after the production of the bare copper wire by drawing or rolling, thermal cleaning or annealing of the bare wire is carried out, both of which are solvent-free processes. Enamel coating, drying and curing of the resin and then lubricant application are the following steps. Solvent use only occurs during enamel coating, and, depending on the specific process, lubricant application; drying and curing also gives rise to solvent emissions.

9.2.1 Typical manufacturing process for enamelled wires

A typical manufacturing process for enamelled wires is shown in Figure 9.1.



Source: [148, COM 2009]

Figure 9.1: Typical manufacturing process and flow chart for winding wire manufacturing

Rolling and drawing

These are deformation processes. Rolling is a continuous or stepwise forming process under compressive conditions. The material can be rolled at ambient or elevated temperatures. Wires for enamelled and other insulated winding wires are preferably manufactured by a drawing process. The wire is drawn through dies which reduce its size and extend its length. Fine wires require several drawing stages to reach the desired dimension. The drawing process applies tractive and pressure stress to the drawn material.

Annealing

The wire drawing process is followed by annealing where the wire passes through heated tubes (containing an inert atmosphere to prevent oxidation) and leading to recrystallisation and softening of the wire.

Enamel coating

The next process step is enamel application, followed by the drying and curing of the enamel film. The coating is normally applied to the moving wire by the following methods:

- Passing the wire continuously through a bath of enamel (with a solvent concentration of 50-80 %, depending on the product) and metering the amount by an accurately sized die to remove the surplus enamel. Each layer applied is typically 1-10 µm thick, depending on the wire diameter, to allow the solvents to evaporate as the wire moves through the enamelling oven. Typically 5 to 20 layers are applied onto the surface of the winding wire. Dies are cleaned with solvent before reuse.
- Dosed coating supply and felt application: the wire is pulled through a felt impregnated with a solvent-based coating. This technology is typically used for ultrafine and fine winding wires due to the gentle application. The felt has to be treated as waste afterwards.

Drying and curing

The coated wire then passes into the enamelling chamber, which consists of a heated chamber (horizontally or vertically arranged) where the solvent is evaporated before moving into a higher temperature zone (400-700 °C) where the film is cured. The wire may then go back into the coating circuit for an additional layer of coating. In this continuous coating process, up to 30 applications of enamel may be applied until the desired layer thickness is obtained.

Recirculated airflow ovens are in use for contemporary wire coating processes. The direction of the recirculating airflow can be with or against the direction of the moving wire. Recirculating the airflow has the advantage that the vented volumes can be decreased. The solvent evaporation process leads to evaporation of the solvent and the air/solvent mix is usually treated in a catalytic oxidiser which ensures that residual solvent concentrations are below legal emission limits. The process heat from the thermal oxidiser can be used in the drying process for heating up the circulating airflow (loop).

In gas-heated machines, solvent-laden air is passed directly into a gas burner, where the design of the burner allows intimate mixing of the secondary air and oxidation occurs. To ensure that the solvent concentration does not rise beyond the lower explosive limit, it is important that excess air is supplied.

Using electrical heating, the solvent-laden air is passed over heating elements to reach a temperature in excess of 500 °C. This is generally sufficient to support the catalytic oxidation. The efficiency of oxidation is sufficient to ensure that VOC emission limit values are always achieved. After the process-inherent thermal or catalytic oxidation of the solvents, the air stream is recirculated to provide complete or partial heating of the enamelling chamber. Exhaust gas velocities may be lower than in other industries to ensure a maximum energy efficiency balance from the use of recirculated air. It is important that any oxidation takes place where the air stream is recirculated. Oxidation in the stack will produce only hotter exhaust air.

Contemporary ovens in use for very fine enamelled wires work with heat transfer by radiation or a combined radiation and circulating airflow/convection.

The enamelling chamber is typically maintained under sub-atmospheric (negative) pressure to allow the capture of any fugitive emissions from the enamel supply system and to prevent any degradation products or products of combustion from entering the workplace air.

Lubricant application

Depending on the final product requirements, the enamelled round wire may be lubricated before being wound onto a reel. Several lubricants contain different volatile organic solvents.

The lubricant layer is necessary for the coil winding operation. Too little or too much lubricant makes the winding wire sticky and prevents close coiling. The lubricant film is nearly mono-molecular with about 30-60 mg/m^2 of lubricant applied for medium or thick round wires and 5-10 mg/m^2 of lubricant applied for ultrafine and fine round wires with a diameter below 0.10 mm.

The solvent-based lubricant cannot be dried in the enamelling oven as the wax would burn off at such high temperatures. Therefore drying takes place at room temperature in a non-enclosed area (required drying distance ~ 10 m). Extraction and subsequent treatment of these large quantities of air with low VOC concentrations (50-100 ppm) and temperature may be very inefficient and energy-consuming. The solvent from the lubricant accounts for about 60 % of the fugitive emissions from the process as a whole. In the case of rectangular wires, no lubrication takes place [148, COM 2009].

Typically paraffin is applied with an organic solvent content from 98 % to 99.9 %. Lubricants, as concentrated emulsions, with a solvent content of between 50 % and 95 %, water-based emulsions or even solvent-free hot melts are also used, though with limited success. Regarding the use of solvent-free alternatives, customer quality requirements related to the thickness and evenness of the lubricant film have to be respected. The lubricant is generally specified by customers. Generally, it can be stated that high quality requirements and thin wires are less appropriate for solvent-free lubricants. Wherever possible, customers should be encouraged to use products such as self-lubricating enamels or solid wax.

An alternative to solvent application may be the application of a molten solvent-free lubricant onto the wire surface by a lubricant-wetted felt or by applying onto the finished enamelled wire a lubricant filament that melts due to the residual heat of the wire. The latter technique applies the lubricant by looping the filament two or three times around the enamelled wire and moving it in the same direction as the wire, although at a lower velocity. Both techniques are not yet suitable for applying lubricants to ultrafine and fine wires with diameters of less than 0.1 mm.

9.3 Current consumption and emission levels in winding wire manufacturing

[155, TWG 2016]

Data for seven winding wire manufacturing plants were received in the data collection and they are analysed in the following sections.

9.3.1 Consumption

[4, Germany 2002] [19, Austria 2003] [40, EWWG 2004] [155, TWG 2016]

The range of diameters of the wires produced (between 0.01 mm and 6.0 mm) results in a large variation between production quantity (tonnes of wire) and product surface coated (m^2). As a consequence, the technologies and varnishes applied for fine wires are different to those for larger-diameter wires.

Reported data on raw material consumption show an average solvent consumption between 70 kg and 80 kg per tonne of copper. It is noted that there may be significant differences among plants due to the different types of wires produced.

An installation for producing winding wire is made up of several machines. Usually the machines of an existing plant correspond to different technical grades that may have an influence on the overall emissions from the installation. Important parameters in this context are:

- the technology applied at each single machine;
- the wire diameter that is produced;
- the quality that is produced.

Generally, fine wires are associated with higher specific VOC emissions (calculated as g VOCs per kg of product) compared to thicker wires. This is due to the product weight/product surface relationship and to the achievable share of VOCs in varnishes and lubricants. As an example: a wire with a diameter of 0.02 mm results in VOC emissions that are four times higher than those generated by a wire with a 0.1 mm diameter. Analysis of measurements in fine wire and ultrafine wire installations shows disproportionately high VOC emissions from both lubricant application and from the enamelling process for specific application techniques with a very high solvent content [4, Germany 2002] [38, TWG 2004] [40, EWWG 2004].

The process steps in the application of solvents are the coating including the drying/curing of the coating, and the application of the lubricant.

9.3.1.1 Coatings

Typical solvents for enamels (coatings) are n-methyl-pyrrolidone (NMP), naphtha and other aromatics, e.g. cresols (cresylic acid) with xylol as a diluent. These solvents all have very low evaporation rates. The creosol isomers for example have an evaporation rate which is 40 to 100 times lower than butyl acetate. Cresol and n-methyl-pyrrolidone are very strong solvents and typically used to dissolve high-molecular-weight polymers, which are necessary to achieve high-temperature-resistant coatings. Propylene carbonate, which has a lower toxicity potential, might be used as an alternative to cresol [148, COM 2009]. Cresol application may result in odour nuisance, therefore appropriate extraction and good housekeeping (see Section 17.2) are necessary to limit odour emissions.

Table 9.3 shows the different coating systems applied and their average solvent content in relation to the type of winding wire produced. The coating systems that are marked with an asterisk (*) contain n-methyl-pyrrolidone (NMP) as the volatile organic compound. NMP (CAS number: 872-50-4) is classified according to the harmonised classification and labelling process as a substance that may damage the unborn child, causes serious eye irritation, causes skin irritation and may cause respiratory irritation.

In addition, the classification provided by companies to ECHA in REACH registrations identifies that this substance may damage fertility or the unborn child. Reported data on NMP consumption are presented in Table 9.4.

For many years there has been an ongoing discussion with the suppliers of NMP-requiring enamel systems, on replacing NMP with non-nitrogen solvent. This has been tried in different ways, but the results have not been technically acceptable up until now. For the insulation systems mentioned, the use of NMP is unavoidable today and in the near future according to enamel manufacturers. The market for the electromagnetic components using enamelled wires needs to be aware of the requirements of technical and security specifications, products for which the insulation has to meet the requirements of high thermal, mechanical and electrical performance specified in the thermal class.

Table 9.3: Main winding wire products and applied coating systems

Product	Insulating coating system	Share of total production (%)	Average solvent content (%)
Solderable round wires	Polyurethane	13	65-80
High temperature round wires	Epoxy, polyester, polyamide, polyimide, polyester-imide with additional polyamide-imide layers (*)	70	55-75
Self-bonding round wires	As above (first and second lines in this table) with additional bonding layers of aliphatic or aromatic polyamide (*)	11	55-75
Rectangular wires	Depending on temperature class: polyvinylacetal, polyester-imide, polyamide-imide with an additional bonding layer (*)	6	60-80
	Total	**100**	**55-75**

* Coating systems may partially contain NMP (n-methyl-pyrrolidone) as a VOC.
Source: [4, Germany 2002] [38, TWG 2004]

The solids content of wire coatings usually varies between 20 % and 45 %; the remaining 55-80 % is organic solvent. For ultrafine wires, (with diameters in the 10 micron range) high solvent contents of up to 75 % are necessary, whereas with increasing wire diameters less solvent is needed in the coating application, i.e. around 55 %. The choice of solvent for the coating application depends on the coating type.

Currently, a handful of possible alternative coating techniques have been developed:

- hot-melt coatings;
- medium- and high-solids coatings;
- cresol-free coatings;
- water-based coatings;
- electrocoat applicable coatings;
- two-component coatings;

- powder polyester coatings;
- UV-cured coatings;
- extrusion coatings with thermoplastic materials.

However, for many reasons, such as lack of quality performance, as well as economical, technological or safety aspects, most of these alternatives have not yet overtaken the classical winding wire coatings.

Table 9.4: Reported levels of NMP consumption

Plant	2015 NMP input quantity (kg)	2014 NMP input quantity (kg)	2013 NMP input quantity (kg)	Remarks
#032	26 070-39 120	20 920-31 380	27 360-41 040	NMP content in the enamel is given in the safety data sheet as a range
#033	Small increase compared to data of 2013	Small increase compared to data of 2013	301 ± 46	No exact data known, individual recipe
#034	320 000-500 000	320 000-500 000	340 000-520 000	NMP content in the enamel is given in the safety data sheet as a range
#035	232 000	255 000	227 000	Estimation based on consumption of enamels and solvents based on range presented in safety data sheet
#142	3 990	-	-	-
#160	73 000-127 000	79 000-129 000	78 000-136 000	-
Source: [155, TWG 2016]				

9.3.1.2 Lubricants

Several lubricants contain different volatile organic solvents; however, paraffin (wax) is typically applied with an organic solvent content of 98-99.9 %. Alternatives such as concentrated lubricant emulsions, with a solvent content of between 50 % and 95 %, water-based emulsions or solvent-free hot melts, are also used, albeit with limited success.

For lubricants, white spirit is a commonly used solvent. No data on lubricant consumption have been made available.

9.3.1.3 Energy

[155, TWG 2016]

The energy consumption in a winding wire manufacturing installation is mainly electricity. Electrical energy is used for heating the curing ovens and running electric motors and ventilators.

For the manufacturing of winding wire, data were submitted as predefined ranges (i.e. < 5 kWh/kg of coated wire, 5-10 kWh/kg of coated wire and > 10 kWh/kg of coated wire). With the exception of only one installation that produces ultrafine/fine wires, all installations reported specific energy consumption values of less than 5 kWh per kg of wire. A Swiss installation that produces ultrafine and fine wires reported a specific energy consumption value greater than 10 kWh per kg of wire.

The main energy-saving efforts are focused on the enamelling process and on how the excess energy can be used. The main reported techniques for the reduction of energy consumption are:

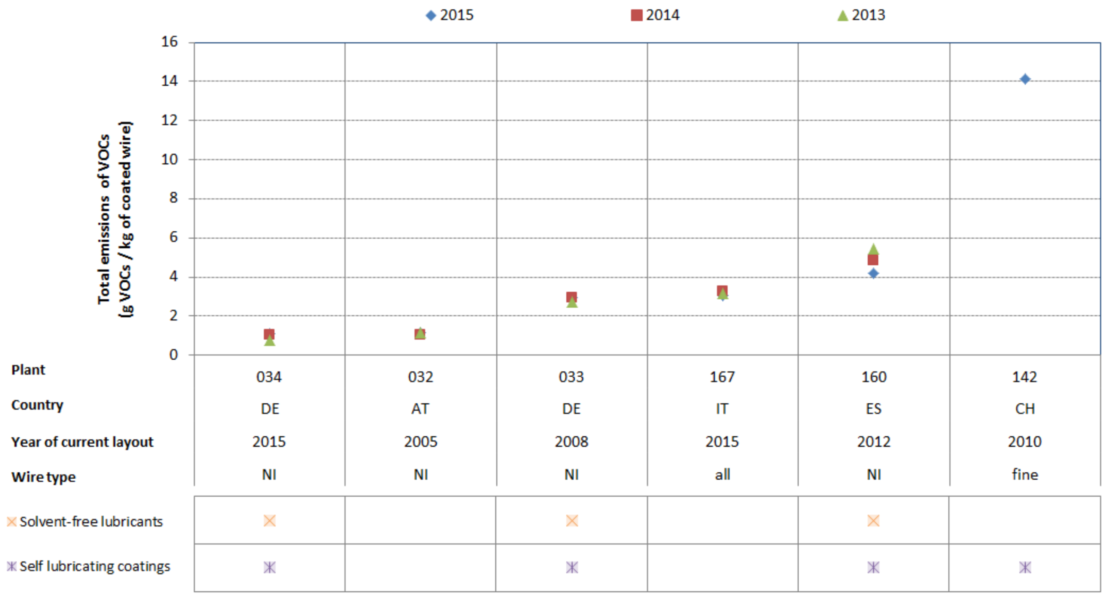
- exhaust air heat exchanger in ventilation systems (enamelling process fans);
- energy recovery from drying processes in the oven and cooling;
- variable speed electric motors.

9.3.2 Emissions

9.3.2.1 Total emissions of VOCs

[155, TWG 2016]

VOCs are the main emitted pollutant for the winding wire manufacturing process. Figure 9.2 shows the reported values of total emissions of VOCs expressed in g of VOCs per kg of coated wire.



Source: [155, TWG 2016]

Figure 9.2: Total emissions of VOCs expressed in g VOCs per kg of coated wire for the period 2013-2015

It should be noted that Plant #142 in Switzerland is producing ultrafine and fine wires (with diameters of less than 0.1 mm down to 0.01 mm and even below) and the specific emission values are expected to be higher than in medium and thick wire production plants.

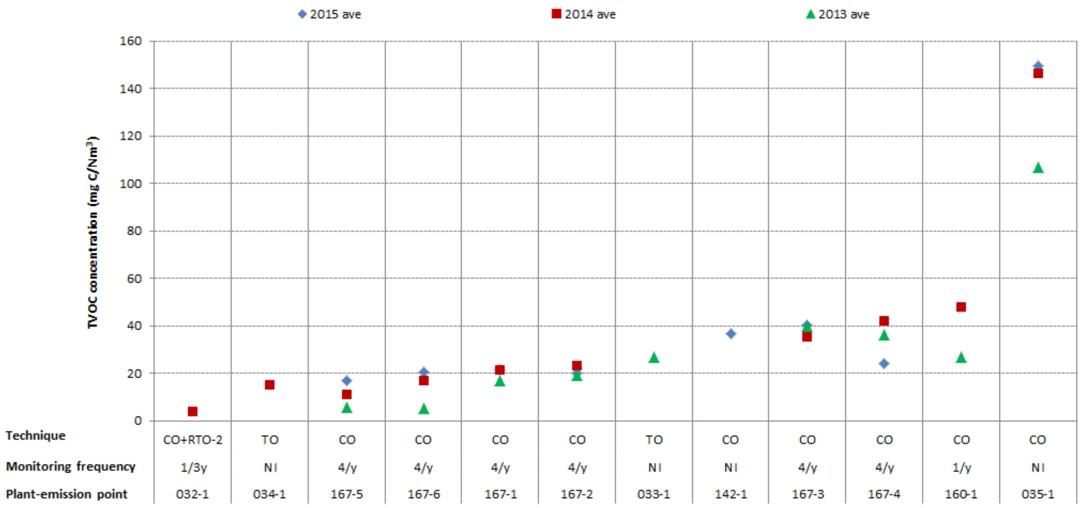
All reported values from plants producing thick wires or at least mixtures of fine (with diameters less than 0.1 mm) and non-fine wires (with diameters greater than 0.1 mm) are below the IED limit values of 5 g/kg of wire produced. Data from plants with a product mixture that contains thick, medium and thin wires show that specific emission values of the order of 3 g/kg are achievable.

Additional emission data for two plants submitted by industry indicate total emission levels in the range of 4.50-4.70 g VOCs/kg of coated wire for a Greek plant (data for the period 2015-2017) and a level of 3.63 g VOCs/kg of coated wire (data for 2017) for a Spanish plant [225, EWWG 2018].

9.3.2.2 TVOC emissions in waste gases

[155, TWG 2016]

Reported values of TVOC emissions in waste gases expressed as mg C/Nm^3 are presented in Figure 9.3.



Source: [155, TWG 2016]

Figure 9.3: TVOC emissions in waste gases for the period 2013-2015

All submitted data with only one exception are below 40 mg C/Nm^3. The best performance is seen for the plant #032 where regenerative thermal oxidation is applied in addition to the process-integrated catalytic oxidation of VOCs from the curing oven. It is also noted that these data refer to a sampling frequency of once every 3 years.

9.3.2.3 NMP emissions in waste gases

[155, TWG 2016]

N-methyl-pyrrolidone (NMP) emission data were reported for only one plant (Plant #034) with an average value for 2014 of 0.79 mg/Nm^3. It is noted that NMP is classified as a CMR substance (H360D) and, according to the IED (Article 58), shall be replaced as far as possible by less harmful substances within the shortest possible time. In addition and according to Part 4 of Annex VII to the IED, for installations at which the flow mass of the sum of compounds referred to in Article 58 is greater than or equal to 10 g/h, an emission limit value of 2 mg/Nm^3 shall be compiled with.

9.3.2.4 NO_X and CO emissions in waste gases

[90, EWWG 2006] [111, EWWG 2005] [155, TWG 2016]

Limited data (for four emission points) were submitted in the STS data collection for periodic monitoring of NO_X emissions in waste gases, with values varying from 17 mg/Nm^3 up to 470 mg/Nm^3 [155, TWG 2016].

Many attempts have been made to reach a low level of CO and NO_X emissions; however, running the enamelling machine efficiently and the destruction of VOCs are both prioritised.

For the abatement of NO_X, see also Section 17.10.8.

NO_X is produced as a result of the oxidation of VOCs in off-gases and gives rise to the cross-media conflict between abating VOCs and creating NO_X. One source of NO_X emissions is the direct result of oxidation of the nitrogenated solvents used in the production of certain enamel systems. The concentration of NO_X is proportional to the destruction of VOCs for the products that contain the nitrogen-containing solvents. Only a part of the nitrogen contained in NMP is converted to nitrogen oxides, at a ratio of 90 % NO and 10 % NO_2. The other major source of NO_X is the oxidation of atmospheric nitrogen during combustion of VOCs in the oven. When using enamels containing nitrogen, emission values of NO_X can be well over 150 mg/Nm^3 depending on the specific airflow conditions in the enamelling machine and the number of machines using solvents containing nitrogen. In other cases with different airflows and lower NMP usage on process machines, lower NO_X levels may occur. This is a common problem for all installations across Europe. Enamels based on nitrogen-free solvents, such as polyvinyl-acetal, result in wires of low heat class, and do not meet the specifications required by the customers that the polyamide-imide products attain. NO_X emissions after catalytic oxidation do not currently undergo treatment.

Table 9.5: Winding wires: Further examples of NO_X emissions

Installation(s)	Group of 34 enamelling ovens	Group of 165 enamelling ovens	Installation 1 enamelling	Installation 2
Short description	Exhaust gases collected in three tubes leading to one stack (flue) Special local conditions: industrial area, close to a power station	Exhaust gases collected by hoods over single sources in four stacks (flues), 35-50 m high. In order to avoid odour emissions (olfactory trouble with neighbourhood), a large amount of air from the production hall is extracted together with the gas from the oven. Sources are spread over an area of about 10 000 m^2. Special local conditions: mixed industrial and residential zone (climatic spa).	80 % of all product lines used NMP during measuring period. Dilution of the exhaust gas in the hood: 10 % from oven, 90 % from hall Estimation: 2/3 of the NO_X is caused by nitrogen contained in solvent input (NMP), 1/3 is caused by the thermal process.	Measurement on ventilator on the roof (ventilation of production hall and air from the cooling of the enamelling oven). NO_X emissions caused by small, uncontrollable process source. Number of fans: more than 100, spread over the production area of 10 000 m^2.
Volume flow rate (Nm^3/h)	3 700, 7 000, 34 500	53 600-98 000 in each of the stacks, average mean value: 68 480	60-810	-
Temperature (°C)	~ 80, gas temperature at the entrance of the stack	70-110, gas temperature at the entrance of the stack	250-550, temperature of undiluted exhaust gas at the source	30-45, temperature of air
Concentration (mg NO_X/Nm^3)	19, 60, 34	Average: 51.3	550-1 500, Average: 615	Average value: 12
Mass flow NO_X (kg NO_X/h)	-	Total: 14.07	Average: 0.0835 from a single source	Total: 4, mean single sources: < 0.040
Source: [90, EWWG 2006]				

The total amount of NO_X emitted by the industry is estimated to be between 1 kt and 2.7 kt per year (based on 2000 EUROSTAT figures).

***Carbon monoxide* (CO)**

Very little data (for four emission points) were submitted for periodic monitoring of CO emissions in waste gases, with values varying from 40 mg/Nm^3 up to 990 mg/Nm^3 [155, TWG 2016].

CO is formed by the partial combustion of the enamel components during catalytic oxidation in the enamelling machine. Carbon monoxide is a consequence of the destruction of solvent rather than of the burner efficiency. The concentration of carbon monoxide is dependent on the residence time within the burner rather than the burner being incorrectly set. If the combustion efficiency is increased, the CO emissions would be reduced, but with a corresponding increase in CO_2 and NO_X emissions.

An enamelling machine is not controlled according to CO emissions but according to completely different conditions, and these are as follows:

- Ensuring the correct temperature within the enamelling machine in order to achieve the optimum properties from the enamel film. Increasing the burner temperature would require dilution air to reduce the temperature in the enamelling chamber overall. This would require a greater amount of energy and is not considered to be the best environmental option.
- Using excess air to prevent the lower explosive limit from being exceeded and so preventing explosions within the machine. Reducing the airflow to increase the residence time is therefore not an option.

Attempts have been made to limit the emission of carbon monoxide by using secondary catalysts; however, complying with the emission limits will remain an issue because of the relatively short life of the catalysts and the corresponding financial implications.

9.3.2.5 Dust emissions in waste gases

As the films applied to the wire are extremely thin (in the order of 10 µm) any dust present in the enamelling process would cause very serious surface quality problems. As any emission to the air is only a portion of the recirculated air, no dust emissions are expected.

9.3.2.6 Emissions to water

The water used in a winding wire plant is normally used in closed circuits. There are not emissions to water from the enamelling process; however, overall water use should be kept as low as possible and this is commonly done by:

- minimising the flow through cooling baths and recycling the water through filters and de-ionisers when practicable;
- using conductivity meters to optimise the treatment and conserve water in cooling towers;
- prolonging the life of water-based wire drawing lubricant emulsions by using filtration, centrifugation where practicable and ensuring efficient management of the lubricant to prevent premature ageing by stagnation and bacterial degradation.

9.3.2.7 Waste generation

[78, TWG 2005] [155, TWG 2016]

The main sources of waste are from the drawing process and in the enamelling stage of winding wire production.

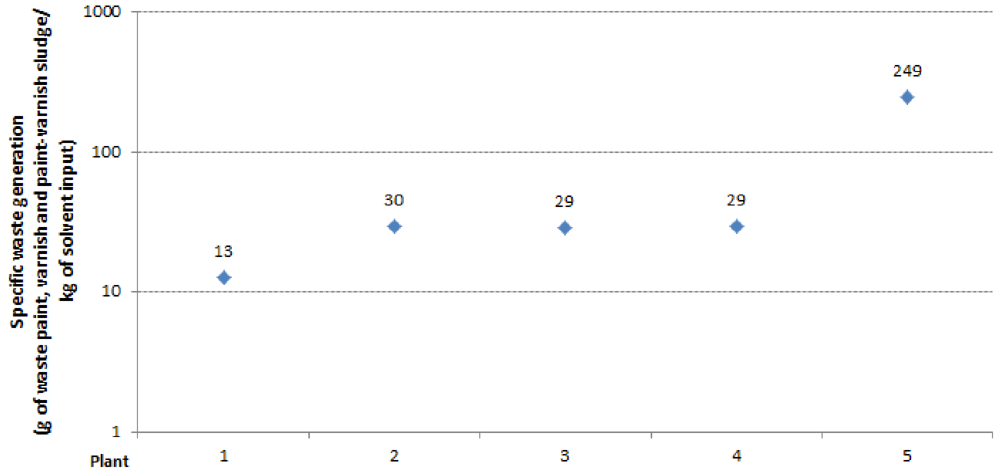
Drawing

- The drawing emulsion is used in a closed-loop system; it is continuously cleaned using a paper filter or a hydrocyclone separator. In order to reduce waste amounts, emulsion treatment (reconditioning) is carried out with demineralised water; water is evaporated during the process and waste amounts are minimised.
- The filters of the drawing emulsion circuit contain a certain amount of copper particles from the drawing process. They are recycled externally for the copper content. Reported values for filter and paper waste generation indicate a waste quantity of the order of 5-8 t per year [155, TWG 2016].

Enamelling

- Varnish application. In order to reduce varnish losses, the varnish is applied in varnish baths, during die stripping using the varnish circuit and by using dosed felt application.
- Recycling of bare or enamelled wires. All of the production scrap (bare and enamelled wires) is recycled.
- Used solvents, residual enamels and cleaning wipes containing solvent are collected and disposed of (usually by incineration).

The reported figures for generation of waste paint/coating and varnish (code 08 01 11 of the European waste catalogue) and sludges from paint/coating and varnishes (code 08 01 13) from the enamelling vary between 13 g and 30 g of waste paint/varnish and paint/varnish sludge per kg of solvent input with only one exception (see Figure 9.4) [155, TWG 2016].



NB:
1. Y-axis is in logarithmic scale
2. Data include "waste paint and varnish containing organic solvents or other hazardous substances" (code 08 01 11) and "sludges from paint or varnish containing organic solvents.." (code 08 01 13)

Source: [155, TWG 2016]

Figure 9.4: Specific waste generation values (g of waste paint/varnish and paint/varnish sludge per kg of solvent input) - Average values for the period 2013-2015

9.4 Techniques to consider in the determination of BAT in winding wire manufacturing

9.4.1 General techniques in winding wire manufacturing

[78, TWG 2005]

In Chapter 17, techniques are discussed which might also be applicable to winding wire manufacturing. In Table 9.6, the general techniques relevant for winding wire manufacturing are shown. These techniques are not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 17.1, and the applicability is discussed below.

The EGTEI background document for the coating of winding wires (see Annex 21.3.1) gives some data on the costs and benefits at the European level for some techniques to reduce VOC emissions. However, the EGTEI approach necessarily has to limit its complexity, and only key techniques are given without consideration of the other BAT factors, such as cross-media effects, or the technical characteristics of individual installations and products [78, TWG 2005] [82, EGTEI 2005].

Table 9.6: Reference to techniques generally applicable to the sector

Technique	Section number
Environmental management techniques	17.1
Storage and handling of raw materials	17.2
Monitoring	17.3
Water use and waste water generation	17.4
Energy management and energy efficiency	17.5
Raw material management (including substitution)	17.6
Coating processes and equipment	17.7
Drying and/or curing techniques	17.8
Cleaning techniques	17.9
Off-gas extraction and treatment	17.10
Waste water treatment techniques	17.11
Waste management techniques	17.12
Odour emissions	17.13

Techniques described in the subsections of Section 17.2.4 are not applicable in winding wire manufacturing. The enamelling compound is supplied in the final state by the manufacturer of the compound according to the requested content of solvent and polymer; there is no mixing operation in the winding wire installation and no dilution or addition of solvents during the manufacturing process of the enamelled wires.

Section 17.7: Due to the specialist and integrated nature of the process equipment for the coating of winding wires (described in Sections 9.1, 9.2 and 9.4), the general techniques covering only single aspects are not technically applicable to integrated winding wire machines. In the coating of winding wires, a technique similar to flooding may be applied (see Section 0).

Section 17.7.2: The performance of the insulating layer is fixed in international standards and specified by the customers. All substitutions described in Section 9.3.1.1 and in the subsections of Section 9.4.2 were performed in close cooperation with the customers; most of them failed to meet the requirements as stated in the specific subsections.

The off-gas treatment most commonly used in the in-line process in winding wire installations (process-integrated catalytic oxidation, see Section 17.10.5.6) is described in detail in Section 9.4.3.1. Submitted information shows that additional treatment steps (e.g. regenerative thermal oxidation, see Section 17.10.5.4) may be applied at the outlet of the process-integrated catalytic oxidation treatment.

Techniques to consider in the determination of BAT in the winding wire industry and substitution techniques are given in the following subsections.

9.4.2 Material-based techniques

These sections describe possible alternatives for conventional enamel coatings and lubricants. See also Section 17.7.2.

9.4.2.1 High-solids enamel coatings

Description
Use of enamel coating with a solids content of up to 45 %. In the case of fine wires (with a diameter less than or equal to 0.1 mm), the solids content is up to 30 %.

Technical description
During the last 20 years, the solids content in general has been increased from 30 % to about 45 % (resulting in a solvent reduction from 70 % to 55 %), and up to 30 % solids content for wire sizes finer than 0.10 mm. These are considered ‘high-solids’ coatings in the winding wire industry.

All plants in the EU are currently applying coatings with a solid content of at least 30 % for winding wires with diameters of less than 0.2 mm.

Achieved environmental benefits
A relatively significant reduction in solvent emissions.

Environmental performance and operational data
A greatly increased solids content shows a tendency to result in insulation films of an inferior quality. It is also more complicated to achieve the right thickness of each layer of the insulation. Experience shows a direct correlation between the solids content and the amount of scrap produced. Therefore, it is necessary to deliberately reduce the solids content because of the amount of material wasted.

Cross-media effects
A very high solids content requires additional high energy input for the production process and, therefore, a higher energy input for heating. Also, more waste is produced.

Technical considerations relevant to applicability
Applicable to new and existing plants. Applicability may be limited due to product quality requirements or specifications.

Economics
There is a limited cost benefit. There is a reduction of costs for the solvent in the enamels, but less energy is recovered from the solvents’ abatement in the off-gases.

Driving force for implementation
Cost reduction for the solvent (see also Economics above).

Example plants
All plants for the production of wires with diameters of less than 0.2 mm apply coating systems with +/- 30-45 % solids content.
Plants #032, #033, #034, #035 and #160 in [155, TWG 2016]

Reference literature
[28, EWWG 2004] [38, TWG 2004] [78, TWG 2005] [155, TWG 2016]
[212, TWG 2018]

9.4.2.2 Solvent-free lubricants

Description
Solvent-free lubricants are applied as follows:

- the wire is drawn through a lubricant-wetted felt; or
- a lubricant-impregnated filament is run with the wire and the paraffin wax melts due to the residual heat of the wire and the frictional heat

Technical description
Solvent-free lubricants can be applied by means of lubrication filaments or felts. Two alternative systems are in use in some factories: molten lubricant is applied to the wire surface by a lubricant-wetted felt or by feeding the finished enamelled wire with a lubricant filament that melts due to the residual heat of the wire. The latter technique applies the lubricant by looping the filament two to three times around the enamelled wire and moving it in the same direction, although at a lower velocity.

Achieved environmental benefits
Solvent emissions from lubrication are avoided. For non-fine wires, yarn can reduce VOC emissions to 3-4 g/kg of product.

Environmental performance and operational data
The lubricant is not a means of preservation for the winding wire but a well-defined means of achieving the specific performance of the wire required and approved by the customer. The application systems have to ensure that the small amount of lubricant required is homogeneously applied to the surface of the wire. Solvent-free lubricant application systems cannot be applied to wires of less than 0.15 mm, because the friction generated between wire and lubricant is higher than normal, resulting in more wire breaks. Subsequently more scrap is generated when manufacturing wires of less than 0.15 mm.

The quality requirements of the customer, regarding the thickness and evenness of the lubricant film, have to be recognised when dealing with solvent-free alternatives. The lubricant is usually specified by customers. Generally, it can be said that high quality requirements and thin wires are less appropriate for solvent-free lubricants.

There is also a need for supervision and maintenance of the application system and there is also a danger of malfunction. Compared to the conventional system, these alternatives are not effective or simple enough to be reliable.

Cross-media effects
Waste is generated from used yarn, and to date there are no possibilities for recycling.

Technical considerations relevant to applicability
Applicable to new and existing plants. Most plants have some lines (although a few have up to 20 % of their lines) with solvent-free lubricant applicators. However, its applicability may be limited due to product quality requirements or specifications. This technique is applicable only to a restricted wire diameter range, i.e. 0.15-1.5 mm (i.e. not feasible for fine wires).

Economics

An economic gain is that solvents are omitted. The alternative systems using a soaked yarn have been under development already for several years. These systems require high investment costs for each line and have running costs comparable to the solvent solution. A break in the yarn will cause a large amount of scrap.

Driving force for implementation

- Customers' requirements to use the alternative.
- Health and safety reasons.

Example plants

Plants #033, #034, #035 and #160 in [155, TWG 2016]

Reference literature

[4, Germany 2002] [28, EWWG 2004] [38, TWG 2004] [78, TWG 2005] [155, TWG 2016]

9.4.2.3 Self-lubricating coatings

Description

A solvent-containing lubrication step is avoided by using a coating system that also contains lubricant (a special wax).

Achieved environmental benefits

Solvent emissions from a separate lubrication step are avoided.

Environmental performance and operational data

Current experiences show that this self-lubricating coating needs an additional application of a different lubricant to prevent friction during coiling operations.

Technical considerations relevant to applicability

Applicability of this technique may be limited due to product quality requirements or specifications. For fine wire, the achievable coefficient of friction is worse than that of solvent-based systems. This alternative is not applicable to flat wire manufacturing.

Economics

There is likely to be zero impact as the enamel cost is higher but the cost of the solvent-based lubricant is eliminated.

Example plants

Plants #033, #034, #035, #142 and #160 in [155, TWG 2016]

Reference literature

[4, Germany 2002] [28, EWWG 2004] [38, TWG 2004] [155, TWG 2016]

9.4.3 Off-gas treatment

9.4.3.1 Process-integrated VOC catalytic oxidation

Description

The air/solvent mix resulting from solvent evaporation during the repeated enamel curing process is treated in a catalytic oxidiser integrated in the curing oven/dryer. The waste heat from the catalytic oxidiser is used in the drying process to heat up the circulating airflow and/or as process heat for other purposes within the plant.

Technical description

This drying and curing process happens inside the enamelling chamber, which consists of a heated chamber (horizontally or vertically arranged) where the solvent is evaporated before moving into a higher temperature zone (> 400-700 °C) where the film is cured.

Recirculating airflow ovens are in use for contemporary wire coating processes. The direction of the circulating airflow can be with or against the direction of the moving wire.

Achieved environmental benefits

Intregrating drying and curing with off-gas extraction and oxidation achieves:

- reduction of VOC emissions; and
- optimal energy recovery from the waste solvent.

Environmental performance and operational data

No specific measurement is available for the ratio between the energy input from external heating (gas or electricity) and from solvent-laden air. Plants' estimations show that of 40 % of the total heat/energy used comes from the catalytic oxidation of the evaporated solvents.

In gas-heated machines, the solvent-laden air is passed directly into a gas burner, where the design of the burner allows adequate mixing with secondary (recirculated) air and oxidation occurs. To ensure that the solvent concentration does not exceed the lower explosive limit (LEL), it is important that excess air is supplied.

Using electrical heating, the solvent-laden air is passed over heating elements to reach a temperature of more than 500 °C. This is generally sufficient to support the catalytic oxidation. In all cases, electrically heated machines use precious metal catalysts. After thermal or catalytic oxidation of the solvents, the air stream is recirculated to provide complete or partial heating of the enamelling chamber. Exhaust gas velocities may be lower than in other industries to ensure a maximum energy efficiency balance from the use of recirculated air. It is important that any oxidation takes place where the air stream is recirculated. Oxidation in the stack will only produce hotter exhaust air.

Contemporary ovens in use for very fine enamelled wires work with heat transfer by radiation or a combined radiation and circulating airflow/convection.

The enamelling chamber is typically maintained under sub-atmospheric (negative) pressure to allow the capture of any fugitive emissions from the enamel supply system and to prevent any degradation products or products of combustion from entering the workplace air.

Cross-media effects

Maintaining high VOC destruction rates is vital to guarantee conformity with VOC emission legislation as well as keeping the finished wire free of solvent residues. This main aim might conflict with the target to maintain low CO and NO_X emissions.

Input of nitrogen-containing enamels and the high temperatures at the catalysts could give rise to non-optimised CO and NO_X emissions.

Technical considerations relevant to applicability
Generally applicable in the winding wire plants.

Contemporary ovens in use for very fine enamelled wires work with radiation or a combined radiation and circulating airflow.

Economics
A rough estimation of the purchase cost for a complete line gives a range from EUR 120 000 to EUR 250 000, and the average might be EUR 200 000 per line (data from 2017). This large variability is the result of the significant differences in machines in terms of size and layout. Any specific line design for specific wire sizes will be far from that average value.

Driving force for implementation

- Local environmental legislation.
- Prevention of odours.
- Reduced operating space and time due to integration.
- Reduced costs for gas extraction and treatment due to integrated destruction of VOCs combined with energy recovery.

Example plants
Implemented in all winding wire plants in the data collection.

Reference literature
[173, EWWG 2017] [155, TWG 2016]

10 COATING AND PRINTING OF METAL PACKAGING

10.1 General information on coating and printing of metal packaging

[159, MPE 2017]

The consumer rigid metal packaging industry in Europe covers more than 760 companies, employing over 177 000 people. A total of 90 % of member companies are small and medium-sized enterprises. Together, they produce some 98 billion units every year for the beverage, food, health and beauty, household and industrial markets[33].

The metal packaging industry converts raw materials into metal containers and components which are supplied to the packer/filler who in turn supplies the retailers.

Metal packaging is manufactured from steel and aluminium, and is commonly referred to as cans, components and drums used for food and beverage processing, product protection and storage, and to facilitate transport. This packaging is used for a wide range of different products, for example:

- food and beverages;
- dairy products;
- paint;
- cosmetics;
- pharmaceuticals;
- chemicals;
- mineral oils.

Metal packaging has a variety of different manufacturing techniques but it can be summarised primarily into whether the container is formed first and then the coating and printing process application is carried out on the finished shape or whether coating and printing is performed on flat sheets before assembly into finished products.

The finished shape process is usually called coating and printing in the round and this covers industrial drums, beer and beverage cans and some aerosol containers. Coating and printing on flat sheets is the older process that covers a wider range of products. It is a more flexible system and a production unit may carry out a mixture of different techniques although some may require some protective repair as well. These are reflected in Table 10.1 where all the major techniques and products are listed.

After the production of the container, it is then transported to the product manufacturer where the container is filled and then the correct type of component (can end, closure or crown) is mechanically connected to the container, thus producing a filled package.

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[33] Data taken from MPE website (www.metalpackagingeurope.org) in April 2019.

Table 10.1: Overview of manufacturing processes used for coating and printing of metal packaging

Packaging manufacturing process			Substrate used	Solvent treatment applications							Typical products (not a full listing)
				Spray	Roller coating (coils, sheets and can externals)	Direct dip application	Powder spray	Electro-coating	Compound lining	Printing	
Coating and printing in the round	2-piece wall ironed cans		Steel	X	X	X				X	Food, pet food, beverages
			Aluminium	X	X					X	Beverages
	Impact extrusion		Aluminium	X	X					X	Aerosols
	Industrial drums		Steel	X	X					X	Industrial
Coating and printing on the flat	3-piece container	Food: grocery & general	Steel	X	X		X			X	Food, pet food, aerosols, beverages, industrial, general line,
		Aerosols	Steel	X	X		X			X	Aerosols and some food applications
		Industrial	Steel	X	X		X			X	Industrial, general line
	Drawn cans	2-piece drawn	Steel	X	X					X	Food
			Aluminium		X					X	Food
	Components	Can ends	Steel	X	X			X	X	X	Food, pet food, aerosols, beverages, industrial, general line, ends and closures
		Closures	Steel		X				X	X	Food
			Aluminium		X				X	X	Beverages
		Crowns	Steel		X				X	X	Beverages

Source: [159, MPE 2017]

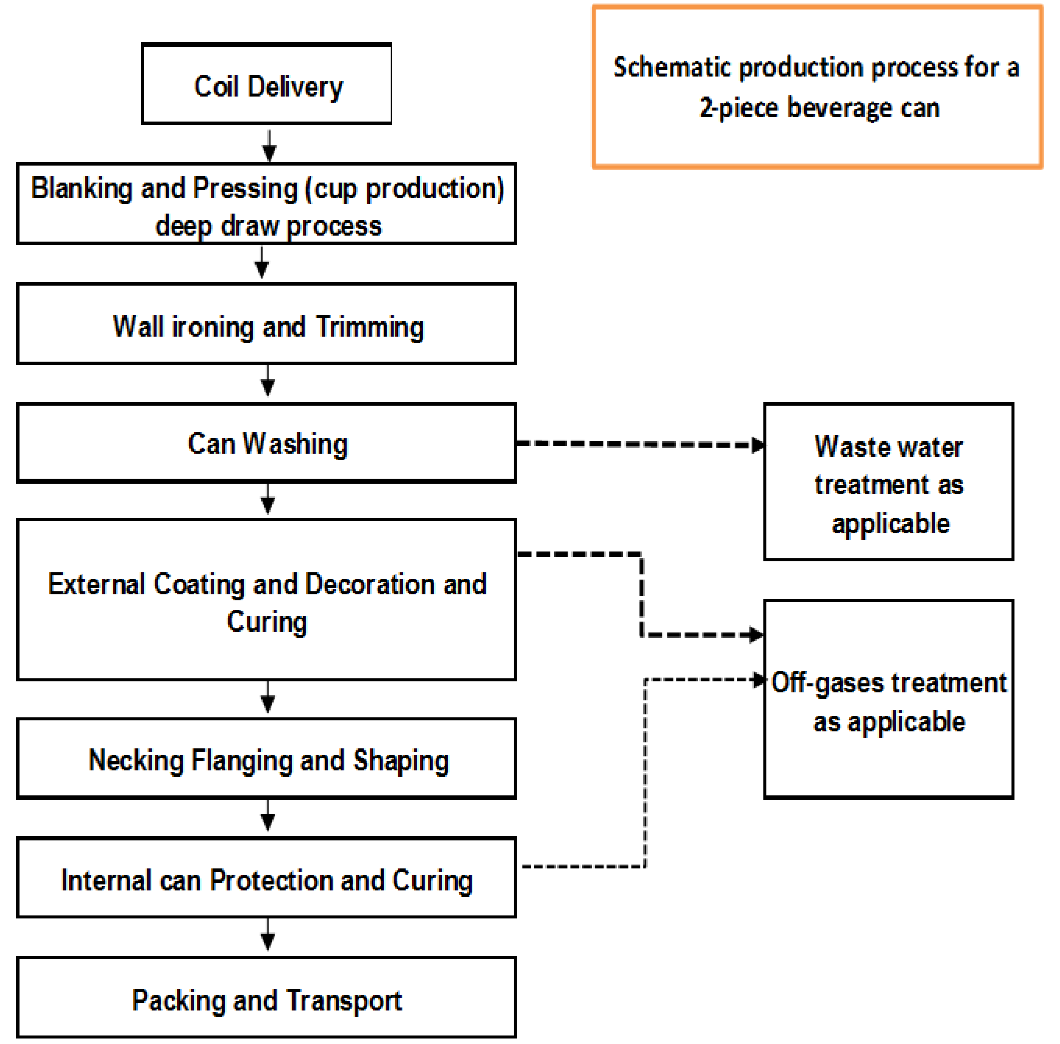
10.2 Applied processes and techniques in the coating and printing of metal packaging

[159, MPE 2017]

In the following sections the production processes for the main product types are presented.

10.2.1 Two-piece can manufacture (draw and wall ironing - DWI)

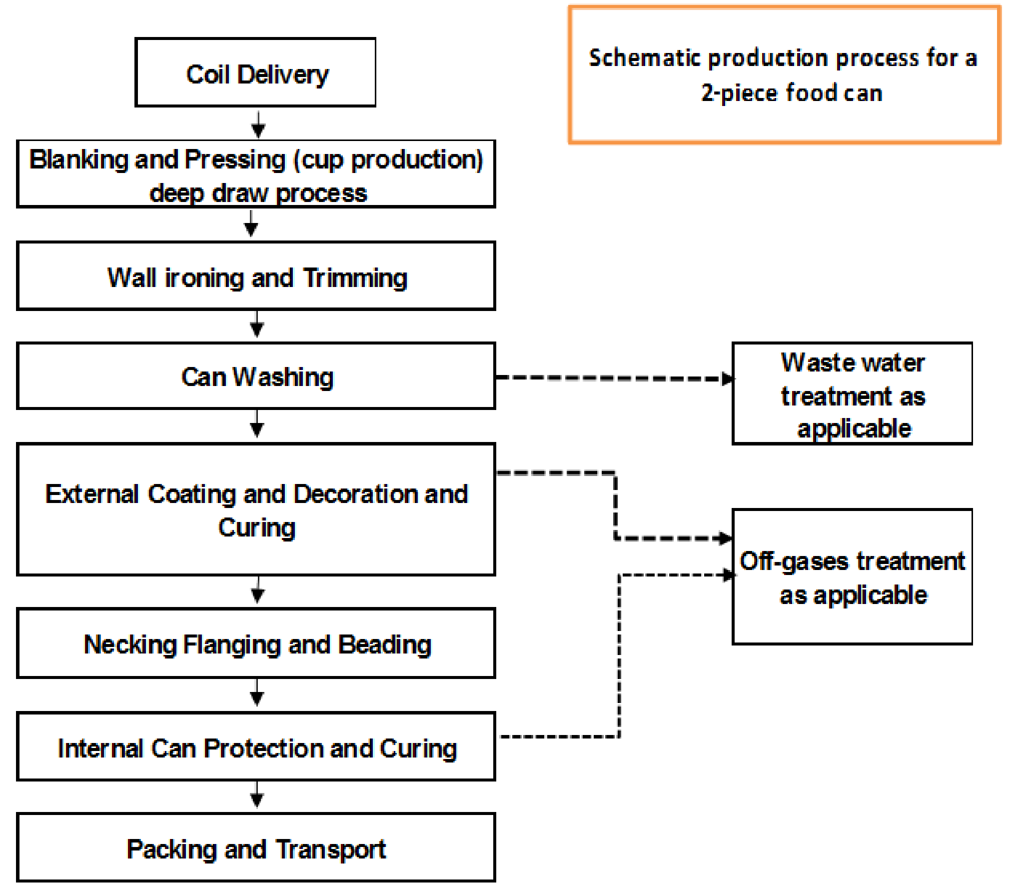
Figure 10.1 shows the schematic production process for beverage cans.



Source: [159, MPE 2017]

Figure 10.1: Production process for beverage cans

Figure 10.2 shows the schematic production process for food cans.



Source: [159, MPE 2017]

Figure 10.2: Production process for food cans

The following generic description covers the manufacture of beverage cans, which normally carry an external printed design, and food cans, which are usually finished with a colourless clear external coating and not printed. The entire process including conveying between the process stages is fully automated.

Aluminium or tinplated packaging steel is supplied in continuous coil strips and fed automatically through a mechanical cupping press where blanks are stamped and deep-drawn into cups.

The cups are conveyed to the body makers (long-stroke horizontal presses) where the cup walls are elongated by wall ironing and the bottom profile is formed. Immediately after wall ironing, the surplus metal of the can wall length is trimmed off so a fixed-height can is attained. Scrap arising from the blanking and trimming operation is recovered and recycled.

The metal-forming operations use a water-based synthetic coolant with an added lubricant plus a small amount of biocide, both subsequently removed in the can washer. There is also the possibility of tramp hydraulic oil from the presses mixing with the coolant. The coolant is in a closed-loop system where it is filtered, treated and reused.

Cans exiting the trimmer are then conveyed into a can washer where the excess lubricant is cleaned off. This can washing process differs for aluminium and steel substrates.

Steel cans are first cleaned with water by passing repeated spray stations in a reverse cascade arrangement, then rinsed with demineralised water and finally dried in a natural-gas-fired oven.

Aluminium cans follow the above sequence with the additional stage of pretreatment using acid or alkaline aqueous solutions before rinsing with demineralised water. A mobility enhancer may be applied before the aluminium cans are finally dried in the oven.

Food cans, which are normally not decorated, require a clear external protective coat applied to the upturned can via a curtain coater or wash coat system, between the last can washer stage and before the drying oven. The coated cans then have a period of drainage, before entering the oven to dry them and cure the external coating.

The external curtain/wash coat system is a recirculating system with the process designed to collect as much of the excess coating as possible.

Waste water from the can washer, demineralisation unit and the wash coat is treated prior to discharge. There is a natural carryout of water via the wet cans entering the oven.

For aluminium, the waste water from the can washer is treated before discharge and the cleaned treated water can be recycled to substitute fresh make-up water.

Waste hot air from the can cleaning and drying is emitted directly to the atmosphere via an exhaust stack.

After cleaning, the cans are next passed automatically for external decoration. Usually the first step is base coating (but not always), followed by a second decoration step. The base coater applies either a coloured or clear layer of lacquer via a roller offset process onto the rotating can. The cans are then fed through a thermal convection oven.

After the curing of the base coat, the cans are transferred to the decorator (printing machine) where the decoration is applied by using printing inks in a dry offset process. If an over-varnish is required, it is applied as the last stage (wet-on-wet), directly by a roller offset process on the decorator.

Aluminium cans are usually coated on the external bottom rim by another set of application rollers. This operation is carried out before the can enters the decorator oven and the rim varnish is cured together with the inks and the optional over-varnish in the oven.

After the external coating and printing is completed, the can would normally undergo the necking, flanging and any shaping operations to give the final can appearance. The cans are first conveyed to the necker/flanger, which reduces the neck diameter of the cans to accept the ends. The neck-forming operation is supported by compressed air and small amounts of synthetic lubricants are used.

Steel cans are usually spray-coated on the external bottom prior to the inside spray application for rust protection. This bottom coat dries at room temperature. The inside of the can is then coated with an airless spray technique using water-based materials. A set of nozzles sprays the lacquer into the rotating can, ensuring that the desired film weight distribution is achieved. The cans are then passed through a thermal oven where both the inside lacquer and the bottom spray receive the final cure.

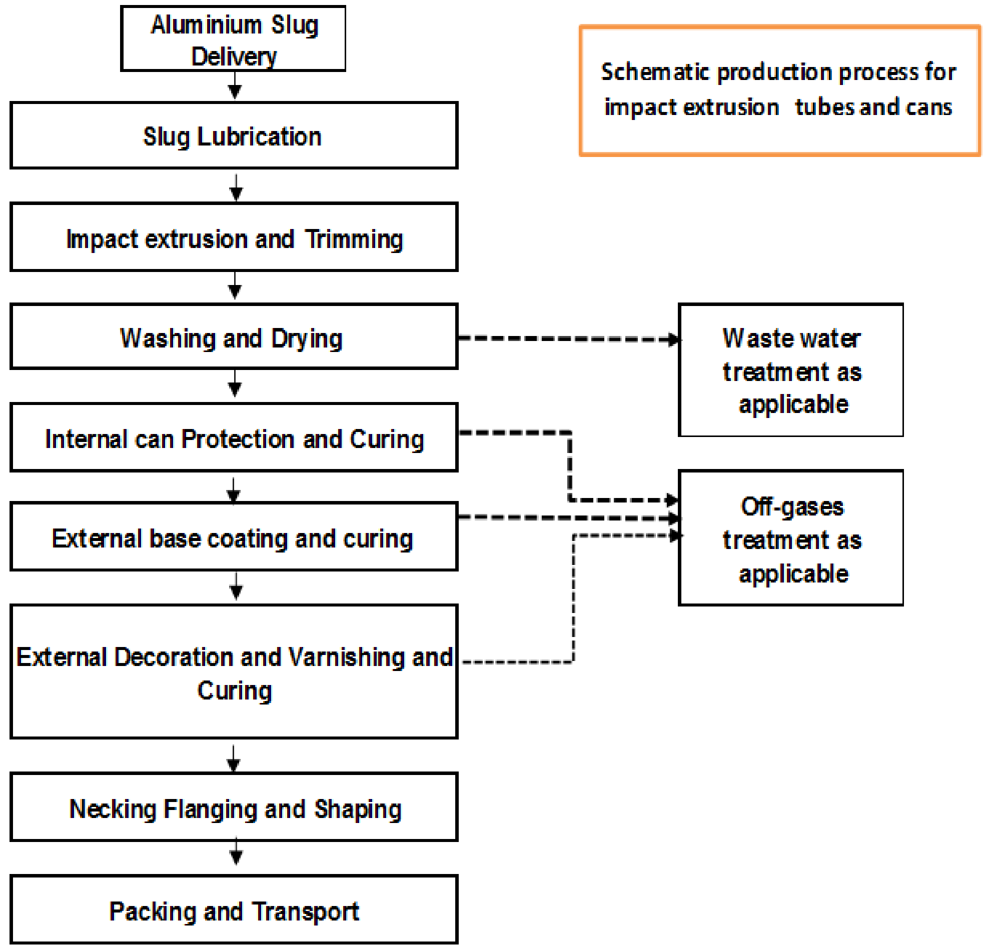
After each lacquering operation, the cans immediately pass into a gas-fired oven at typical drying temperatures of 180-200 °C. The emissions of the curing process are collected and exhausted by fans to the atmosphere or to abatement equipment.

Food cans have an additional forming operation of beading that has two parts. There is a rolling bead which is done to allow the can to roll through the industrial food process and there is a single bead placed near the base of the can to assist in pressure resistance through the industrial cooking process.

Finally, prior to palletising, all cans must pass through a light tester and camera for inspection. Any potentially damaged product is rejected.

10.2.2 Impact extrusion of aluminium for aerosols and collapsible tubes

The production process of extruded aluminium tubes is shown in Figure 10.3.



Source: [159, MPE 2017]

Figure 10.3: Production process of extruded aluminium tubes

In concept, this process is very similar to two-piece can making. The difference is primarily in the draw and wall ironing (DWI) metal-forming process where the initial aluminium coil is 'thinned' to form the container; this process extrudes an aluminium slug into a finished container with a constant wall thickness.

Aluminium slugs, which are 99.5 % pure aluminium, are lubricated and then converted through a series of high-impact drawing operations into a tube with a single open end. The open end is trimmed to produce the required cylinder height and the produced trim is collected for recycling. Further separate metal-forming operations may inwardly dome the closed end for pressure resistance (aerosol), perforate it for later addition of a plastic screw thread and cap or further form it into a screw thread (the latter two for collapsible tubes).

The formed can is then cleaned in a continuous washer to remove residual lubricant. The chemicals used in the cleaning and etching process comprise caustic-based anionic detergents. The contaminated waste water may be discharged partly or totally to a sewer and/or reused to feed the caustic scrubber system described below as a means of fume abatement.

The inside of the can is then coated with an airless spray technique using solvent-based or water-based lacquer materials. A set of nozzles sprays the lacquer into the rotating can, ensuring that the desired film weight distribution is achieved. The cans are then passed through a thermal oven where the inside lacquer is cured.

The cylinders are then transferred to a base coater whereby a metered coating of clear or pigmented base coat is applied by a roller using either a gravure or a conventional metering roller system with the rotating cylinder. The typical base coats are solvent-based but water-based coatings may also be used. Air from the coating station is extracted by fan and generally ducted to the air via high stacks. From the base coater, the coated cans pass automatically into a drying/curing oven, from which the extracted air is collected and discharged directly via high stacks or directed to abatement equipment.

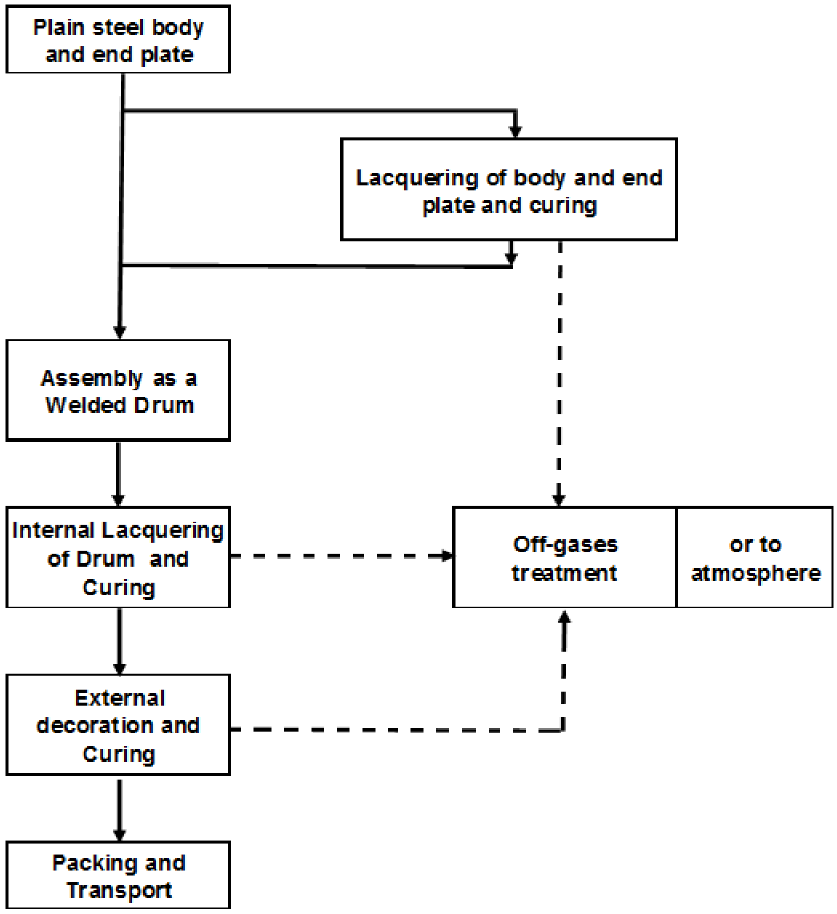
The cured base coat provides the key for the subsequent printed design, which is applied via a multicolour decorator using the dry offset process. A protective over-varnish is applied as the final operation before the cylinder passes automatically into an oven for drying and curing. The containers are usually coated on the external bottom rim by another set of application rollers. This operation is carried out in the decorator oven. There is fume extraction from the decorator, which is ducted to the air, having passed through a caustic scrubber, and separate extraction of the oven exhaust directly to the air or to abatement equipment.

For aerosol cans, the cylinder undergoes further reforming, with controlled application of a mineral lubricant, to ‘neck-in’ and curl the open end to accept the valve assembly which will be fitted subsequently to filling. Body shaping can also be undertaken prior to the final neck and curl operation for certain aerosol products.

The aerosol container is now tested for any leaks in a light tester and then sent to the packing station.

10.2.3 Industrial drums

Steel drums are manufactured primarily for industrial use. The principle of manufacturing drums is similar to the three-piece can manufacturing process (see Section 10.2.5). This is shown in Figure 10.4.



Source: [159, MPE 2017]

Figure 10.4: Production process of drums

Whether or not a drum will be internally coated depends on the goods that will be packed into it. Thus, internal coating is not limited to food-related use of drums but will also be done for chemicals that should not come into contact with the steel.

The drum body is welded out of a sheet of plain steel and the top and bottom panels are produced separately on cutting and forming lines. If required, these formed drum bodies and ends are separately coated with internal lacquer and cured. In the seaming machine, the assembly of the drum takes place. During this step the seaming compound is applied, when this has not already been done on the tops and bottoms in a separate process step.

After seaming, the drum is coated on the outside with external drum paint and the coating is cured (simultaneously with the seaming compound). As a final step, drums can be further decorated by screen printing or other printing techniques. Inks used in that process are usually solvent-based, but UV curing techniques are also used.

Internal drum coatings are generally applied via rotation discs (for the body) or by hot airless spraying. The majority of internal coatings are solvent-based because of the required chemical resistance between the steel and the contents and contain 45-60 % organic solvents. External drum paints are generally applied by hot airless spraying. These are mainly solvent-based and contain around 45-50 % organic solvents. In specific cases, water-based external drum paints are used, containing less than 10 % organic solvents. VOC process emissions are treated by abatement techniques prior to discharge.

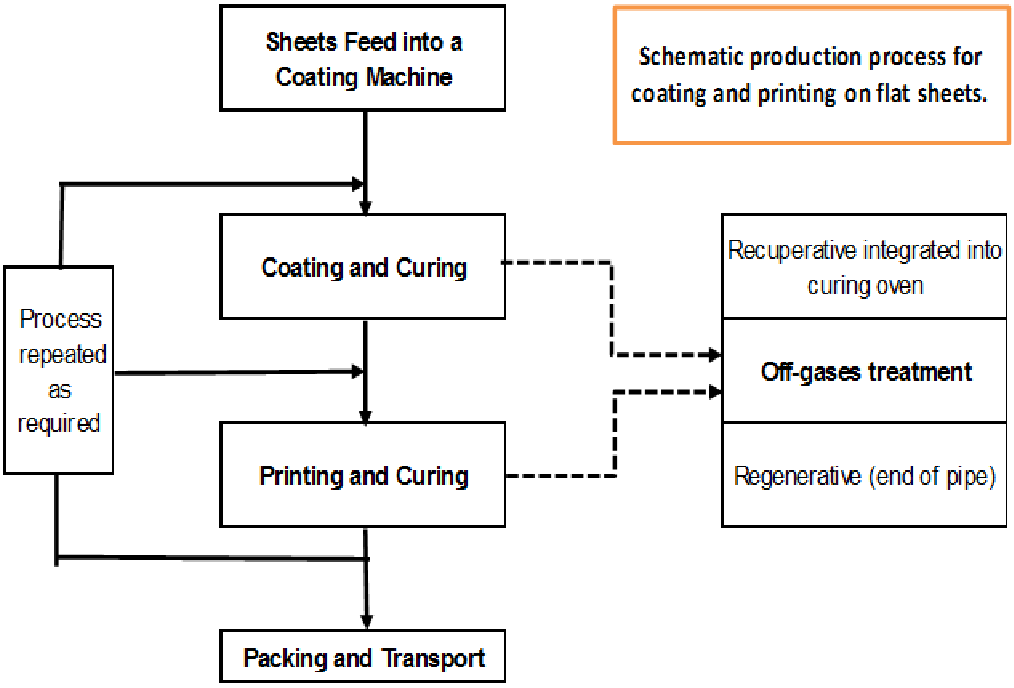
10.2.4 Flat sheet coating and printing

Flat sheet coating and printing operations can be split into four stages (not all of these operations are applicable to every case):

- internal coating;
- external base coat or size coat, however conventional printing can be directly applied to tinplate;
- printing;
- varnish or top coating.

Curing of solvent-based coatings and inks takes place in thermal ovens usually at rates of up to 6 000 sheets per hour at temperatures of between 150 °C and 210 °C. Speeds and temperatures are dependent on sheet sizes, thickness and the coating specification.

Flat sheet coating and printing is the first separate and distinct operation necessary for the subsequent operations for the manufacture of three-piece and drawn cans, ends or caps and closures. This is shown in Figure 10.5.



Source: [159, MPE 2017]

Figure 10.5: Production process for flat metallic sheet

The substrate materials used in the flat sheet printing and coating process are mainly tinplate, electrolytic chromium-coated steel (ECCS), and cold-rolled steel or aluminium. The material is received either as stillages of pre-cut sheets or as coils which have to be processed on site into cut sheets first.

Metal sheets may pass through the printing and coating lines several times as multiple coating and decorative applications and curing passes are sometimes required. Different coating sequences are undertaken and are related to the product being packed.

The coating material is transferred onto a synthetic coated applicator roller and then transferred onto the sheet in a pressured contact method. The film weight is controlled by different techniques that optimise the coating flow onto the applicator roller. Any potential transfer of coating onto the bottom cylinder is removed whilst the machine is running by a scraper, to prevent contamination of the underside of the sheet.

On the printing lines, ink is transferred through a series of flow control rollers to give the correct application rate onto an application blanket to achieve the desired depth of colour. The printing techniques commonly used are wet offset, dry offset and, in some cases, a waterless lithographic process.

Periodic cleaning of the coating and print applicator rollers is required to remove the build-up of coating and ink constituents. At changeovers, more thorough cleaning of the coating and printing machines is carried out using various organic solvents, including reclaimed solvents, either manually or automatically. The waste organic solvent is often distilled and reblended either on or off site.

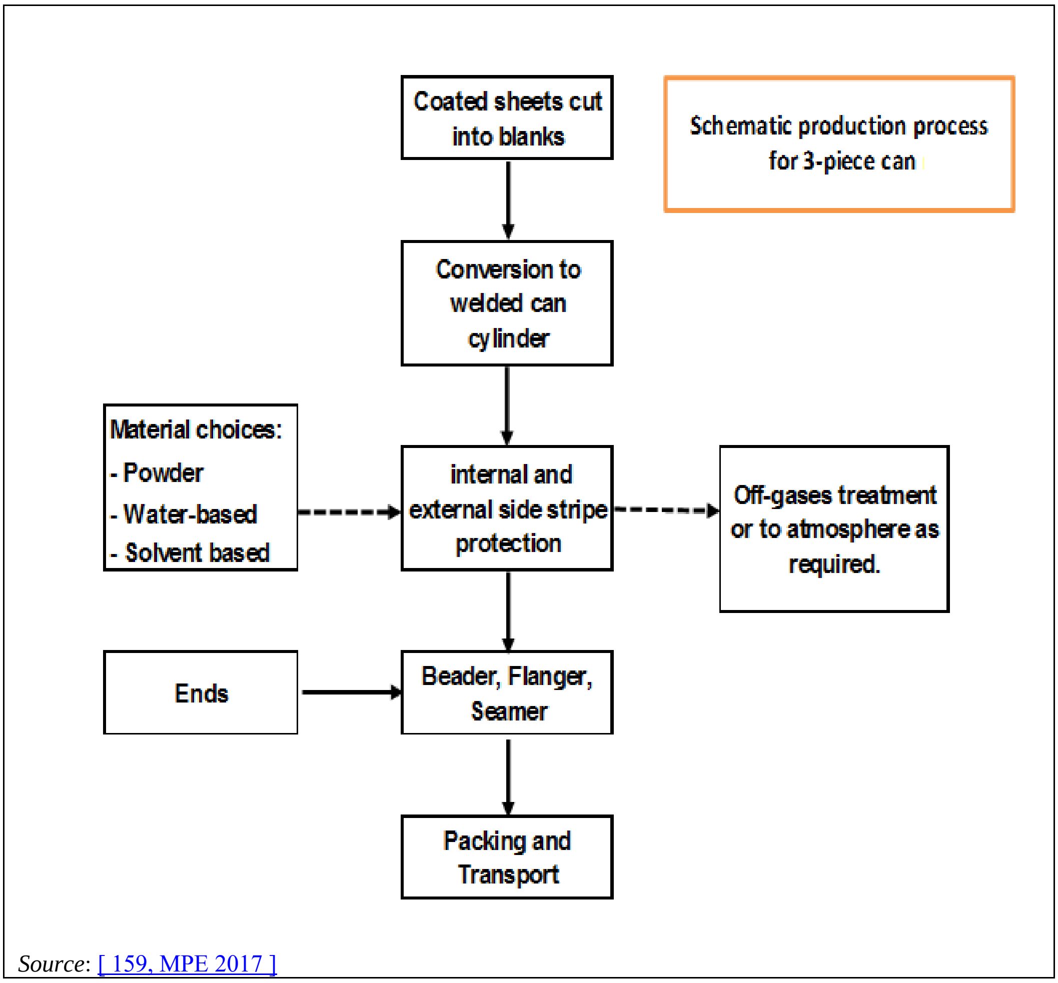
The coated or printed sheet is then transferred to the thermal curing oven where it is heated to the required curing temperature. VOCs from the organic solvent used in the materials applied are collected from the oven and the machine hoods with ducts and exhausted by fans to the atmosphere or sent to the abatement equipment.

Following this, the cured sheet is cooled with ambient air. This reduces the materials sticking together and the stack of sheets is rebuilt onto stillages for subsequent transfer to the next stage of the process.

Where UV-cured inks and coatings are used, UV lamps are employed. This does not release VOCs but creates a low level of ozone (ppm) which is exhausted to the atmosphere.

10.2.5 Three-piece can manufacture

Three-piece cans can have a variety of seam constructions; however, welded is the most common across different product sectors. The production process for welded three-piece cans is shown in Figure 10.6.



Source: [159, MPE 2017]

Figure 10.6: Production process for three-piece cans

Three-piece can manufacture covers diverse products such as food cans, paint cans, industrial oblongs and aerosol containers. Tinplate sheets which have been previously coated and/or decorated, as described in Section 10.2.4, are slit into individual body blanks. These body blanks are usually automatically fed, but sometimes manually fed, into a welding machine that rolls the body blank into a tube and then welds it along its length to produce a straight-sided welded cylinder. During slitting, the excess tinplate is trimmed off and subsequently recycled. An alternative means of joining the side seam is by mechanical clinching. In some cases, the circular cylinders can be reformed into other shapes, e.g. rectangular industrial oblongs.

Immediately after welding and while still on the welding machine, the internal and external surface of the weld may have a protective coating applied, depending on the specification of the three-piece can being manufactured. This protective coating is called a side stripe and may be either a solvent-based, a water-based or a powder coating, depending on the intended end use of the container. In the case of side stripe lacquers, these are applied using rollers or airless spray guns on the internal face and spray guns, brushes and rollers on the external face. Any overspray is collected and ducted to the air. In the case of powder coatings, these are applied electrostatically and any overspray is collected and recycled.

Following welding / side stripe application, the cylinders pass through an oven to cure the applied side stripe. The oven types are generally either hot air or induction and apply localised heat to the welded area of the cylinder. Emissions from the side striping oven are in most cases emitted directly to the air via exhaust stacks and sometimes are extracted to the off-gas treatment system.

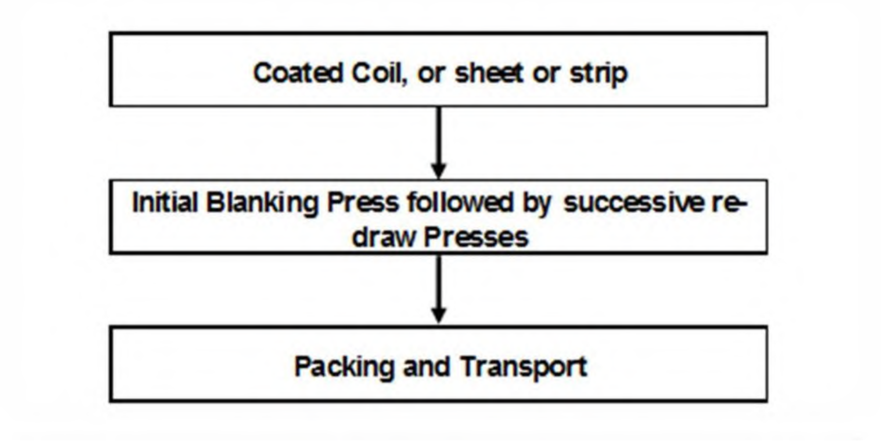
Following side stripe curing, some specifications of three-piece cans (typically food cans) are then automatically fed into a beading machine so that strengthening beads can be fabricated into the body wall of the cylinder. This process is purely mechanical and requires no additional process materials. Depending on the can specification, after beading or side stripe curing, the welded cylinders are automatically fed into either necking and/or flanging machines so that both ends of the cylinder can be profiled ready to accept the end component.

The fabricated body is then automatically passed to an end-seamer where the end component, previously manufactured, is fed and seamed onto one end of the fabricated cylinder. The necking, flanging and seaming operation is also purely mechanical and does not require any additional process materials.

For some specifications, such as food cans, the three-piece can is supplied to the user with only one end seamed and in this case the end seaming is followed by palletisation. However, other three-piece cans such as paint cans, oblong cans and aerosol cans pass through a second seaming machine and a second end component is seamed prior to palletisation.

10.2.6 Two-piece drawn cans in steel and aluminium

The production process for two-piece cans is shown in Figure 10.7.



Source: [159, MPE 2017]

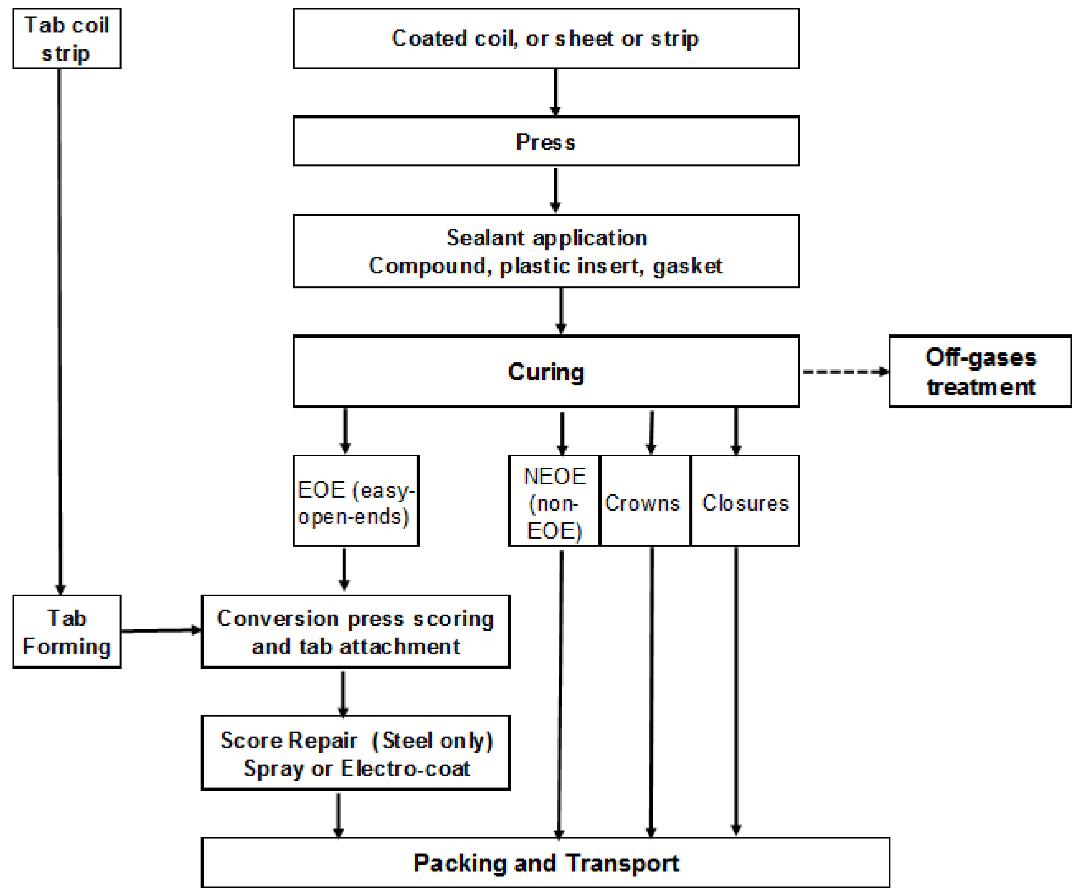
Figure 10.7: Production sequence of two-piece drawn cans

Two-piece drawn cans are produced from pre-coated coil, sheets or strips as described in Section 10.2.4. They can be produced in either rectangular shapes or cylinders but they have constraints in the height of the container. They are commonly used with fish products.

In the manufacturing cycle, there are no VOCs used apart from in the flat sheet application process.

10.2.7 Ends, crowns and closures manufacture

The production process for ends, crowns and closures is shown in Figure 10.8.



Source: [159, MPE 2017]

Figure 10.8: Production process for ends, crowns and closures

The manufacture is from either plain or pre-coated/decorated sheets or coil made from aluminium, or tinplated or electrolytic chromium-coated steel (ECCS). The metal may be pre-lubricated prior to fabrication. The metal is fed to a stamping press where the initial round blank disc is formed. This disc is then repeatedly reformed depending on which type of component it will become: easy-open ends (EOE); sanitary or non-easy-open ends (NEOE); crowns or caps for bottles or closures for jars. These components are usually round, but there can be rectangular EOE and industrial components as well. There are also: cones and domes that are made for three-piece aerosol cans, other industrial components such as lever lids for paint and other specific closing mechanisms such as rectangular pouring components for liquid products.

Multiple forming operations are carried out to complete the profile. The completed component shell then proceeds to a lining machine where a sealant (sometimes referred to as a lining compound) or gasket (sometimes referred to as a compound) is applied. Organic solvents may be contained in the sealant.

For easy-open ends, once the shell has had the compound applied, it proceeds on to a conversion press where the opening feature is created; the tab is fabricated and a final assembly is carried out to complete the end. For easy-open ends made from tinplate, the end score will be repaired with a spray lacquer or electrocoat material and an associated oven for curing. Some sealants and gaskets require passage through an oven for forced drying or curing. Once completed, the ends, crowns or closures are packed and palletised for dispatch to customers.

10.3 Current consumption and emission levels in the coating and printing of metal packaging

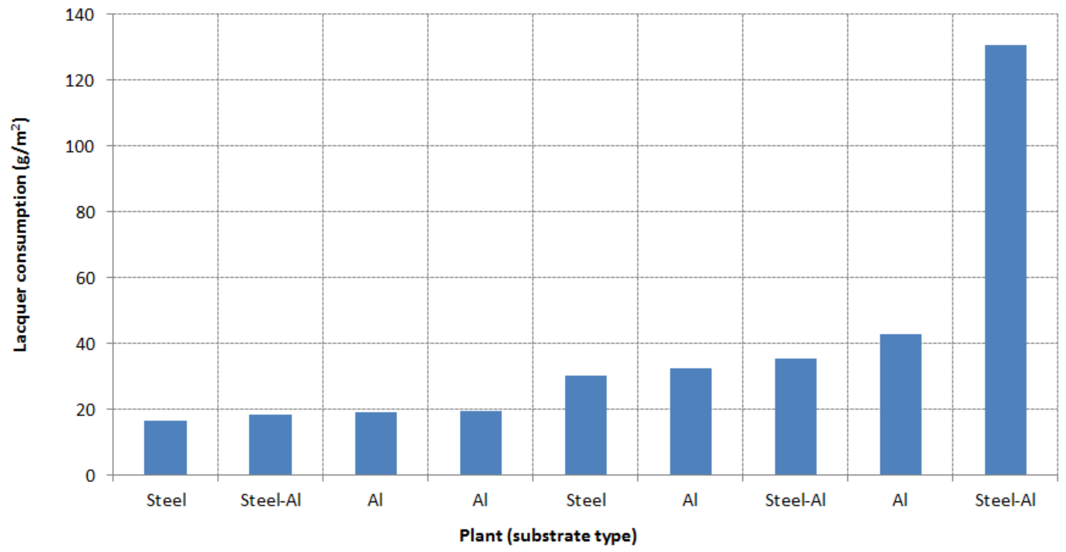
Data were submitted for 17 plants in total. Metal packaging is a sector where the application of the solvent reduction scheme for the demonstration of compliance with the provisions of the IED is a common practice. For example, in the current data collection, more than half of the participating plants apply the reduction scheme. Reduction scheme (RS) is an alternative methodology for demonstrating compliance with the IED provisions which requires that generally an equivalent emission reduction of VOCs is achieved based on the use of raw materials with a low organic solvent content. Data for all plants irrespective of whether they apply RS or not are presented and discussed in the following sections [155, TWG 2016].

10.3.1 Consumption

[155, TWG 2016]

10.3.1.1 Materials

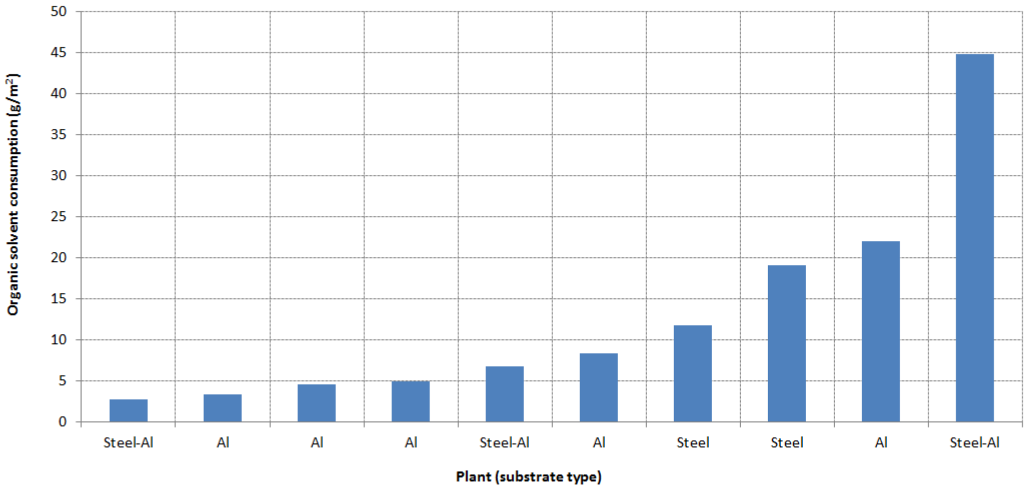
Reported mass balance data show an average lacquer consumption that varies between 16 g and 131 g of lacquer per m^2 of product. The reported values are presented in Figure 10.9.



Source: [155, TWG 2016]

Figure 10.9: Specific lacquer consumption from metal packaging installations (g of lacquer consumption per m^2 of product) - Average values for the period 2013-2015

The average solvent consumption varies from 2.7 g up to 45 g of solvent per m^2 of product. The reported organic solvent consumption data are presented in Figure 10.10.



Source: [155, TWG 2016]

Figure 10.10: **Organic solvent consumption from metal packaging installations (g of solvent input per m2 of product) - Average values for the period 2013-2015**

Other lacquer and organic solvent consumption data for the various products and pre-products are given in Table 10.2 and Table 10.3.

Table 10.2: Lacquer and organic solvent consumption data from plants producing two-piece cans and can ends

Plant reference	**Plant 1**	**Plant 2**	**Plant 3**	**Plant 4**	**Plant 5**	**Plant 6**
Substrate	Steel - Aluminium	Aluminium	Aluminium	Steel - Aluminium	Aluminium	Aluminium
Lacquer consumption (g/m^2), average for the period 2013-2015	18	19	20	35	NA	32
Solvent consumption (g/m^2), average for the period 2013-2015	2.7	3.4	8.3	6.8	4.5	5.0
Source: [155, TWG 2016]						

Table 10.3: Lacquer and organic solvent consumption data from plants for the coating and printing of flat sheet

Plant reference	**Plant 1**	**Plant 2**
Substrate	Steel	Steel
Lacquer consumption (g/m^2), average for the period 2013-2015	16	30
Solvent consumption (g/m^2), average for the period 2013-2015	11.7	19.0
Source: [155, TWG 2016]		

10.3.1.2 Water

[155, TWG 2016]

Reported values of specific water consumption for the manufacturing of two-piece DWI beverage cans vary from 90 l up to 110 l per 1 000 cans.

The main reported techniques for the minimisation of water consumption are related to:

- control of water usage;
- reverse cascade rinsing;
- use of ion exchange;
- membrane filtration.

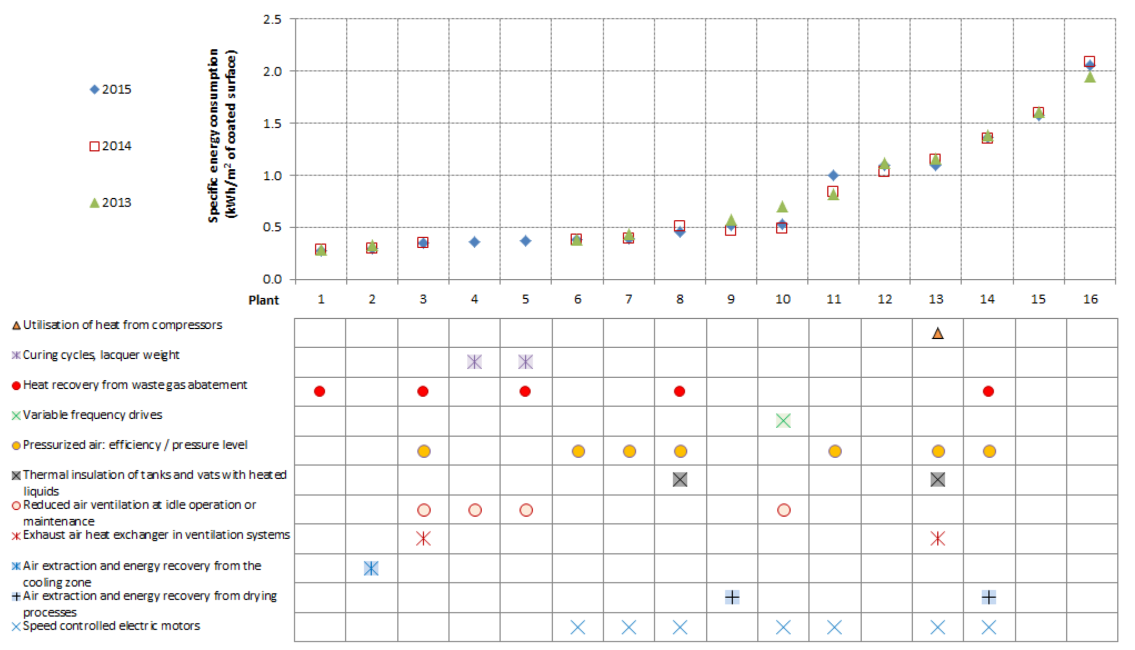
10.3.1.3 Energy

[155, TWG 2016]

Natural gas and electricity are the main energy inputs in metal packaging installations. A significant part of the total energy consumption is dedicated to the off-gas extraction and treatment.

It is estimated that between 30 % and 50 % of the total electricity consumption is dedicated to gas extraction and treatment, while most of the gas consumption (up to 80 %) is used for thermal off-gas treatment.

The reported values of the specific energy consumption are presented in Figure 10.11.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
△ Utilisation of heat from compressors													△			
✳ Curing cycles, lacquer weight				✳	✳											
● Heat recovery from waste gas abatement	●		●		●			●						●		
× Variable frequency drives										×						
● Pressurized air: efficiency / pressure level			●			●	●	●			●		●	●		
☒ Thermal insulation of tanks and vats with heated liquids								☒					☒			
○ Reduced air ventilation at idle operation or maintenance			○	○	○					○						
✳ Exhaust air heat exchanger in ventilation systems			✳										✳			
✳ Air extraction and energy recovery from the cooling zone		✳														
+ Air extraction and energy recovery from drying processes									+					+		
× Speed controlled electric motors						×	×	×		×	×		×	×		

Source: [155, TWG 2016]

Figure 10.11:Specific energy consumption values expressed in kWh per m^2 of coated surface for the period 2013-2015

All plants reported specific energy consumption values below 2 kWh/m^2. No significant differences in specific energy consumption according to the product type were identified.

The main reported energy saving techniques are:

- air extraction and energy recovery from the drying processes; a reported figure shows annual savings of the order of EUR 110 000;
- exhaust air heat exchanger in ventilation systems;
- air extraction and energy recovery from drying processes;
- air extraction and energy recovery from the cooling zone;
- pressurised air: efficiency/pressure level: use of lower pressure level and substitution of pneumatic systems by electric control systems;
- reduced air ventilation at idle operation or maintenance;
- thermal insulation of tanks and vats with heated liquids;
- heat recovery from off-gas treatment;
- central off-gas treatment with variable frequency drives;
- oxidiser heat saving during shutdown periods;
- optimising of curing cycles and lacquer weight.

10.3.2 Emissions

[155, TWG 2016]

The abbreviations used in the presentation of emission data for metal packaging installations are presented in Table 10.4.

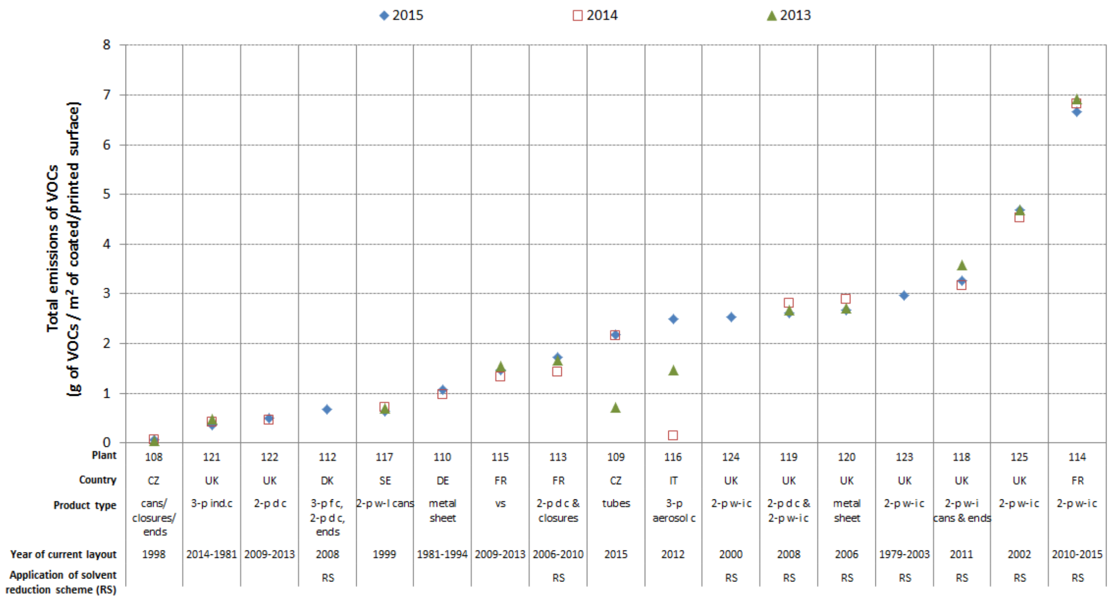
Table 10.4: Abbreviations used in this chapter

Abbreviation	Meaning
2-p d c	Two-piece drawn cans
2-p w-i c	Two-piece wall ironed cans
3-p aerosol c	Three-piece aerosol cans
3-p f c	Three-piece food contact cans
3-p ind. c	Three-piece industrial containers
vs	Varnished sheets
RS	The installation is implementing a solvent reduction scheme according to IED Annex VII, Part 5 provisions

10.3.2.1 Total emissions of VOCs

Figure 10.12 shows an overview of reported data on total emissions of VOCs expressed as g VOCs per m^2 of coated/printed surface for installations producing various product types (mainly two-piece drawn cans, two-piece wall ironed cans, cap ends and closures).

It is worth noting that a significant share of installations in this sector apply the solvent reduction scheme (RS) according to IED Annex VII, Part 5 provisions.



NB:
Abbreviations are explained in Table 10.4.
For Plant #116, the 2014 value is based on effective working hours while for 2013 and 2015 the values are based on authorised working hours.
Source: [155, TWG 2016]

Figure 10.12:Total emissions of VOCs expressed in g VOCs per m2 of coated/printed surface for the period 2013-2015

Some basic statistical figures on total emissions of VOCs are presented in Table 10.5.

Table 10.5: Statistical parameters of total emissions of VOCs expressed in g VOCs per m^2 of coated/printed surface for the period 2013-2015

Parameter	2015	2014	2013	Average (2013-2015)
Average	2.15	2.00	2.27	2.07
Median	2.18	1.38	1.61	1.61
25th percentile	0.68	0.52	0.72	0.68
75th percentile	2.68	2.88	2.93	2.76

Source: [155, TWG 2016]

Additional anonymised data (without any additional contextual information) reported from the relevant industry sector on total emissions of VOCs according to the product type and the abatement technique implemented are presented in Table 10.6.

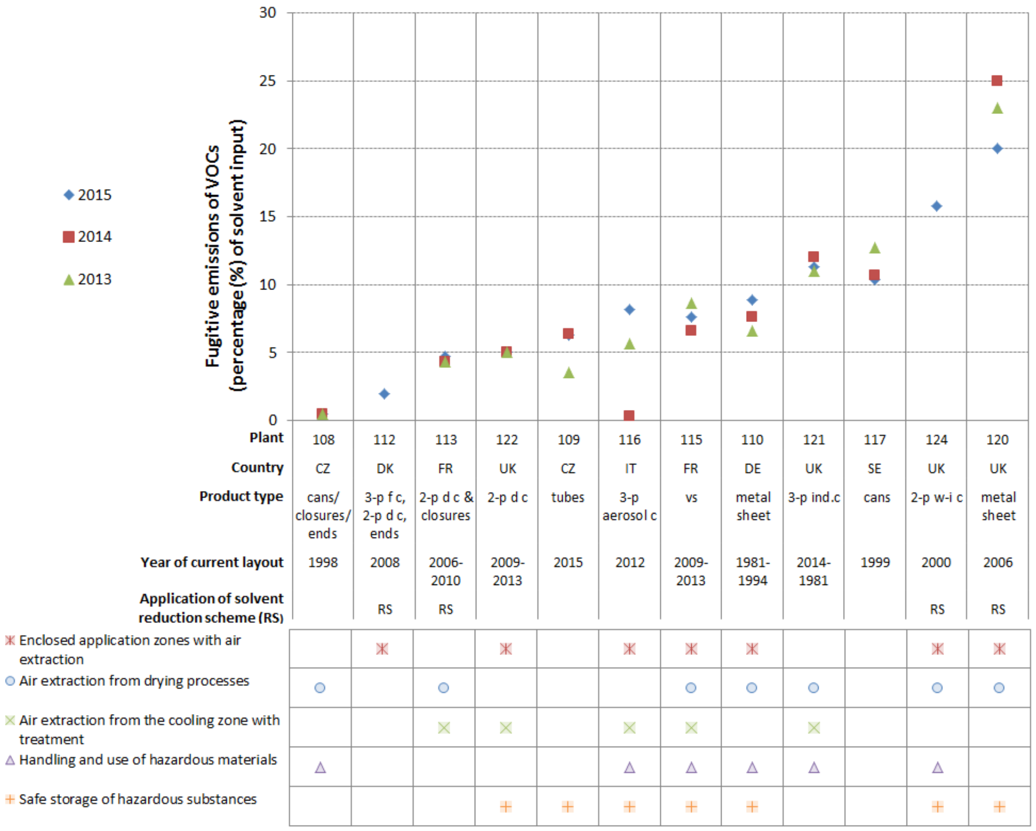
Table 10.6: Total VOC emission values (g VOCs per m^2 of coated area) reported by industry

Specific emission (g VOCs/coated area in m^2)	Substrate	Production	VOC abatement/
< 1	Steel/ Aluminium	• DWI • Flat sheet coating and printing	Complete treatment of captured VOCs
1-3	Steel	• DWI • Manufacturing comprising more than one technology (flat sheet coating and printing, three-piece can making, end making, DWI)	Partial treatment of captured VOCs
2-4	Aluminium	• DWI • Monobloc	No abatement (reduction scheme)
5-10*	Steel	• DWI • Flat sheet coating and printing	No abatement (reduction scheme)

* Specific emissions may be higher in sectors where special requirements on lacquer composition are required.
Source: [172, MPE 2017]

10.3.2.2 Fugitive emissions of VOCs

Off-gases from printing machines, coating applications and dryer units are usually extracted and treated in regenerative thermal oxidation systems. In addition, the application of techniques related to solvent storage and handling and the prevention of unplanned releases result in fugitive emissions lower than 12 % of the solvent input in most cases (see Figure 10.13).



NB: Abbreviations are explained in Table 10.4.
For Plant #116, the 2014 value is based on effective working hours while for 2013 and 2015 the values are based on authorised working hours.
Source: [155, TWG 2016]

Figure 10.13:Fugitive emissions of VOCs expressed as percentage of the solvent input for the period 2013-2015

The main reported techniques for the limitation of fugitive emissions of VOCs are:

- safe storage of solvents and measures to prevent unplanned releases;
- handling and use of hazardous materials;
- air extraction from drying processes;
- air extraction from the cooling zone with treatment;
- enclosed application zones with air extraction.

10.3.2.3 TVOC emissions in waste gases

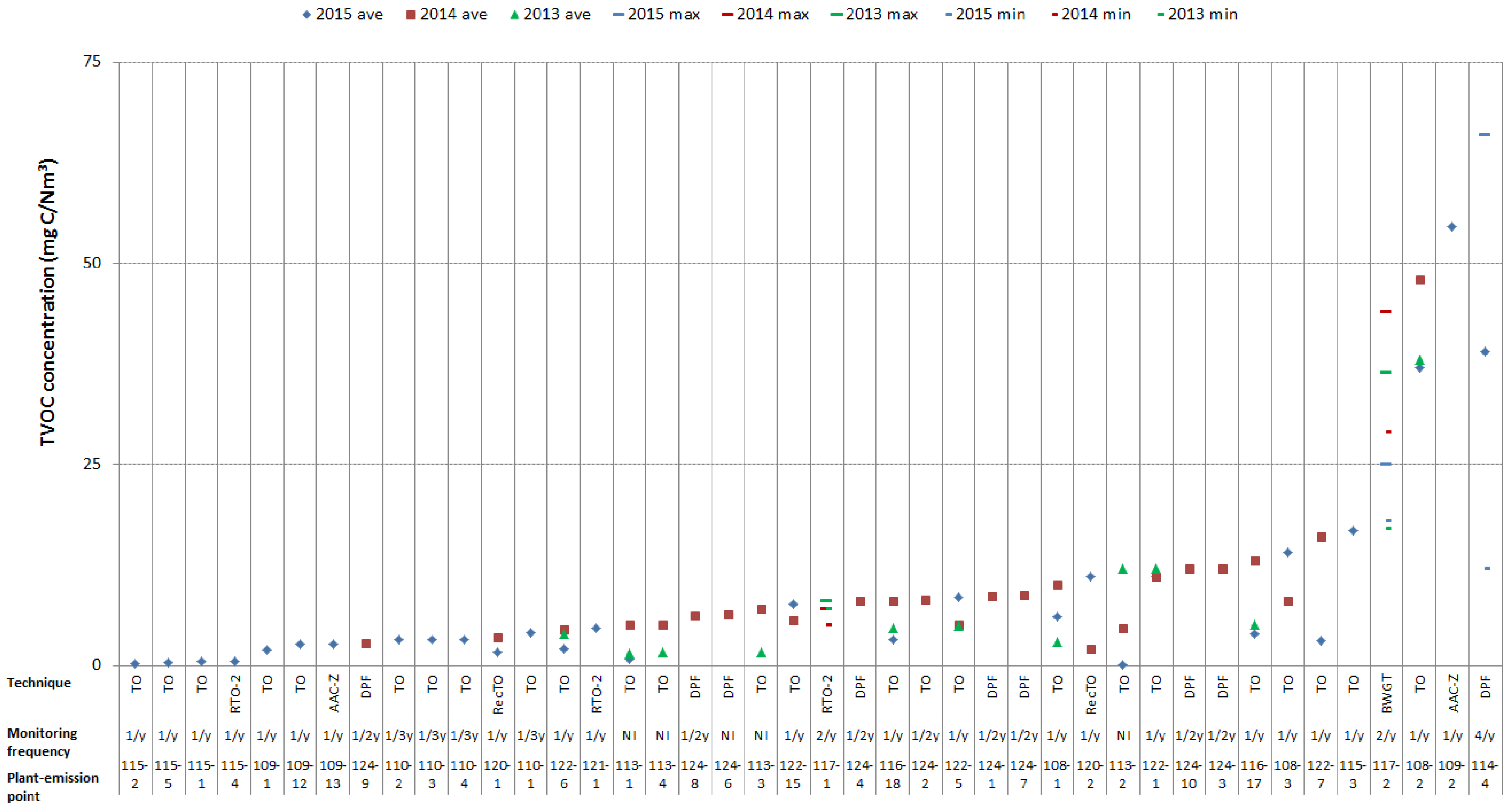
In general, TVOC emission values in waste gases below 20 mg/Nm^3 are achieved, depending on the origin of the emission (the process), the applied abatement technique and the inlet (off-gas) concentration. Reported levels for TVOC emissions in waste gases, expressed in mg C/Nm^3, are presented in Figure 10.14.

Most of the reported data refer to a monitoring frequency of once a year with a few cases of monitoring every 6 months and one case with a monitoring frequency of once every 5 years. The basic statistical parameters of the reported data are presented in Table 10.7.

Table 10.7: Statistical parameters of reported data for TVOC emissions in waste gases for the period 2013-2015

Applied technique	2015				2014				2013			
	No of values	Ave-rage	Max.	Min.	No of values	Ave-rage	Max.	Min.	No of values	Ave-rage	Max.	Min.
		mg C/Nm^3				mg C/Nm^3				mg C/Nm^3		
TO	22	6.1	37.0	0.1	15	10.6	48.0	4.5	12	22.4	180.0	1.5
RecTO	2	6.4	11.1	1.6	2	2.8	3.5	2.1	NA	NA	NA	NA
RTO-2	3	3.7	6.0	0.6	1	6.0	NA	NA	1	7.5	NA	NA
AAC-Z	2	28.6	54.5	2.6	NA	NA	NA	NA	NA	NA	NA	NA
DPF	1	39.0	NA	NA	9	65.2	522.0	2.8	1	222.0	NA	NA
BWGT	1	21.5	NA	NA	1	21.5	NA	NA	1	28.0	NA	NA
NI	NA	NA	NA	NA	NA	NA	NA	NA	1	466.0	NA	NA

NB:
NA: Not available / not applicable.
NI: No information.
Source: [155, TWG 2016]



NB: Plant #113, #112 & #117 data for 2012 instead of 2015

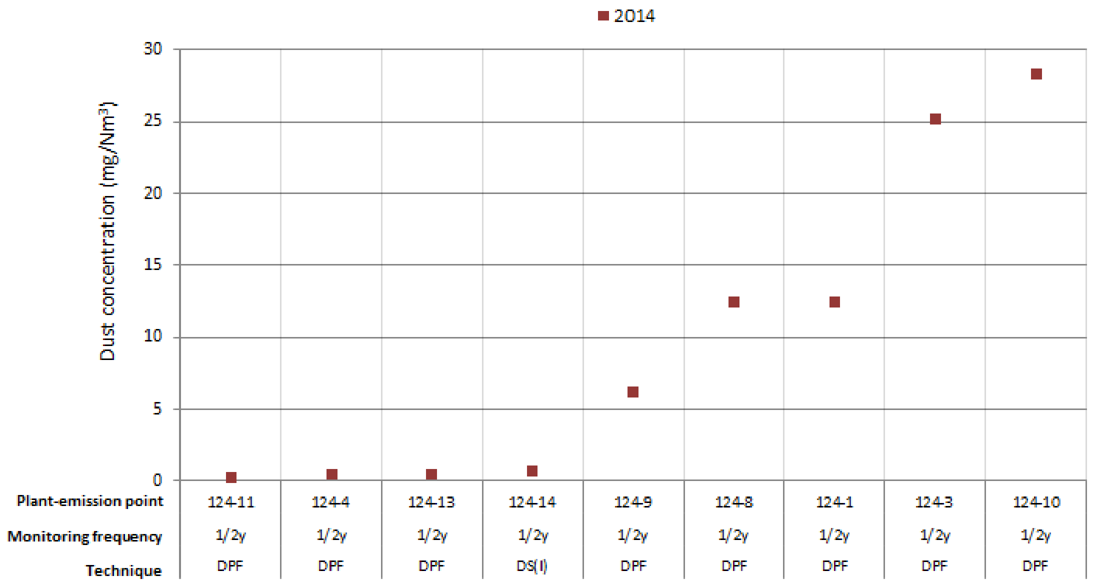
Data not shown: Plant #112-1: 2013: 180 mg C/Nm³ (ave), plant#114-1: 2013: 466 mg C/Nm³ (ave), plant #124-12: 2014: 522 mg C/Nm³ (ave), 2013: 222 mg C/Nm³ (ave).

Source: [155, TWG 2016]

Figure 10.14: TVOC emissions in waste gases for the period 2013-2015

10.3.2.4 Dust emissions in waste gases

The reported levels of dust emissions in waste gases are presented in Figure 10.15. Reported data refer to various emission points of only one plant with a reported monitoring frequency of once every 2 years.

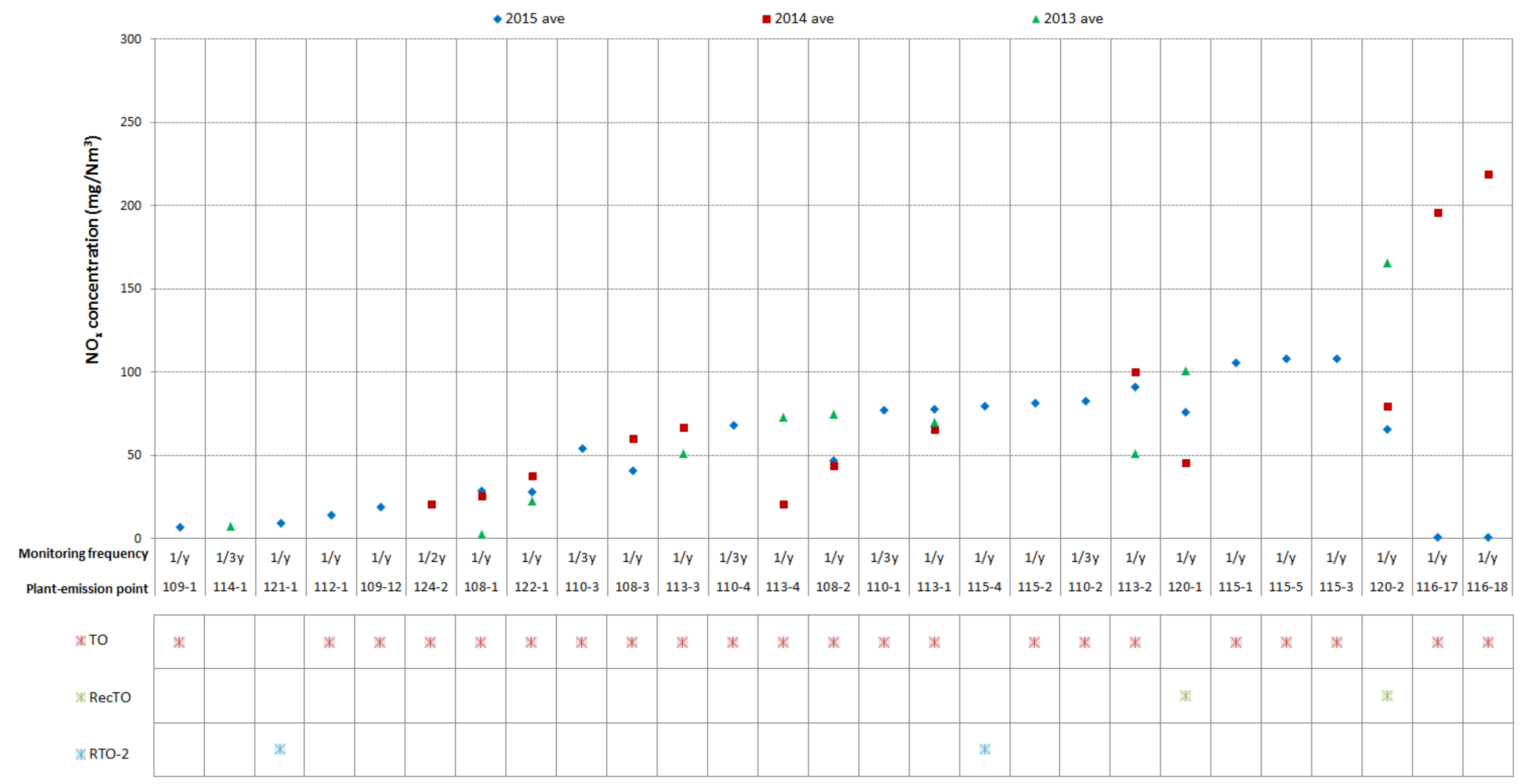


Source: [155, TWG 2016]

Figure 10.15: Dust emissions in waste gases (periodic monitoring) - Average values for the period 2013-2015

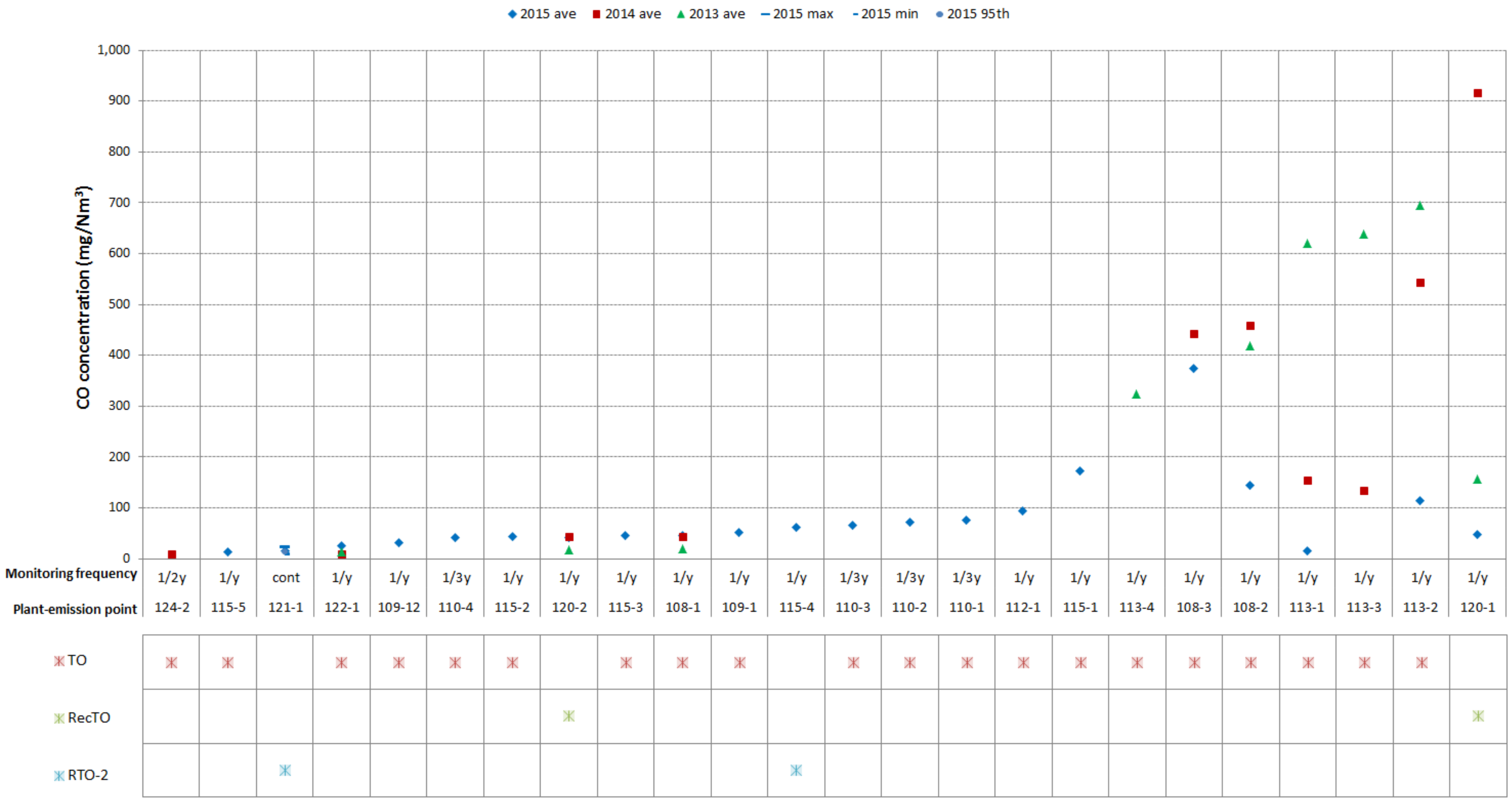
10.3.2.5 NO_X and CO emissions in waste gases

Nitrogen oxides (NO_X) and carbon monoxide (CO) emissions result from the thermal treatment of VOC-laden off-gases. The reported values of nitrogen oxides (NO_X) and carbon monoxide (CO) emissions in waste gases are presented in Figure 10.16 and Figure 10.17. The reported monitoring frequency varies from once a year up to once every 3 years.



Source: *[155, TWG 2016]*

Figure 10.16: NO$_X$ emissions in waste gases for the period 2013-2015



Source: [155, TWG 2016]

Figure 10.17: CO emissions in waste gases for the period 2013-2015

10.3.2.6 Emissions to water

[155, TWG 2016]

Data for emissions in waste water were submitted for only three plants. Two of them discharge to a sewage system with downstream waste water treatment and the third discharges directly to the receiving water body after mixing with other treated waste water streams from other activities.

The reported levels/ranges of pollutant concentrations are as follows:

- COD: 293 mg/l (maximum value for daily monitoring, 95th percentile: 191 mg/l direct discharge);
- TSS: 20 mg/l (maximum value for daily monitoring, direct discharge);
- Zn: 0.02-0.091 mg/l;
- Crtotal: 0.01075-< 0.046 mg/l;
- F-: 6.1-31 mg/l (maximum values for two plants, direct and indirect discharge);
- AOX: 0.037-0.795 mg/l (maximum values for two plants, direct and indirect discharge);
- Al: 0.75 mg/l.

See Section 10.4.6 for applied waste water treatment techniques.

10.3.2.7 Waste generation

[155, TWG 2016]

Waste generation from coating and printing of two-piece cans
The main reported waste streams are related to:

- waste inks, lacquers;
- waste related to cleaning activities such as: absorbents, filter materials, cleaning cloths;
- paint or varnish sludges;
- sludges from the waste water treatment;
- empty containers and other contaminated packaging;
- oil residues and oil separator waste.

Reported values for the main waste categories are presented in Table 10.8.

Table 10.8: Reported values of waste generation for the main waste streams for two-piece can coating installations

Waste type	Waste quantity generated (g waste per m^2 of coated surface)
Paint and varnish sludges	0.16
Lacquers and grease	0.22
Inks, paints and varnishes	0.30
Absorbents, filter materials, cleaning cloths	0.21-5.1
Other solvents and solvent mixtures	0.5-1.8
Empty containers and other contaminated packaging	5.4
Source: [155, TWG 2016]	

10.4 Techniques to consider in the determination of BAT for the coating and printing of metal packaging

In Chapter 17, techniques are discussed which might also be applicable to the coating and printing of metal packaging. In Table 10.9, the general techniques relevant for the coating and printing of metal packaging that are described in Chapter 17 are shown. These techniques are not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 17.1.

Table 10.9: Reference to techniques generally applicable to the sector

Technique	Section number
Environmental management techniques	17.1
Storage and handling of raw materials	17.2
Monitoring	17.3
Water use and waste water generation	17.4
Energy management and energy efficiency	17.5
Raw material management (including substitution)	17.6
Coating processes and equipment	17.7
Drying and/or curing techniques	17.8
Cleaning techniques	17.9
Off-gas extraction and treatment	17.10
Waste water treatment techniques	17.11
Waste management techniques	17.12
Odour emissions	17.13

10.4.1 Material-based techniques

10.4.1.1 Water-based coating and ink systems

Description
For a general description, see Section 17.7.2.2.

Achieved environmental benefits
Reduced VOC emissions.

Environmental performance and operational data
The exhaust air from the spray application and the dryers is usually treated. Substitute coatings are mainly available for draw and wall ironing (DWI) can coating processes.

Cross-media effects
Changing to water-based coating and ink systems means increased energy use (and therefore CO_2 emissions) for dryers and thermal oxidisers. However, if the VOC emission reduction is sufficient and the use of an oxidiser can be avoided, the energy usage may be the same or less (see the ECM REF, Annex 14 on water-based printing).

Technical considerations relevant to applicability
Aluminium cans are mainly coated with water-based coatings (e.g. lacquers).

Example plants
Plants #123, #116, #118, #119, #113, #117 and #124 (inside spraying, base coat) in [155, TWG 2016].

Reference literature
[5, DFIU et al. 2002] [29, UKDEFRA 2003] [34, Germany 2003] [38, TWG 2004] [50, COM 2006] [78, TWG 2005] [155, TWG 2016]

10.4.1.2 Water-based coating systems and compounds in metal packaging manufacture based on sheetfed technology

This section gives information on three-piece cans as well as the other metal packaging which is not DWI.

Description
For a general description, see Section 17.7.2.2.

Technical description
The following water/solvent-based coating systems are applicable to metal packaging as follows:

- three-piece cans for food, drinks, aerosols and speciality products;
- three-piece cans welded side stripe protection; water-based coatings may be applied onto the side stripe of weldings;
- ends, caps, lids and closures for three-piece cans, jars and bottles;
- two-piece non-DWI cans.

Achieved environmental benefits

- Reduction in organic solvent emissions.
- Reduced health and safety risks for operators of coating machines because of a reduced exposure to solvents.
- Reduced fire and explosion risks.

Environmental performance and operational data
Exhaust air from the coating process and the dryers is usually treated. Water-based coating systems have to be stored in a frost-free environment.

Cross-media effects

- Increased machine cleaning frequency and downtime.
- Increased sludge in the extract system (condensate and resin). Requires thermal drying ovens.

Technical considerations relevant to applicability
Water-based compounds are often available and applied. Wet-on-dry applications are only subject to quality parameters. The technique is applied to metal packaging components, caps and closures.

Economics
Process pumps and pipework need to be of high-quality steel. There are increased maintenance costs for wear to scraper blades, and increased extract system cleaning costs. Investment is necessary for drying ovens and high-quality supply of distribution pipework systems.

Driving force for implementation
VOC emissions reductions.

Example plants
Ardagh Hoogeveen and Ardagh Deventer both in the Netherlands.
Plant #113 in [155, TWG 2016].

Reference literature
[29, UKDEFRA 2003] [38, TWG 2004] [155, TWG 2016]

10.4.1.3 Powder spray side stripe coating

Description
For a general description, see Section 17.7.2.6.

Achieved environmental benefits
No organic solvent emissions.

Environmental performance and operational data
Electrostatic control of spray is necessary.

Cross-media effects
The film weight is typically 10 times that needed for a liquid side stripe.

Technical considerations relevant to applicability
This technique is applied to metal packaging manufacture based on sheetfed technology for inside side stripe protection of cans for aggressive filling goods. Powder coatings may be applied onto the welding and are called ‘side stripes’. Powder coatings are used for three-piece welded can side stripe protection.

Economics
Applied costs of powder are higher than for liquid lacquers.

Example plants
Plants #112 (side stripe powder coating) and #121 in [155, TWG 2016].

Reference literature
[29, UKDEFRA 2003] [38, TWG 2004] [155, TWG 2016]

10.4.1.4 UV-radiation-cured coatings (varnish and inks)

Description
See Section 17.7.2.3. See also Section 10.4.4.1 for the UV curing technique in metal packaging.

Technical description
UV inks are applied to a wide range of products: aerosols, food cans, general line containers, closures, and caps. UV varnishes are also used for aerosols, food cans and some general line containers.

Achieved environmental benefits

- No organic solvent emissions.
- No thermal curing ovens and associated energy and emissions implications.

Environmental performance and operational data
Caution must be exercised with the use of UV materials and their suitability for any fill product.

Cross-media effects
Ozone is emitted.

Technical considerations relevant to applicability
This technique applies to three-piece cans as well as other metal packaging which is not DWI.

Use of UV inks for metal packaging has increased in non-food applications and is commonly applied to metal packaging manufacture based on sheetfed technology. UV lamp curing replaces conventional thermal drying ovens. Applications of UV varnish are highly limited by standards related to flexibility and resistance to abrasion.

Example plants
Plants #112, #121, #122, #123, #116, #118, #119, #114, #120 (only used UV-cured inks in printing), #117 and #124 in [155, TWG 2016].

Reference literature
[29, UKDEFRA 2003] [38, TWG 2004] [155, TWG 2016]

10.4.2 Application of coatings and inks

10.4.2.1 Roller coating

Description
A coating is applied from a rotating rubber roller onto a flat (sheet or coil) or cylindrical (cans) substrate. The coating thickness can be adjusted by variation in the pressure between the roller and the substrate. In metal packaging manufacturing, roller coaters are used for sheets coated both sides in different passes, for beverage cans and the outside of monobloc aerosol cans (see also Section 17.7.3.1).

Technical description
A train of steel rollers feeds the rubber roller with coating. A wet film weight of up to 30-35 microns can be achieved when rubber rollers rotate in the same direction as the sheet. Nowadays, the rubber roller is also fed by a single steel roller of the anilox type (cell structure) in combination with a doctor blade. Sheetfed application also requires a steel support roller under the substrate. Sheet application also means a gap between the sheets, causing contamination on the support roller, which must be removed by a scraper blade system.

In sheetfed application, only lacquers with a certain viscosity can be applied, in contrast to the reverse roller application as used in coil application. Roller coaters are normally combined with a curing step as the sheets are directly staggered and are therefore combined with a thermal oven and/or UV curing step.

Coating of cylindrical surfaces requires a high rotation speed of the application roller, which leads to misting of the wet lacquer. As a consequence, frequent cleaning of the machine is necessary. The metal parts of the roller coater in contact with the coating are cleaned in a cleaning machine operating on water with detergents. The rubber rollers are manually cleaned with a mild solvent.

The most commonly used materials are rubber based on EPDM (ethylene-propylene-diene terpolymer), butyl rubber and PU. The choice depends on multiple factors.

Achieved environmental benefits
The introduction of anilox rollers reduces the amount of lacquer applied due to better production margins and the option of spot coating.

Environmental performance and operational data

Efficiency is almost 100 %. Coaters are normally equipped with air extraction to minimise the VOCs for health and safety reasons. All solvents are extracted in the oven and can then be treated.

Coatings used can be diluted to achieve good viscosity; however, more and more coatings are ready-for-use.

Cross-media effects

Solvents are used to clean the roller coater. But nowadays a cleaning machine is often used for parts of the coater in contact with the coating.

Technical considerations relevant for applicability

Roller coaters for metal packaging can be used for all types of coatings including water-based and UV coatings.

In some cases, an anilox roller system is used to improve the flow of the coating on the substrate. Also, pretreatment of the surface is possible when placing this between the feeder roller and the roller coater of the line (e.g. flame treatment).

Economics

The roller coater is not a stand-alone piece of equipment but is part of a line including an oven and equipment to transport the sheets or cans through the oven and the roller coater.

Additional process equipment is needed; this makes such a line expensive.

Driving force for implementation

The technique has almost 100 % coating efficiency on sheets. Mostly the required film weight is achieved in one pass. Also, it offers flexibility as every type of lacquer needed for three-piece operations can be applied. Coating of ends is possible because of spot coating and, for body application, welding margins can be made on the sheet by the use of a roller coater.

Example plants

Plants #121, #112, #108, #122, #123, #118, #119, #114, #120, #117 and #124 in [155, TWG 2016].

Reference literature

[155, TWG 2016] [189, MPE 2017]

10.4.2.2 Electrostatically assisted air or airless spraying

Description

For a general description, see Section 17.7.3.12.

Achieved environmental benefits

The application efficiency of the interior spraying ranges from 93 % to 97 % for two-piece DWI can manufacture.

Environmental performance and operational data

The overspray is commonly separated by applying dry filter systems. The overspray coating is not reused or recycled.

Cross-media effects

Waste generation if dry filtering applies.

Technical considerations relevant to applicability
Compressed air spraying is commonly applied for the application of internal coating for two-piece DWI can manufacture and in the manufacture of metal packaging based on sheetfed technology.

Economics
Minimisation of the use of lacquer through targeted profile application.

Driving force for implementation
Environmental benefits and economic reasons.

Example plants
Plant #108 in [155, TWG 2016].

Reference literature
[5, DFIU et al. 2002] [29, UKDEFRA 2003] [34, Germany 2003] [38, TWG 2004] [155, TWG 2016]

10.4.2.3 Air-assisted airless spraying

Description
For a general description see Section 17.7.3.8. Side stripes can be applied by using air-assisted airless spray guns. Air-assisted airless spraying (electric) is commonly used for the application of the internal coating.

Achieved environmental benefits
The application efficiency of the interior spraying is 90 % in the manufacture of two-piece DWI cans. Lacquer consumption is minimised through targeted profile application.

Cross-media effects
Waste generation if dry filtering applies.

Environmental performance and operational data
The overspray is commonly collected by dry filter systems. The overspray coating is not reused or recycled.

Technical considerations relevant to applicability
Airless spraying is commonly applied for the internal coating of two-piece DWI cans and in metal packaging based on sheetfed technology.

Economics
High application efficiency and lower raw material use, see 'Driving force for implementation' below.

Driving force for implementation
The technique reduces emissions to air and is cost-effective.

Example plants
Plants #123 and #124 in [155, TWG 2016].

Reference literature
[5, DFIU et al. 2002] [29, UKDEFRA 2003] [34, Germany 2003] [38, TWG 2004] [155, TWG 2016]

10.4.2.4 Liquid side stripe

This section gives information on three-piece cans only.

Description
A lacquer side stripe is applied to the external and internal areas of the welded region of the can cylinder. The film weight per typical can is approximately 0.02 g/can and the type of lacquer is selected according to the aggressive nature of the products that will fill the can. Water-based materials are available for selective can products after having undergone extended qualifying pack tests (see Example plants below).

Achieved environmental benefits
Reduced VOC emissions.

Environmental performance and operational data

- Water-based lacquers may be used with standard side striping equipment.
- Reduced health and safety risks for operators of coating machines because of a reduced exposure to solvents.
- Reduced fire and explosion risks.

Technical considerations relevant to applicability
Water-based materials are not suitable for inside side striping of cans for aggressive products.

Economics
The cost of water-based and solvent-based techniques is roughly the same.

Example plants
Plants #112 (project to substitute SB lacquer with WB), #121, #116 (WB) and #120 in [155, TWG 2016].

Reference literature
[29, UKDEFRA 2003] [38, TWG 2004] [78, TWG 2005] [155, TWG 2016]

10.4.2.5 Curtain coating

Description
For a general description, see Section 17.7.3.4.

Technical description
This is a coating technique used for the external anti-corrosion protection of DWI cans for food products where a plain (non-decorative) protective finish is required. The coating normally also contains a lubricant to aid can mobility during subsequent manufacture and filling. The coating is applied by the passage of previously cleaned and rinsed upturned (base uppermost) cans, en masse on a wide conveyor belt, under single or multiple waterfalls or curtains of a dilute water-based ‘wash coat’. The excess wet coating runs off the cans into a capture and recirculating system, then the can immediately enters an oven to evaporate the liquid carrier and cure the remaining solids into a protective film. The curtain coater is normally constructed as an integral part of the overall can cleaning, rinsing and drying facility. The continuous ingress of deionised water on the can from the prior can rinsing process dilutes the wash coat in the system which is reconcentrated by ultrafiltration and/or periodic additions of concentrated wash coat. The wash coat is primarily water-based but with a small VOC content to aid wettability of the can surface.

Achieved environmental benefits
Use of water-based coating materials minimises solvent content.

Environmental performance and operational data
When cans are not to be decorated as is the normal case for food cans, then a clear external protective coat is applied to the upturned can via a curtain coater. Curtain coating systems incorporate a closed-loop capture and recirculating facility.

Technical considerations relevant to applicability
The technique provides food cans with external protection. It is applied in two-piece draw and wall ironed (DWI) can manufacture.

Economics
Optimisation of materials.

Driving force for implementation
Cost and environmental benefit.

Reference literature
[29, UKDEFRA 2003] [38, TWG 2004]

10.4.3 Printing

10.4.3.1 Lithography (wet offset) for sheetfed technology

This section gives information on three-piece cans as well as the other metal packaging which is not DWI.

Description
For a general description, see Section 10.2. Modern lithographic printing presses are capable of speeds in excess of 6 000 sheets per hour. The number of printing colours employed is design-specific, e.g.:

- milk powder containers can have 10/11 colours;
- promotional metal containers can have 13/14 colours.

Achieved environmental benefits
Printing inks used for lithographic processes typically contain less than 10 % organic solvent, resulting in low VOC emissions.

Environmental performance and operational data
Printing lines are comprised of between one and six printing decks and can apply from one to six colours in sequence. Some designs are achieved with a four-colour process set, whilst others are achieved with the six-colour hexachrome printing set. However, a large proportion of designs are still achieved using spot colours (i.e. ink colour matched to a specific shade to meet the needs of the design).

Cross-media effects
The organic solvents are typically dispersed directly to the air from the drying ovens.

Technical considerations relevant to applicability
Common technology used in the flat sheet metal packaging printing industry.

Example plants
This technique is commonly applied. Plants #112 (UV-cured inks), #121 and #120 (flat sheet coating lines) in [155, TWG 2016].

Reference literature
[29, UKDEFRA 2003] [38, TWG 2004] [155, TWG 2016]

10.4.3.2 Waterless lithography

Description
See also Section 11.4.2.3.

Waterless offset is an offset printing technique that does not use water/oil separation to ensure that the ink only covers the image-carrying parts of the plate: separation is achieved by special plates and inks. In normal offset, the plate is hydrophobic in the image-carrying places and hydrophilic elsewhere. Water is used to make sure that the oily inks do not attach to the non-image-carrying parts. In waterless offset, the non-image-carrying parts have a coating that achieves the same effect. No water is needed.

Achieved environmental benefits
This technique achieves resource and raw material savings and emissions from dampening solutions are eliminated. The set-up times for decoration changes are reduced. To reduce the material consumption for the exterior varnish, the can can be directly printed via the offset process and then coated with a thin layer of varnish (clear coat) for protection of the print.

Cross-media effects
Additional energy consumption for the cooling of the plant is required.

Technical considerations relevant to applicability
This process is normally used when printing on the product is not possible such as on circular surfaces; examples are drink cans, caps and extruded aluminium tubes. This technique can be applied for selected metal packaging products. In new installations, engraving rollers are utilised for the application of the printing ink.

Economics
There is an additional cost for cooling the press. For existing installations, the investment costs are considerable.

Driving force for implementation
The reduction in chemical usage improves workplace health and safety.

Reference literature
[5, DFIU et al. 2002] [29, UKDEFRA 2003] [38, TWG 2004]

10.4.3.3 Waterless offset lithography for aluminium extruded tube manufacture

Description
See also Section 10.4.3.2. The cured base coat provides the key for the subsequently printed design, which is applied via a multicolour decorator using the waterless offset process.

Achieved environmental benefits
This technique achieves resource and raw material savings and emissions from dampening solutions are eliminated.

Environmental performance and operational data
Inks are spooned by hand to the reservoir rolls and a precise system of rolls accurately measures each colour separately onto the application roll. Usually, there is a fume extractor at the decorator, which is ducted to the air once it has passed through a caustic scrubber.

Reference literature
[29, UKDEFRA 2003]

10.4.4 Curing

10.4.4.1 Ultraviolet (UV) curing of coatings for metal packaging

Description

UV-cured is a process where ultraviolet light is used to initiate a photochemical reaction that generates cross-linking and polymerisation between resins. See also Section 17.8.5.4.

Technical description

UV curing can be used for the printing and coating in the metal packaging industry. Its main application is for the outside of cans as there are restrictions concerning food contact. It is a low-temperature and solvent-free process. Low-molecular-weight resins/monomers, with a low viscosity, start a rapid chemical reaction/cross-linking. This reaction is initiated by the formation of reactive cleavage products of the so-called photoinitiators. This cleavage process is started if the photoinitiator is in contact with UV light of a specific frequency. Different types of coating demand different photoinitiators. The UV light is generated by the use of doped mercury lamps, with the types used depending on the end use and the corresponding photoinitiator. The end use is mainly flat sheets with the exception of UV coating for the rim of a beverage can's base. Although the process is solvent-free, extraction is still necessary due to the formation of ozone and a need to avoid possible odour problems caused by the used monomers. The cleavage products of the photoinitiator are by theory bound to the backbone of the formed polymer.

Achieved environmental benefits

UV curing uses solvent-free lacquers / printing inks (see Section 17.7.2.3). In combination with a lower amount of energy compared to the thermoset lacquers which need a long thermal oven, CO_2 emission is also avoided.

Environmental performance and operational data

UV curing systems are often combined with the roller coaters that are normally used in metal packaging manufacturing. However, combinations of UV application and conventional gas ovens can also be found. UV curing systems also require less space. UV varnishes and UV printing inks have a limited adhesion towards metal and can therefore not be used for some applications.

Cross-media effects

Off-gases from the application and curing of UV coatings will still need extraction for health and safety reasons due to ozone formation.

Technical considerations relevant for applicability

UV curing is currently limited to the outside of cans due to restrictions relating to food contact legislation. Also, direct application on electrolytic tinplate is more difficult due to limited adhesion. New UV resin technologies, like cationic curing, have less restriction concerning smell and will have more possible end uses than the old technologies. New types of UV light sources are developed like UV-LED, with less energy consumption, longer lifetimes and a better curing control. However, the tighter frequency range of LEDs requires lacquer modifications when changing from mercury lamps to LEDs. There are presently no UV lacquers available which suit the high-speed roller coater application for DWI cans.

Economics

The cost depends greatly on whether UV curing equipment is installed in an existing line or in a new line.

Driving force for implementation

Lower energy consumption, lower emissions and in typical cases economic reasons.

Example plants

Plants #112, #121, #122, #123, #116, #118, #119, #114 and #120 (only used UV-cured inks in printing), #117, #124 in [155, TWG 2016].

Reference literature

[155, TWG 2016] [189, MPE 2017]

10.4.5 Off-gas extraction and treatment

Available techniques for the extraction of off-gases and minimisation of fugitive emissions are discussed in Section 17.10.2.

Extraction and treatment of air from the coating application point and drying/curing ovens is commonly applied.

The following off-gas treatment techniques are commonly applied:

- oxidation: recuperative and regenerative oxidation, see Section 17.10.5;
- adsorption using activated carbon or zeolites, see Section 17.10.6.2;
- dry scrubbing, see Section 17.10.6.3;
- biological off-gas treatment, see Section 17.10.7.

Example plants

Widely applied. For detailed information, see Section 10.3.2.3.

10.4.6 Waste water treatment

For general descriptions of waste water treatment techniques, see Section 17.11.

10.4.6.1 Coagulation and flocculation

For a general description, see Section 17.11.4.1. This is commonly applied to the waste water generated from a can cleaner. It is used in the case of DWI cans. For the production of steel cans, a discharge tin concentration of < 2 mg/l to a maximum of 4 mg/l has been reported.

Example plants

Plants #114 and #117 in [155, TWG 2016].

Reference literature

[5, DFIU et al. 2002] [38, TWG 2004] [155, TWG 2016]

10.4.6.2 Sedimentation

For a general description, see Section 17.11.4.2.

Example plants

Plants #114 and #117 in [155, TWG 2016].

10.4.6.3 Neutralisation

For a general description, see Section 17.11.1.1.

Example plants
Plants #114 and #117 in [155, TWG 2016].

10.4.6.4 Filtration (ultra and nanofiltration and reverse osmosis)

For a general description, see Section 17.11.4.3. This technique can be applied to waste waters generated from the pretreatment processes of the following industries:

- two-piece draw and wall ironed (DWI) can manufacture;
- metal packaging manufacture based on sheetfed technology;
- aluminium extruded tube manufacture.

Example plants
Plants #114 and #117 in [155, TWG 2016].

10.4.6.5 Ion exchange

For a general description, see Section 17.11.2.5. This technique can be applied as a water-saving process to reduce the waste water volume.

11 HEATSET WEB OFFSET PRINTING

11.1 General information on heatset web offset printing

[1, INTERGRAF and EGF 1999] [78, TWG 2005]

Offset is a printing process using an image carrier in which the printing and non-printing areas are on the same plane. The non-printing area is treated to attract water and thus reject the greasy ink. The printing area is treated to receive and transmit ink to a rubber-coated cylinder and from there to the surface to be printed. Heatset means an offset printing process where evaporation takes place in an oven where hot air is used to heat the printed material. Most offset inks do not dry by evaporation, but by oxidation or absorption in the paper. Heatset inks are the exception. They are the unique offset ink, drying largely through evaporation.

Emissions to air arise primarily from the organic solvents contained in inks. Solvents used in cleaning and dampening solutions (commonly isopropanol) are also important sources of VOC emissions. Solvents driven off through evaporation from the inks may be discharged untreated or destroyed via thermal oxidation. Cleaning techniques range from wiping equipment with a solvent cloth to the use of enclosed cleaning units designed to recycle solvents.

11.2 Applied processes and techniques in heatset web offset printing

[1, INTERGRAF and EGF 1999] [78, TWG 2005]

Offset printing is a planographic printing technique, i.e. where the image and non-image areas are on the same plane as the image carrier. The non-printing areas are kept free of ink by being ink-repellent while the printing areas are ink-receptive. This is achieved by the offset ink being oil-based and the non-printing areas being kept clean with water or water-based solutions, as the water and oil repel each other. The additives to the water are usually isopropyl alcohol (IPA) or isopropyl alcohol substitutes/extenders, etc. However, waterless printing is also possible, where the non-printing areas are kept free of ink by an ink-repellent coating [3, IMPEL 2000] [8, Nordic Council of Ministers 1998] [38, TWG 2004].

Offset is currently the most widely used printing process for an extensive range of products such as books, newspapers, stationery, corrugated board, posters, etc.[34], due to its versatility, speed, quality, and cost-effectiveness achieved by a series of developments in plates and extending their service life, improved materials allowing higher quality and ease of use with photosetting.

Offset machines come in a variety of sizes, from the small offset sheetfed press which prints A3 through the large sheetfed press of 1 200 mm x 1 600 mm or more dealing with many colours at a time, to the large web presses printing paper two metres wide at very high speeds. The versatility of the process allows the production of a very wide variety of printed products [38, TWG 2004].

Modern web presses are built with eight units which makes it not only possible to print eight colours on one side of the substrate, but also to print four colours on each side in one run. Modern presses are also built to meet an increasing demand for automation and new presses come equipped with automatic cleaning systems for plates, blankets and impression cylinders, automatic systems for changing plates, etc. [8, Nordic Council of Ministers 1998] [38, TWG 2004].

Depending on the type of printing process, substrate or products printed, the offset process is further divided into subprocesses [3, IMPEL 2000] [38, TWG 2004]:

- sheetfed offset;
- heatset web offset;
- coldset offset.

Offset inks used in sheetfed and coldset offset dry through adsorption into the paper and by oxidation. With glossy paper especially, adsorption happens too slowly for modern fast printing presses. Modern high-speed webfed offset presses, which print onto non-adsorbent paper, are therefore equipped with forced hot air drying systems; these offset printing processes are called ‘heatset’.

The dampening unit
[1, INTERGRAF and EGF 1999] [78, TWG 2005] [212, TWG 2018]

The task of the dampening unit in an offset machine is to wet the surface of the printing plate with a uniform film of moisture during printing, so that when inking follows it only adheres to the plate in the image areas.

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[34] https://www.prepressure.com/printing/processes (2019)

Film dampening units are the most widely used. These put down a thin film of dampening solution onto the plate using a series of rollers which distribute the liquid in a controlled and consistent way.

This dampening unit construction operates either with water or, in many cases, with a water-isopropanol (isopropyl alcohol - IPA) solution (or, in some cases, ethanol - note that ethanol has a higher ozone formation potential, OFP) and uses the technologically favourable (in respect of printing) properties of IPA. The acidic IPA-based dampening solutions (with a pH of normally between 4 and 5.5) enhance the desensitising action in the non-image areas and maintain their hydrophilic properties. Other commonly used additives are: gum arabic, corrosion inhibitors, wetting agents, drying stimulators, fungicides, anti-foaming agents, etc. [8, Nordic Council of Ministers 1998].

IPA has a lower surface tension than water and, therefore, has the capacity to wet the plate more effectively. The process is complex, but empirically it is generally accepted that a thinner film of dampening solution can therefore be deposited on the plate, which allows greater control, especially on high-quality print jobs. Set-up times can be reduced, so less paper is wasted. The printing can be sharper, and less water on the plate means fewer problems with paper stretch.

The extent of IPA use varies from country to country, and with the make and model of the press, the paper type and the difficulty of the job. Since IPA evaporates faster than water, circulation units for the dampening solution and the dosing of IPA or ethanol are, in many cases, fitted with a cooling unit in order to reduce evaporation. The dampening solution is continuously pumped towards the press, and the excess returns to the container via an overflow. The concentration of IPA in the container is measured continuously. IPA is added automatically when the concentration diminishes.

In the last decade, IPA has been widely reduced and/or substituted by IPA-free dampening solutions. For example, in Germany IPA in the dampening solution was reduced to < 8 wt-% between 2001 and 2007 and to < 5 % in 2013 according to the German 31. BimSchV [DE comment #210 in [212, TWG 2018]].

The inking unit
[1, INTERGRAF and EGF 1999]

The inking unit found on offset presses varies with the size of the press and the job it is designed to do. Large presses and those designed to print quality work are likely to have many rollers in the ink train to ensure uniform ink distribution (more than 20 rollers is not unusual). Three or more of these actually apply the ink to the plate, with the quantity of ink being applied at any point across the width of the plate being adjustable by turning ink screws by hand or, increasingly these days, this can be computer-controlled.

Rollers are made of, or covered with, different materials, such as steel, synthetic rubber or polyurethane. From time to time, the ink needs to be removed by cleaning.

Drying may be accelerated by infrared heating or, alternatively, special inks may be used which are cured by ultraviolet radiation [1, INTERGRAF and EGF 1999].

Cleaning
[38, TWG 2004]

Depending on the printed image, the substrate and the ink being used, paper debris such as dust and lint, and printing ink constituents can build up on the rubber blanket. The quality of printing then declines so the blanket surface has to be cleaned. With smaller and medium-format machines, cleaning is carried out by hand and predominantly with wipes and cleaning agents. In the case of larger sheetfed machines, the use of automatic blanket cleaning units (with cleaning programmes) is increasing.

Obviously, the image has to be removed from the blanket between jobs. In both manual and automated blanket cleaning, mainly hydrocarbons and water (to remove paper solids on the rubber blanket) are used. The cleaning agents are predominantly naphthenic and aliphatic hydrocarbons. Increasingly high-boiling hydrocarbons with a flashpoint of > 100 °C and vegetable oil esters and/or mixtures of hydrocarbons and vegetable oil esters are used.

When a print run (or shift) is finished and the next printing work requires the use of other inks, cleaning of the inking units (ink rollers, ink ducts) and printing units (impression cylinders, etc.) is necessary. In the case of oxidative drying printing inks, such cleaning work may also be necessary at the end of each shift. To clean the inking rollers, cleaning agents are sprayed on and the cleaning residues are wiped off. Sheetfed machines of modern design are increasingly fitted with automatic cleaning units. The cleaning of the ink ducts is done either by hand or in special cleaning units, usually with the same materials as used for blanket cleaning [38, TWG 2004].

11.3 Current consumption and emission levels in heatset web offset printing

Mass balances – heatset

In 1999, the results of an inventory amongst heatset printing plants in Germany were reported. One of the results of this inventory was that the performance data from different units of different plants were compared and used to simulate a virtual plant that could meet the legal requirements, especially those of the then applicable Solvent Emissions Directive (SED)[35]. This virtual plant is not an existing plant, but made up of information from well-performing units from different existing plants representing good practice and good environmental performance. This plant could feasibly exist.

In this section, the mass balances of the theoretical virtual plant from this inventory are reported. Actual plants can vary widely with production parameters, such as ink coverage, run length, type of paper, etc. [38, TWG 2004]. However, it should be noted from Table 11.1 [38, TWG 2004] that:

- off-gas treatment usually operates at 700-800 °C, not 900 °C;
- the percentage of IPA is not defined: w/w or v/v.

The operational data and production conditions of the virtual plant are shown in Table 11.1 and Table 11.2. The mass balances of this virtual heatset offset plant are shown in Table 11.3 and Figure 11.1 shows the VOC balance.

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[35] Directive 1999/13/EC on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations, repealed by Directive 2010/75 (IED).

Table 11.1: Operational data of a virtual heatset offset plant

Machines	2 x 32-page heatset offset machine; 4 blanket-to-blanket units; web width: 1 260 mm; cylinder circumference: 890 mm; max. press speed 17 m/s; average velocity approx. 13 m/s at production run. Total power supply: 1 134 kW for press speed up to 14.8 m/s; Electricity consumption at an average press speed of 13 m/s: 996 kW, of which approx.: • 2 x 470 kW power supply printing press (2 x 295 kW motor power supply; 2 x 120 kW auxiliary drives (printing unit, auxiliary aggregates, control); 2 x 19 kW air blast; 2 x 30 kW roller bearing, 2 x 6 kW remoistening unit) • 2 x 6 kW power supply paper reel transport system • 2 x 91 kW power supply cooling centre
Products	Commercial printing, e.g. advertising supplements; weekly papers
Printing substrate	Web printing papers with an average weight of approx. 60 g/m^2
Printing ink	Heatset ink (vapour pressure < 0.01 kPa at 20 ºC; mineral oil content = 35 % of which about 90 % evaporates in the dryer
Dampening solution	Water (max. 10 ºdH), 8 % IPA, 3 % other dampening solution additives
Dryer	2 x direct combustion (natural gas), temperature (paper web exit): 120-140 °C, waste gas volume flow approx. 7 200 Nm^3/h (at 13 m/s production run), ventilator: 72 kW
Off-gas treatment	1 x regenerative thermal oxidation (thermoreactor), combustion chamber approx. 900 °C, VOC destruction efficiency: 99 %. Purified gas exit temperature at 140 °C; heat recovery: 93 % thermal efficiency. Heating up with 2 100 kW gas, normal operation 2 x 700 kW gas. 2 x 200 kW electricity demand (ventilators); electricity consumption 1 900 kW/yr, auxiliary combustion approx. 15 kW gas (at 13 m/s; 1.2 g/m^2 ink per page)
Cleaning agents	20 % roller/blanket for cleaning by hand (100 %VOC; vapour pressure 0.05 kPa at 20 °C) and 80 % blanket for clean-up device (0 % VOC; vapour pressure < 0.01 kPa at 20 °C), reusable solvent wipes (40 gram dry weight/item)
Source: [7, Germany 2003]	

Table 11.2: Production conditions of the virtual heatset offset plant

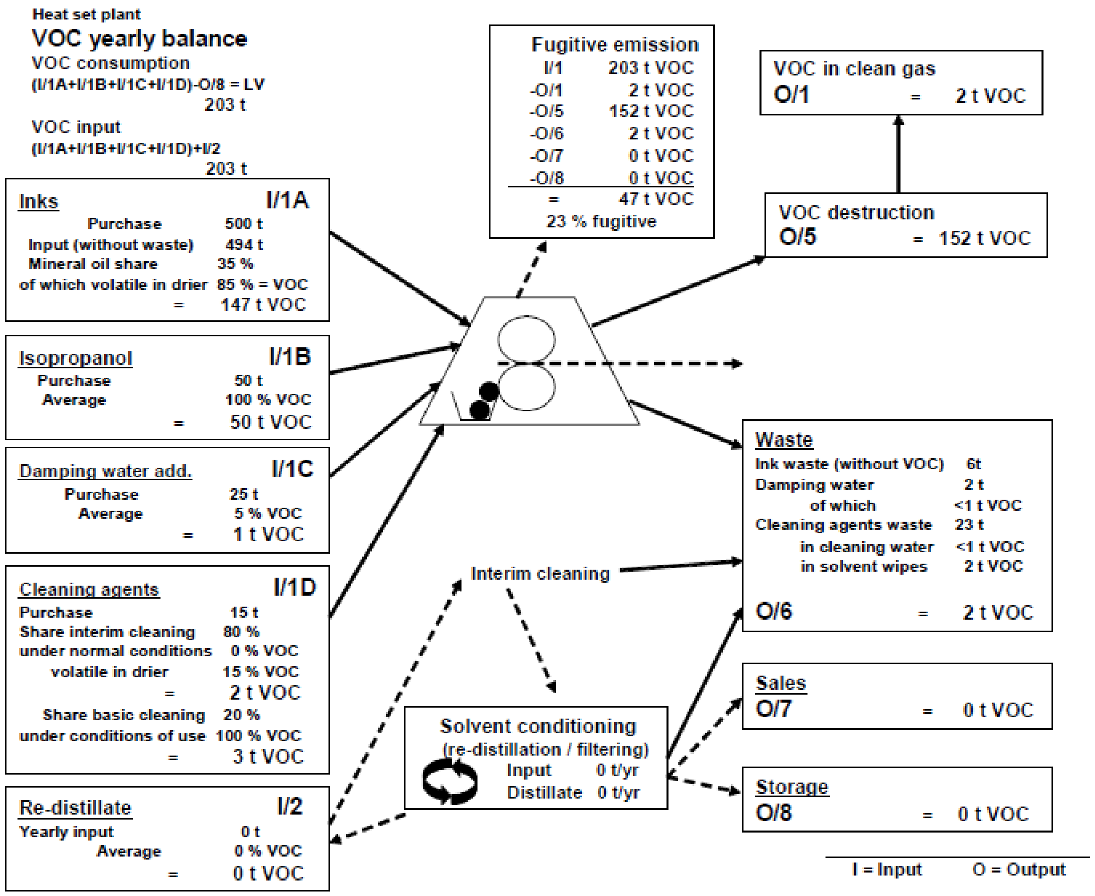
Production	3 shifts on 5.5 weekdays, 280 working days x 24 h = 6 700 yearly working hours; approx. 30 % preparation and servicing time, approx. 70 % production =>4 700 production hours of the printing presses
Products	Approx. 18 000 t/yr commercial printings from approx. 20 000 t/yr paper input and 500 t/yr ink input
Dampening solution	Approx. 1 025 t/yr; consisting of 950 tonnes water, 50 tonnes IPA and 25 tonnes other additives
Cleaning	Approx. 15 t/yr (80 % for interim cleaning, 20 % for basic cleaning) and 100 000 wipes.
Source: [7, Germany 2003]	

The following mass balance in Table 11.3 below is calculated for the virtual plant described in Table 11.1 and Table 11.2.

Table 11.3: Input and output of the virtual heatset plant

INPUT	Amount	Unit	Notes	Output	Amount	Unit	Notes
Material				*Products*			
Printing substrate	20 000	t/yr		Commercial printings	18 000	t/yr	Paper and ink
				Waste			
				Paper/misprints	2 800	t/yr	
Printing inks	500	t/yr	Mineral oil concentration in ink 35 %, of which 85-90 % evaporates in the dryer [38, TWG, 2004]	Ink residues	6	t/yr	Ink waste and in cleaning wipes, no VOCs
Dampening solution	950	t/yr	Without VOCs	Dampening solution residues	2	t/yr	4 % VOC
IPA	50	t/yr	100 % VOCs				
Dampening solution additives	25	t/yr	5 % VOCs				
Cleaning agents	15	t/yr	80 % VOC-free for interim cleaning, 20 % for basic cleaning	Mixture of cleaning agents and water	23	t/yr	50 % high-boiling solvents
Cleaning wipes	100 000	Items/yr	Usually reusable wipes, weight approx. 40 g/item	Cleaning wipes	100 000	Items/yr	Containing 1 t ink and 3 t cleaning agents with 100 % VOCs, of which 50 % evaporate as fugitive emissions
VOC total	203	t/yr		VOCs in waste	2	t/yr	In wipes, cleaning agents and waste dampening solution
Energy				***Exhaust gas***			
Energy in total	27 100	MWh/yr		Volume flow	67.7 x 10^6	m^3/yr	19 mg VOCs/m^3
Gas energy	13 700	MWh/yr		VOCs in purified gas	1.3	t/yr	
Electric energy	13 400	MWh/yr		NO_X in purified gas	2.7	t/yr	40 mg NO_X/m^3
Of which: Printing press	8 900	MWh/yr		CO in purified gas	3.4	t/yr	50 mg CO/m^3
Cooling	1 700	MWh/yr		***Fugitive***			
Off-gas treatment	700	MWh/yr		Fugitive VOCs	47	t/yr	23 %
Source: [7, Germany 2003]							

The VOC balance of the virtual plant is shown in Figure 11.1.



Source: [7, Germany 2003]

Figure 11.1: VOC balance of the virtual plant

However, it should be noted that Figure 11.1 [38, TWG 2004]:

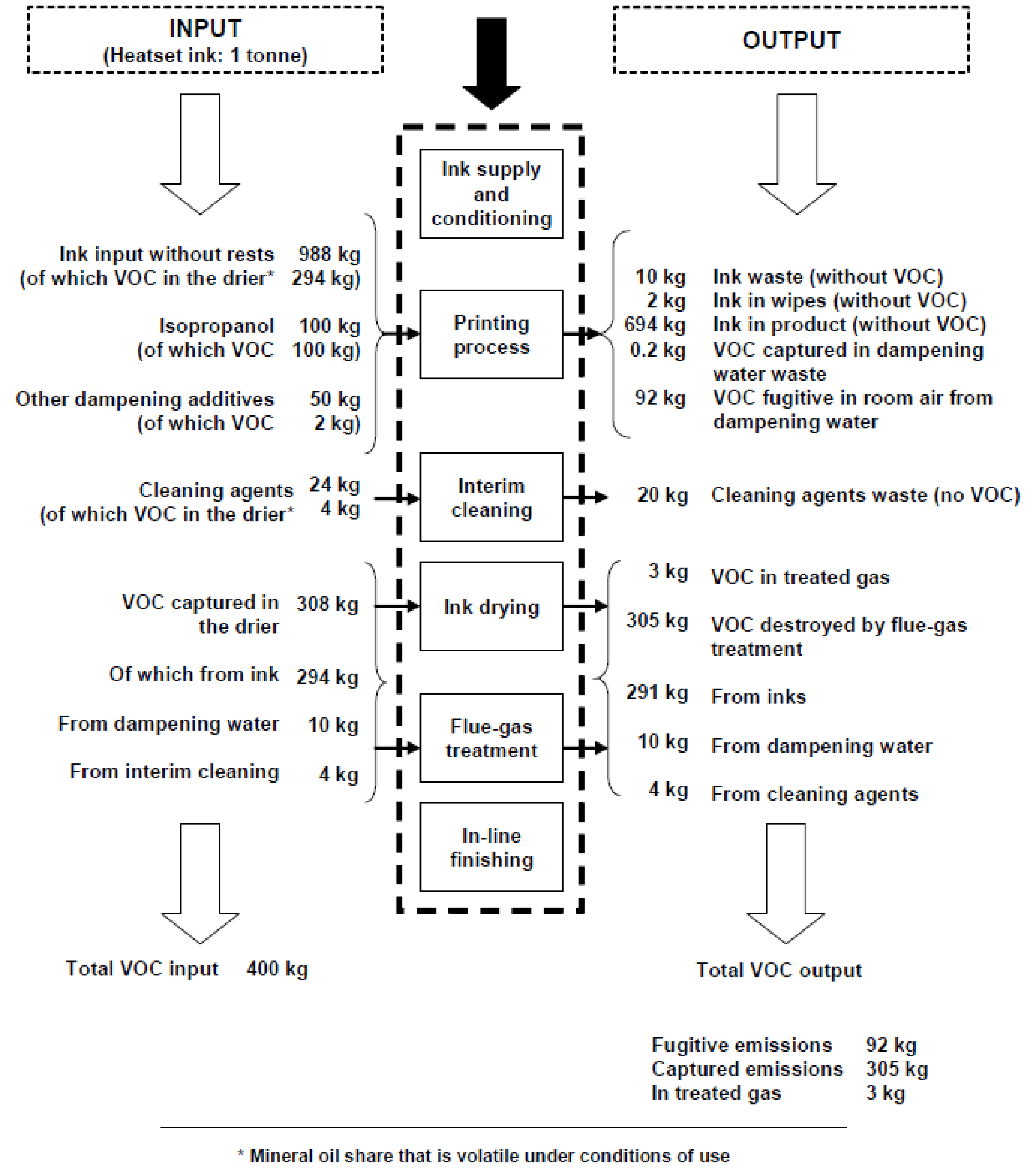
- shows that the IPA VOC content is assumed to be 100 %, although it may contain up to 15 % water;
- shows that, in heatset printing, two large (32-page), fast presses, working three shifts during 280 days per year are needed to exceed a consumption of 200 t/yr.

Heatset plants bigger than this virtual plant can be composed of several printing units which are similar to the virtual plant, although more and more plants are equipped with presses of differing web widths. The specific consumption and emission data can then be taken from this virtual plant. However, the specific consumption and emission values are significantly dependent on the manufactured products and will increase with [38, TWG 2004]:

- decreasing print volume;
- increasing use of special colours or change of colour sequence;
- extremely high demands on the printing quality, or difficult printing images;
- decreasing paper quality.

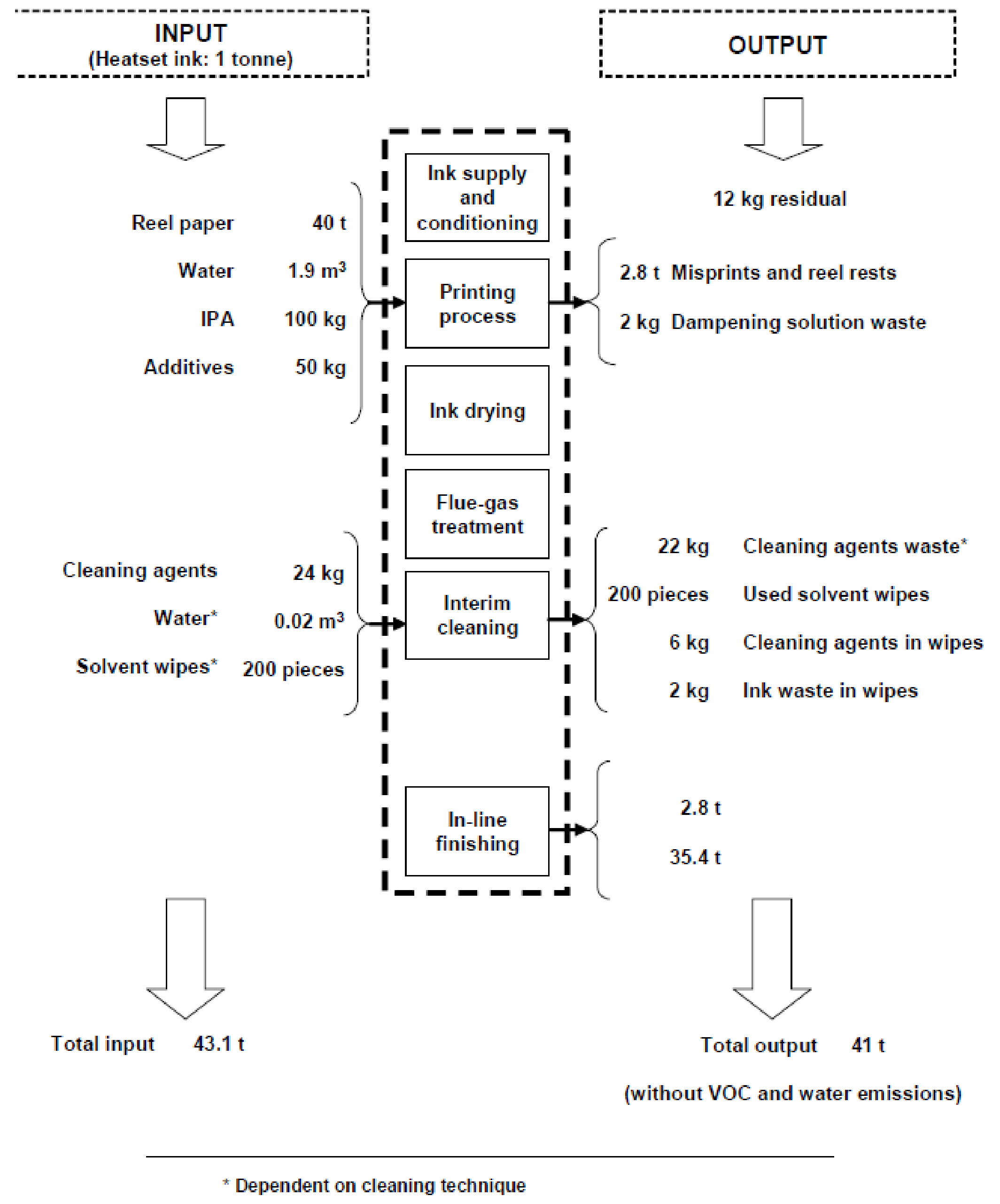
Several theoretical mass balances have been calculated from the virtual plant. Average VOC consumption and emissions in relation to one tonne of ink used are shown in Figure 11.2. The average input of material and output of waste of the virtual plant are shown in Figure 11.3. However, these values are average values, which can – dependent on the aforementioned parameters – vary in practice by more than 10 % [38, TWG 2004].

Figure 11.2 shows that of 400 kg VOC input, 308 kg is captured and treated by thermal oxidation, so 92 kg are fugitive, which equals 23 % of the VOC input. After treatment, 3 kg VOCs are still in the waste gas and emitted (the efficiency of the off-gas treatment is 99 %).



Source: [7, Germany 2003]

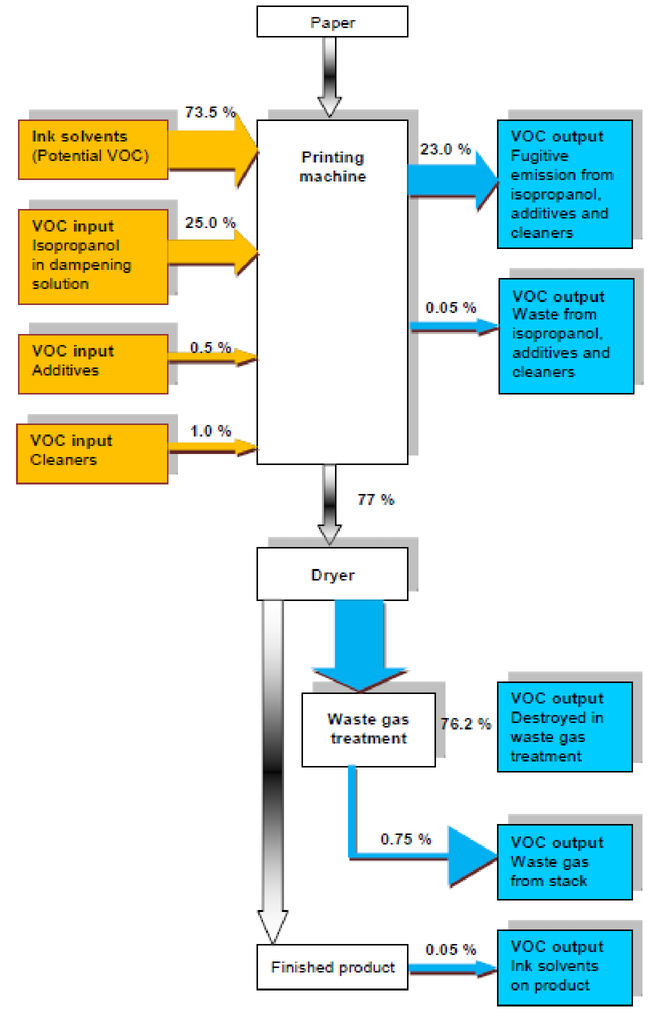
Figure 11.2: Specific VOC consumption and emission levels in a virtual heatset process



Source: [7, Germany 2003]

Figure 11.3: **Specific input of substances and output of waste in a virtual heatset process**

Figure 11.4 shows a general heatset web offset process flow and the relevant associated VOC emissions [148, COM 2009].



Source: [148, COM 2009]

Figure 11.4: Main input and output of heatset web offset printing

Data for eight heatset web offset printing plants were submitted through the data collection and they are analysed in the following sections [155, TWG 2016].

11.3.1 Consumption

[78, TWG 2005] [148, COM 2009] [155, TWG 2016] [212, TWG 2018]

11.3.1.1 Raw materials and additives

The VOC-relevant raw materials and additives are as follows:
[148, COM 2009] [212, TWG 2018]

Inks
Inks are based on about 33-35 % aliphatic hydrocarbons (solvents). The solvents are made of mineral oil. They are not volatile at ambient temperatures but are volatile in the dryer. About 85 % of the oil fraction is evaporated in the dryer as VOCs (equivalent to an average VOC range in heatset inks of 15-45 % of the total ink amount). Solvent residue in the finished product is not considered part of fugitive emissions because it is not volatile at ambient temperatures.

One tonne of ink allows the printing of about 330 000 m^2 (both sides) or approximately 225 000 catalogues (48 pages DIN A4) [INTERGRAF comment #104 in [212, TWG 2018]].

Dampening solution

Dampening (fountain) solution consists mainly of water. It contains VOCs such as isopropanol (IPA), other alcohols and glycol ethers in concentrations up to 10 %. Isopropanol and ethanol not only lower the surface tension when dampening solution is transported onto the printing plate but also cool the printing system when they evaporate; they also prevent the growth of microorganisms in the dampening solution. Where little or no IPA is used, the dampening solution may also contain biocides. It is considered good practice to minimise the isopropanol addition into the dampening solution.

Cleaning agents

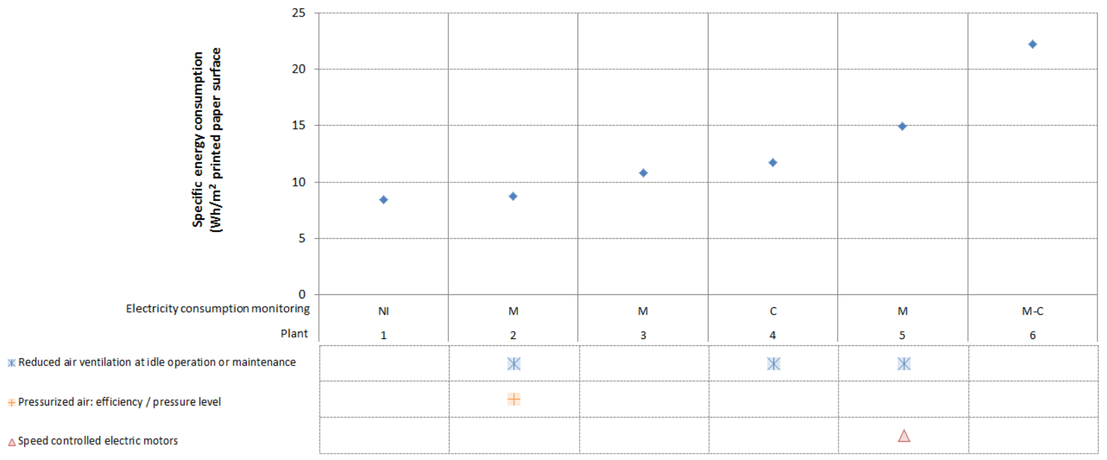
Most cleaning is automatic using non-volatile or low-volatility solvents. In the less frequent manual cleaning, volatile solvents are often used.

11.3.1.2 Energy

[155, TWG 2016] [212, TWG 2018]

The reported values for specific energy consumption expressed in Wh per m^2 of printed paper surface are presented in Figure 11.5.

It is noted that in heatset web offset printing, gas consumption is affected by the ink coverage of the paper which is related to the type of printed products (the product portfolio of the plant). In general, the higher the ink coverage the lower the gas consumption, which subsequently effects the total energy consumption, as gas consumption represents approximately 50 % of the total energy consumption.



Source: [155, TWG 2016]

Figure 11.5: Specific energy consumption expressed in Wh per m^2 of printed paper surface (data for 2015)

Energy efficiency depends among other parameters on local conditions, the level of technological advancement of the plant, the printing process employed, etc. All installations reported heat recovery from the thermal off-gas treatment and reduced air ventilation during idle operation or maintenance. Other widely used energy-saving techniques are: air extraction and energy recovery from drying processes, central off-gas treatment with variable frequency drives, speed-controlled electric motors and air seals at dryer ovens. More information on possible energy efficiency options for the printing sector in general can be found on the EMPSI project webpage[36].

When considering the energy consumption for the heatset web offset printing process at a plant where other non-STS activities occur (e.g. sheetfed or coldset), the energy consumption for those non-STS activities has to be excluded (see also Section 17.5.2).

Information from one installation on the energy-saving projects (techniques) that it applies or is in the process of implementing is presented in Table 11.4.

Table 11.4: Energy-saving projects implemented by a heatset web offset printing installation

Technique	Brief description	Economic elements
Lighting	2 000 lamps, optimised reflectors, one tube instead of two, all with dimmers: 60 % energy savings	15-month payback period of investment
Paper extraction	Paper extraction optimisation - frequency-controlled motors. New motors and new equipment results in higher production security	Economic benefit: EUR 30 000/yr
Printing plates	Printing plates exchanged: no preheating necessary	Economic benefit: EUR 25 000/yr
Compressed air	Compressed air is stopped if machines are stopped for more than 1 minute	Economic benefit: EUR 3 500-4 000/machine per year; payback period < 1 year
Heat exchange for dryers	Use of heat of hot gases from the CHP gas turbine in the dryers of printing machines	NI
Air conditioning	Use of heat of hot gases from the CHP gas turbine for the room heating	NI
Compressed air	Compressed air system leakage measurement once every month	NI

NB:
NI: No information provided.
Source: Plant #148 in [155, TWG 2016]

11.3.1.3 Printing substrates and other consumption

[78, TWG 2005] [212, TWG 2018]

Printing substrates

The substrate used in heatset is typically paper with a specific weight between 40 g/m^2 and 60 g/m^2 but papers as light as 30 g/m^2 and as heavy as 100 g/m^2 are also used in heatset web offset. Often low weight coated (LWC) grades and uncoated paper are used with a specific weight normally between 45 g/m^2 and 70 g/m^2.

Other consumption

Other inputs are materials such as plates, containers and other packaging materials.

In heatset, four standard colours (cyan, magenta, yellow and black) are used and these are supplied in reusable containers, which are either intermediate bulk containers (IBC) with a content of approximately 1 tonne, or common 200-litre metal drums [1, INTERGRAF and EGF 1999].

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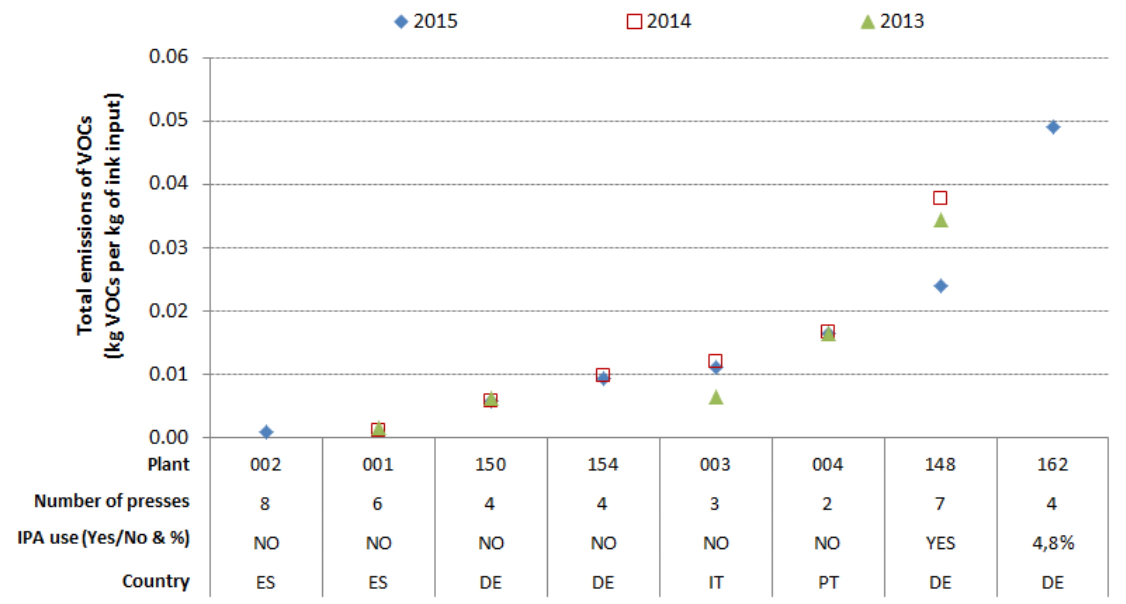
[36] EMPSI: Energy management standardisation in printing industry, http://www.emspi.eu/index.html

11.3.2 Emissions

11.3.2.1 Total emissions of VOCs

[155, TWG 2016] [212, TWG 2018]

The reported values of total emissions of VOCs expressed as kg VOCs per kg of ink input are presented in Figure 11.6.



Source: [155, TWG 2016]

Figure 11.6: Total emissions of VOCs expressed in kg VOCs per kg of ink input for the period 2013-2015

In general, most of the reported values are low and are related to installations where no isopropanol is used (full substitution of IPA). The higher values refer to installations where the dampening solution contains a small percentage of IPA. All installations use thermal off-gas treatment techniques which is the general rule in the sector due to the offensive smell of waste gases. Most installations in the sector apply integrated dryer-oxidisers at each press specifically designed for heatset web offset printing.

The reported data on total emissions of VOCs and relevant contextual information are presented in Table 11.5.

Table 11.5: Total emissions of VOCs and contextual information for heatset web offset printing plants

Plant number	IPA use (Yes/No & %)	No of presses	Rubber blanket washing system (no of presses)	Inking roller washing system (no of presses)	Total emissions of VOCs (kg VOCs per kg of ink input)		
					2015	**2014**	**2013**
002	No	8	Auto tissue (8)	Auto tissue (8)	0.001		
001	No	6	Auto brush (4) Manual (2)	Auto brush (2) Auto tissue (1) Manual (3)		0.001	0.001
150	No (from 2015)	4	NI	NI	0.006	0.006	0.006
154	No	4	NI	NI	0.009	0.010	
003	No	3	Auto brush (2) Auto tissue (1)	Manual (3)	0.011	0.012	0.006
004	No	2	Auto tissue (2)	Manual (1) Auto (1) (spray tube)	0.016	0.017	0.016
148	Yes	7	Auto tissue (7)	Auto (7)	0.024	0.038	0.034
162	4.8 %	4	Auto brush (3) Auto tissue (1)	NI	0.049		

NB:
NI: No information provided.
Source: [155, TWG 2016]

Techniques specifically used in heatset web offset to reduce VOC emissions are (see also Section 11.4):

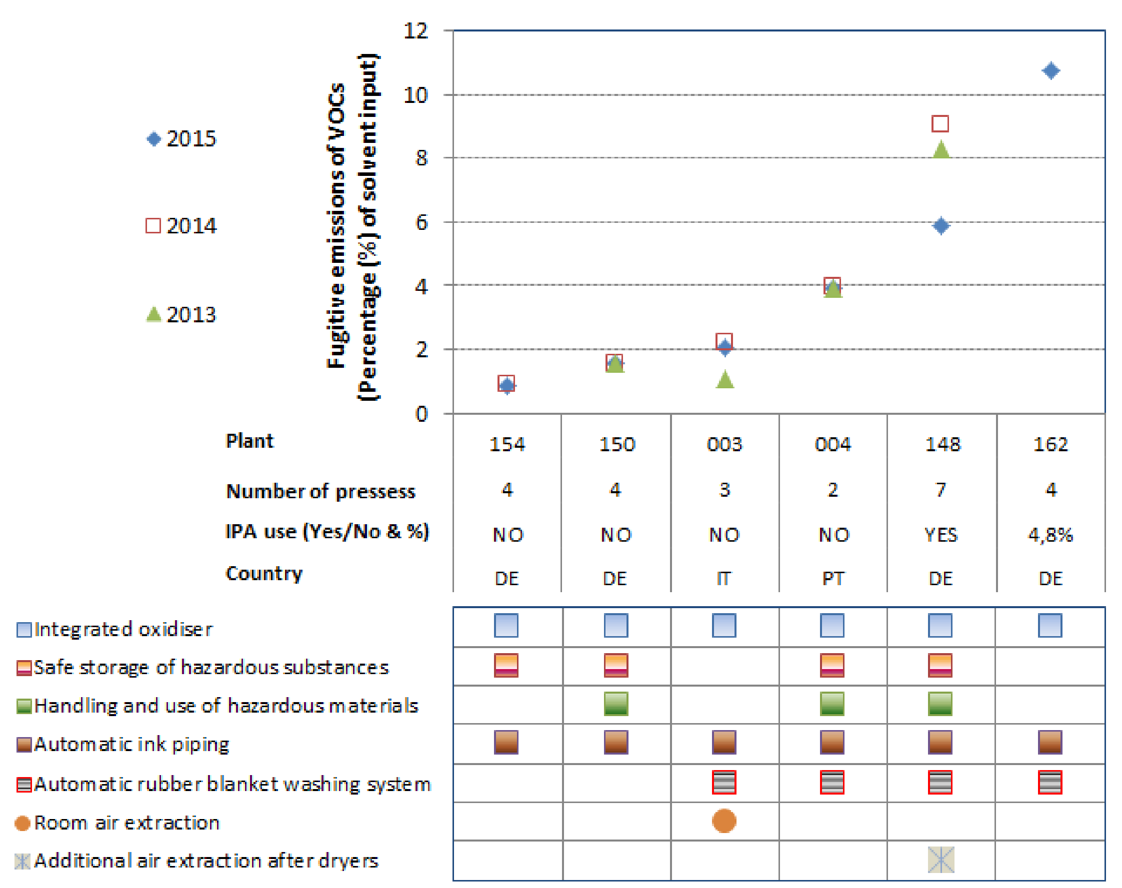
- low-IPAor IPA-free additives for dampening solutions;
- use of waterless offset plates;
- automatic cleaning systems for blanket cylinders, capture and routing of solvent emissions from cleaning to the off-gas treatment system;
- web offset dryer integrated with thermal off-gas treatment.

The percentage of solvent emissions that stem from automatic interim cleaning in heatset processes and that are captured and routed to the off-gas treatment is in the range of ≤ 15-50 % [7, Germany 2003] [19, Austria 2003]. For manual cleaning by hand and basic cleaning, the percentage of solvent emissions that are captured and routed to the off-gas treatment is in the range of 0-5 %. See also Section 21.5.3.

11.3.2.2 Fugitive emissions of VOCs

[155, TWG 2016]

The reported values of fugitive emissions of VOCs expressed as a percentage of the solvent input are presented in Figure 11.7.



Source: [155, TWG 2016]

Figure 11.7: Fugitive emissions of VOCs expressed as percentage of the solvent input for the period 2013-2015

The reported values for fugitive emissions of VOCs and relevant contextual information are presented in Table 11.6. All reported values are significantly lower than the IED limit value (30 % of the solvent input for both new and existing installations).

Table 11.6: Fugitive emissions of VOCs and contextual information for heatset web offset printing plants

Plant number	IPA use (Yes/No & %)	No of presses	Rubber blanket washing system (no of presses)	Inking roller washing system (no of presses)	Fugitive emissions of VOCs (% of solvent input)		
					2015	2014	2013
154	No	4	NI	NI	0.8	0.9	
150	No (from 2015)	4	NI	NI	1.58	1.55	1.57
003	No	3	Auto brush (2) Auto tissue (1)	Manual (3)	2.04	2.23	1.08
004	No	2	Auto tissue (2)	Manual (1) Auto (1) (spray tube)	3.94	3.99	3.93
148	Yes	7	Auto tissue (7)	Auto (7)	5.9	9.03	8.31
162	4.8 %	4	Auto brush (3) Auto tissue (1)	NI	10.72		

NB:
NI: No information provided.
Source: [155, TWG 2016]

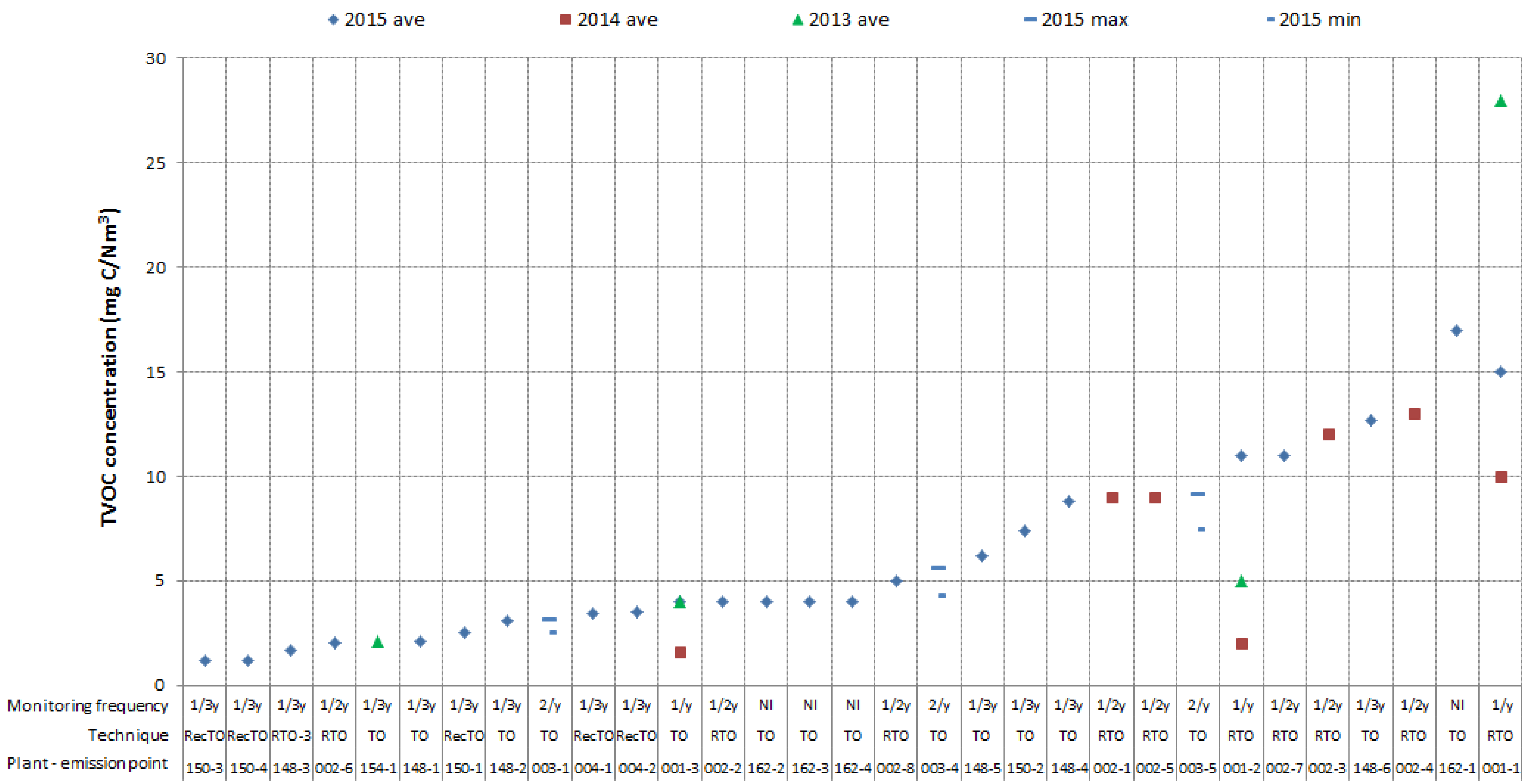
The main reported techniques applied to minimise fugitive emissions are as follows [155, TWG 2016]:

- Direct piping of printing additives from their original packaging to the inkpan.
- Direct piping of solvent from storage to the automatic washing systems.
- Use of small containers for solvents for manual cleaning.
- Air extraction for the drying processes. In one case, solvent-laden air from the drying zones is treated in a two-step solvent recovery unit from where solvents are recovered and returned to the ink-producing company for reuse. Additional air extraction to solvent recovery is installed directly after dryers (to avoid periodic brief emissions at the slot where the paper web leaves the dryer).
- Direct piping of inks: Inks are moved through a closed system from the storage area to the print basket. This was reported from all installations and it is mainly related to economic advantages as the same four colours are always used.
- Air extraction from the cooling zone.
- Safe storage of hazardous substances and measures to prevent unplanned releases.

11.3.2.3 TVOC emissions in waste gases

[155, TWG 2016]

The reported values for TVOC emissions in waste gases, expressed in mg C/Nm^3, are presented in Figure 11.8.



NB: #162 data for 2016 instead of 2015.

Source: [155, TWG 2016]

Figure 11.8: TVOC emissions in waste gases for the period 2013-2015

The monitoring frequency varies from twice a year up to once every 3 years. The basic statistical parameters of reported data for TVOC emissions in waste gases are presented in Table 11.7.

Table 11.7: Statistical parameters of reported data for TVOC emissions in waste gases for the period 2013-2015

Applied technique	2015				2014				2013			
	No of values	Ave-rage	Max.	Min.	No of values	Ave-rage	Max.	Min.	No of values	Ave-rage	Max.	Min.
		mg C/Nm^3				mg C/Nm^3				mg C/Nm^3		
TO	14	6.4	17.0	2.1	1	1.6	NA	NA	2	3.1	4.0	2.1
RecTO	5	2.4	3.5	1.2	NA	NA	NA	NA	NA	NA	NA	NA
RTO	6	8.0	15.0	2.0	6	9.2	13.0	2.0	2	16.5	28.0	5.0
RTO-3	1	1.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NB:
NA: Not available/applicable.
Source: [155, TWG 2016]

11.3.2.4 Nitrogen oxides (NO_X) and carbon monoxide (CO) emissions in waste gases

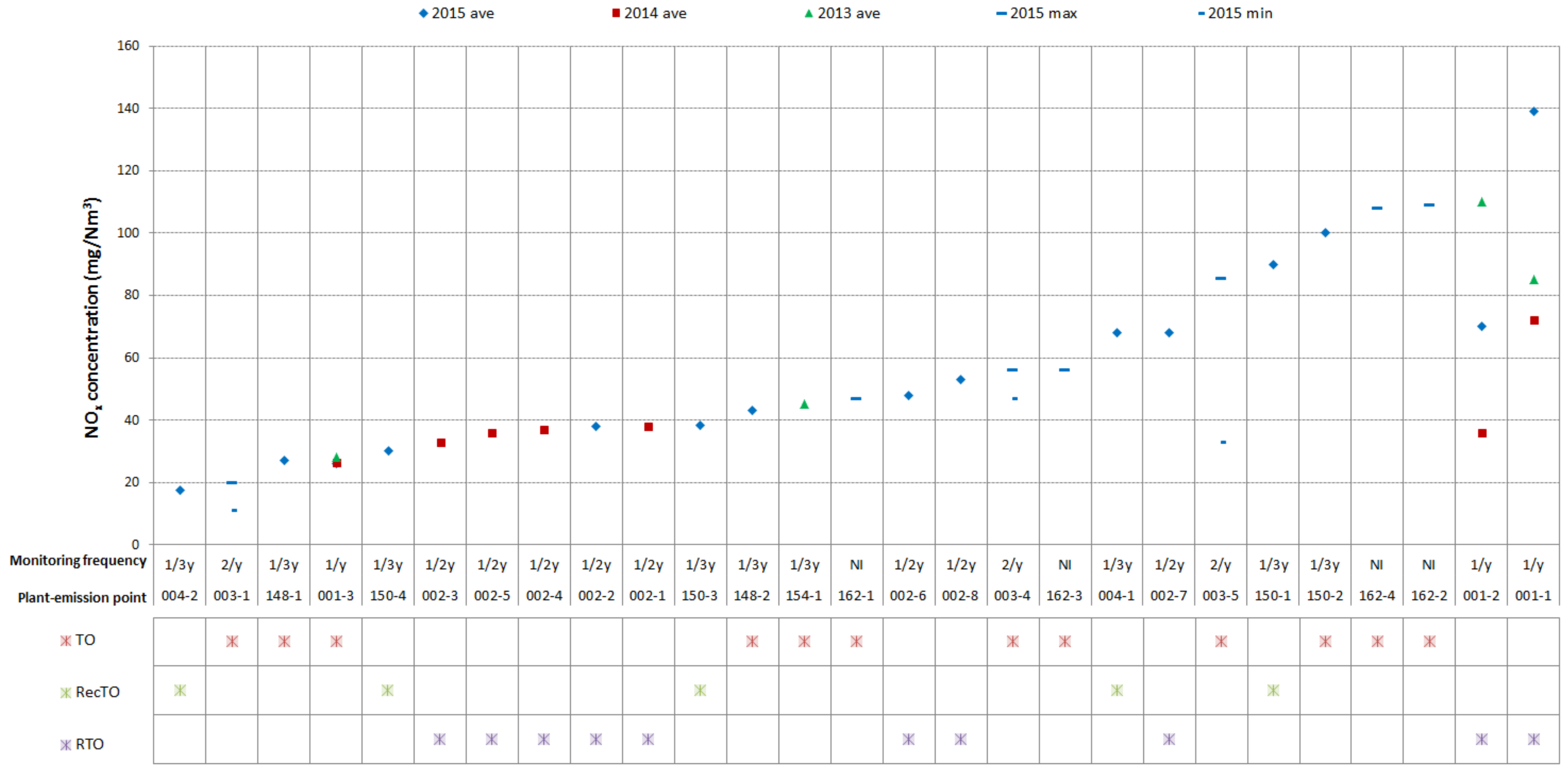
[155, TWG 2016] [212, TWG 2018]

Nitrogen oxides (NO_X) and carbon monoxide (CO) emissions result from the thermal oxidation of off-gases from the dryer.

The reported values for periodic monitoring of NO_X and CO emissions in waste gases are presented in Figure 11.9 and Figure 11.10.

According to industry, in heatset web offset printing, CO concentration is often used as an indication of the oxidiser's performance regarding the VOC destruction: where in heatset web offset printing, an integrated dryer-oxidiser has CO emissions < 200 mg/Nm^3; it may be expected to have TVOC emissions < 20 mg C/Nm^3. In practice, the CO concentration is maintained below 200 mg/Nm^3 [INTERGRAF comment #78 in [212, TWG 2018]].

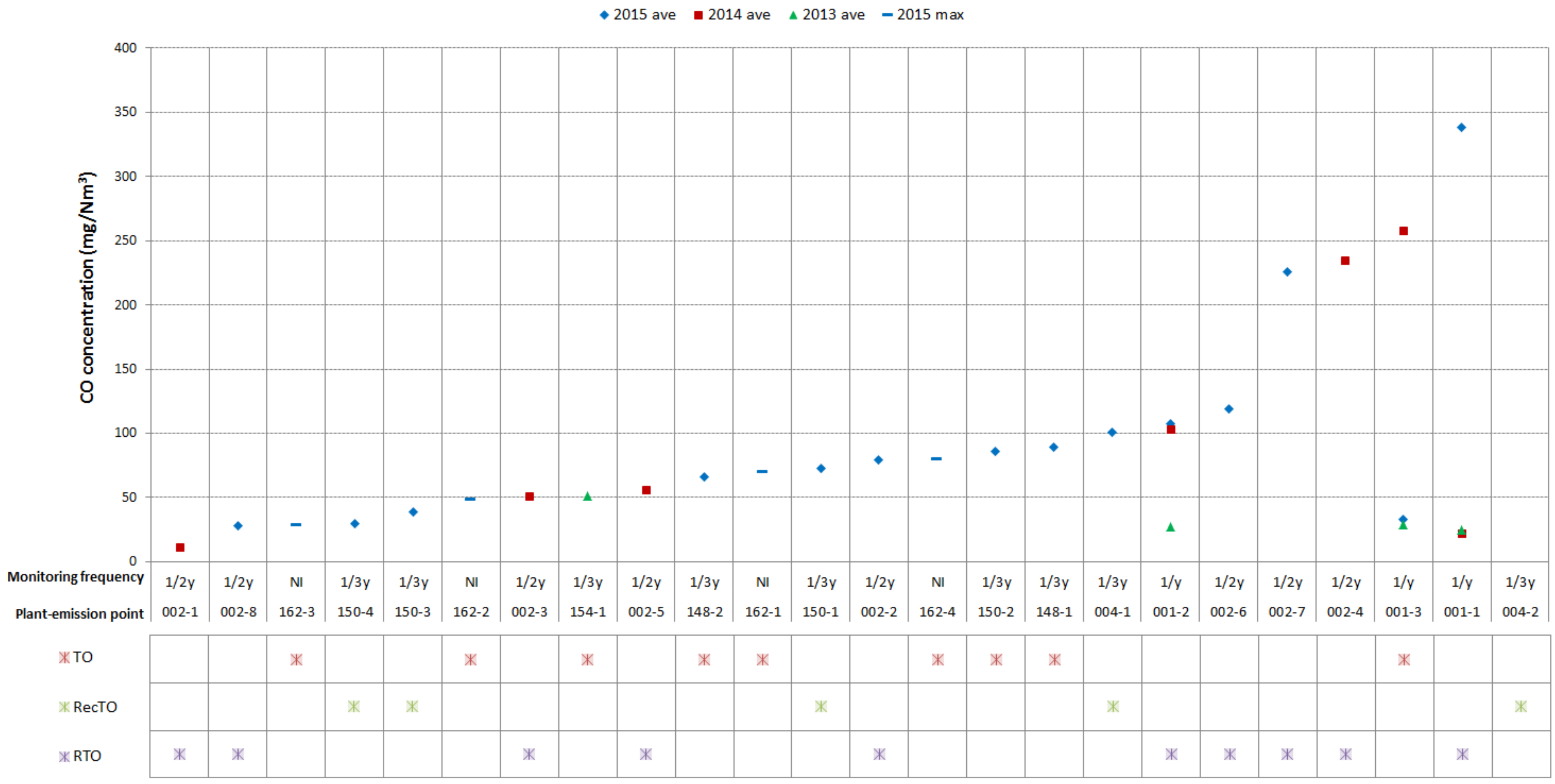
The monitoring frequency varies from twice a year up to once every 3 years.



NB: #162 data for 2016 instead of 2015.

Source: [155, TWG 2016]

Figure 11.9: NO$_X$ emissions in waste gases for the period 2013-2015



NB: #162 data for 2016 instead of 2015. Data not shown for #004-2 (2015: 758 mg/Nm³ (ave)).

Source: [155, TWG 2016]

Figure 11.10: CO emissions in waste gases for the period 2013-2015

11.3.2.5 Dust emissions in waste gases

[155, TWG 2016]

Only a small number of installations reported values for periodic monitoring of dust emissions in waste gases. Dust emissions are mainly related to the paper trimmer and in some cases extracted gases from this process are treated using dry particle filters. In general, reported dust emission values are very low and vary from 0.2 mg/Nm^3 up to 0.8 mg/Nm^3.

11.3.2.6 Waste generation

[78, TWG 2005] [155, TWG 2016] [212, TWG 2018]

Papers
The quantity of waste paper in heatset web offset printing is not normally higher than in other printing processes. The often quoted ink-water balance is one of the many causes of paper losses.

Other causes of paper losses include:

- removal of the packaging of the rolls;
- transport damage;
- paper left on the cores when the paper roll is replaced with a fresh one;
- start of production run (registering the colours, finding ink-water balance, adjustment for adequate drying, etc.);
- end of production and cleaning for the next run;
- trimming the printed product to the required size (may account for 10 % paper loss);
- extra copies printed for losses in each section for the bindery;
- extra copies to prevent the customer running short;
- losses when imprints are changed.

The reported proportion of paper waste in the overall quantity of substrate is about 15 % [155, TWG 2016]. The amount of waste paper generated in heatset web offset printing may vary and is mainly related to the need for trimming, for example trimming of an A4 page 1 cm all around leads to 16 % waste. Trimming is necessary where the printed product should not have any white margin. The start and the finish of the print run also make a small contribution to paper waste generation.

Waterless offset is claimed to produce less waste during the start of a print run, as there is no balance between ink and dampening to be achieved. As mentioned previously, paper losses during start-up are only a small proportion of the total losses, and the start-up losses are only partly due to achieving an appropriate ink-water balance (the four standard colours still need to be registered). When the runs are long, plates will have to be changed, meaning new start-ups. This offsets the small advantage that waterless offset may have in this regard [INTERGRAF comment #83 in [212, TWG 2018]].

Waste paper is delivered to a specialised recycling company off site. In the case of medium- (off-cuts) and high-quality (white) waste paper, direct delivery to the paper mill was reported.

Inks
Reported values show that the quantity of ink waste produced varies from 2 kg up to 6.5 kg per tonne of used ink. Those levels are very low if compared to other printing processes and probably also if compared to other coating processes and may be associated with the fact that in

heatset web offset printing the same four colours are always used, therefore there is no mixing and no leftovers.

Dampening solution

During printing, the dampening solution can become contaminated with paper dust and small amounts of ink. These solutions contain AOX and small amounts of metals.

In the dampening solution from the blue colour printing unit, a small amount of copper phthalocyanide pigment may be found. The copper in these pigments is however bound very strongly and cannot be found in waste water [INTERGRAF comment #85 in [212, TWG 2018]].

On the other hand, where no IPA is used, the dampening solution will contain some biocides to prevent the growth of algae and microbes. For this reason, waste fountain solution is disposed of as hazardous waste and not discharged.

Cleaning agent

Most of the cleaning agent is used for blanket wash, which is generally mixed with 50 % water. Whether it arises as waste depends on the automatic cleaning method. In the case of the tissue system it is taken up by the tissue, in the case of a brush system it is to a large extent collected, and in other cases it may be transported to the dryer and subsequently oxidised.

The reuse of cleaning agents is only possible when they can be distilled in a simple way, which is not the case when they are mixed with water (in the distillation process the emulsifier disappears and as a result the solvent is no longer miscible with water) or contained in wipes or tissue [INTERGRAF comment #87 in [212, TWG 2018]].

Wipes

Wipes from press cleaning contain organic solvents, ink and sometimes varnish. The amount usually varies with the run length, and therefore the number of changeovers per year.

Other wastes

Old printing plates contain metals, primarily aluminium, with traces of other metals, depending on the age of the equipment. Rubber blankets are also discarded. Waste can also contain filters from filtering the dampening solution and discarded UV lamps from the platemaking process [8, Nordic Council of Ministers 1998] [38, TWG 2004].

Standard colours of offset inks can be supplied in reusable IBC containers or in the common 200-litre metal drums. In IED-sized plants, the standard colours are often supplied in bulk and pumped into fixed containers.

11.3.2.7 Emissions to water

[212, TWG 2018]

Dampening solutions

During printing, the dampening solution gets contaminated with paper dust and small amounts of ink. These solutions then contain AOX in concentrations of > 1 mg AOX/l and small amounts of metals such as aluminium, copper, zinc, cobalt and manganese (these last two from drying agents), with a combined concentration of around 0.1 g/l. Normally these waste dampening solutions are disposed of as hazardous waste [INTERGRAF comment #89 in [212, TWG 2018]].

The additives used in dampening solutions in concentrations of around 3 % may contain small amounts of biocides against algae. Common concentrations of biocides are in the range of 0.1-

0.2 %, which means that the final concentrations in the dampening solution are negligible [1, INTERGRAF and EGF 1999].

Normally, printing plants are not equipped with a waste water treatment plant.

A study by the TWG identified the main parameters and other substances of interest that may be discharged in waste waters (including those mentioned above) and therefore to be considered for the data collection[37]. For heatset web offset printing, bisphenol A (BPA) and nonylphenol (NP) were identified as substances of interest; however, no data were received in the data collection.

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[37] COM working document EIPPCB 09/06/2016: Assessment of Technical Working Group (TWG) data submitted on metals and other emissions to water for their consideration as Key Environmental Issues for installations carrying out IED Annex 1 6.7 activities.

11.4 Techniques to consider in the determination of BAT for the heatset web offset printing

In Chapter 17, techniques are discussed which might also be applicable to the printing industry. In Table 11.8, the general techniques relevant for heatset web offset printing are shown. These techniques are not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 17.1.

Table 11.8: Reference to techniques generally applicable to the sector

Technique	Section number
Environmental management techniques	17.1
Storage and handling of raw materials	17.2
Monitoring	17.3
Water use and waste water generation	17.4
Energy management and energy efficiency	17.5
Raw material management (including substitution)	17.6
Coating processes and equipment	17.7
Drying and/or curing techniques	17.8
Cleaning techniques	17.9
Off-gas extraction and treatment	17.10
Waste water treatment techniques	17.11
Waste management techniques	17.12
Odour emissions	17.13

11.4.1 Solvent mass balance for the heatset web offset printing sector

Description

The compilation, at least once every year, of the organic solvent inputs and outputs of the plant as defined in Part 7(2) of Annex VII to Directive 2010/75/EU. See also Section 17.3.1.

Technical description

The solvent mass balance (SMB) elaboration method is strongly affected by the individual Member State's legislative provisions. Two approaches for the heatset web offset printing sector submitted by INTERGRAF and by Germany (DE) are presented in Annex 21.5.3.

Achieved environmental benefits

The heatset SMB not only shows whether a heatset plant complies with its emission limits, but also where in the production process these emissions take place and why. If emission reductions are necessary, this sector mass balance is a management tool that shows where these reductions can be achieved most efficiently.

Environmental performance and operational data

The heatset SMB is, like almost every mass balance, a simplification of the actual situation. Since the sector is reasonably homogeneous, this method will work satisfactorily in most cases. However, where an operator employs machines or working methods differing from the industry standard, the SMB should be amended accordingly. Also, where the operator has more detailed knowledge and relevant data than the minimum necessary to elaborate the SMB for heatset, they should make use of these.

Cross-media effects

None.

Technical considerations relevant to applicability
Applicable in all or most heatset plants.

The method avoids the use of measured solvent concentrations and airflows in exhausted press room air. In these press rooms, other printing processes, such as coldset of sheetfed offset, may take place. These processes do not fall under the scope of the STS BREF, but they may cause VOC emissions. These emissions should not be allocated to the heatset process of the plant.

Economics
Making a SMB of sufficient accuracy is not an easy task. It takes time and effort to find and collect the necessary data. There is however a rapid learning curve. Once the plant-specific emission factors have been calculated and a reliable administrative system for the production parameters is working, the time spent on the SMB is minimised. Only when important changes take place, such as a change of materials used or the installation of a new press, must the emission factors be recalculated.

Driving force for implementation
Annex VII to Directive 2010/75/EU (IED) and environmental permits.

Example plants
All plants participating in the data collection have submitted solvent mass balance data.

Reference literature
[192, INTERGRAF 2017] [204, UNECE 2016] [205, Belgium 2005] [212, TWG 2018]

11.4.2 Material-based techniques

11.4.2.1 Use of low-IPA or IPA-free additives in dampening solution

Description
Reduction or avoidance of isopropanol (IPA) as a wetting agent in dampening (fountain) solutions, through substitution by mixtures of other organic compounds which are not volatile or have a low volatility.

Technical description
To attain a print of acceptable quality in offset, it is necessary to fully wet all the hydrophilic parts of the plate, but with a minimal thickness of the water layer of approximately 2 µm. This needs to be a stable process, even where the press speed varies. A wetting agent is therefore necessary. The wetting agent reduces the surface tension of water and thus minimises the amount of water necessary for a perfect coverage of the hydrophilic parts of the plate.

The fountain solution also needs other additives such as acids to control the pH, plate conditioners to avoid corrosion and gum arabic to further protect the offset plate. These other additives are not discussed here.

Traditionally, the most commonly used wetting agent is isopropanol (IPA). IPA is not only a good wetting agent, it is also ‘forgiving’ in the sense that imperfections in both press and paper web and changes in speed do not quickly lead to an interruption in the tightly controlled wetting process and the resulting immediate and severe problems with print quality. In the past, IPA was frequently employed in the fountain solutions in concentrations of 15 % w/w and more.

Where high-volatility VOCs like IPA are used as a wetting agent, a considerable part evaporates on its way to the plate and the rubber blanket and thus becomes a fugitive emission. The remaining part is absorbed by the paper web, quickly transported to the dryer, evaporated there and destroyed in the oxidiser. In general terms, the lower the volatility of the wetting agents, the lower the proportion that evaporates as fugitive emissions and the lower the initial concentration needs to be. Also, other VOCs may not be as easily released from water as IPA is.

On today's presses, with well-trained operators, good maintenance and adequate quality control, it is often possible to substitute the IPA to a large extent or even completely by additives containing organic compounds that are not volatile or have a low volatility. On modern presses, in particularly demanding circumstances, reduction of the IPA concentration in the dampening solution to 3 % w/w can be achieved. On older presses, it should be possible to reduce the IPA concentration to 5 % w/w.

In all cases, the dampening solution must be cooled to approximately 10-15 °C to reduce the evaporation en route to the plate.

Achieved environmental benefits

Significant reduction of solvent evaporation from the fountain solution, resulting in a considerable reduction of fugitive emissions from the fountain solution.

Environmental performance and operational data

Compared to a situation with an IPA concentration of 15 % w/w, the fugitive emissions from the fountain solution are reduced by some 80 %.

Cross-media effects

Where the use of IPA in the fountain solution is avoided, there is a need to use biocides to prevent the growth of algae and other microorganisms in the dampening system. The biocide is however transported by the paper web to the oxidiser together with the other additives in the fountain solution.

Where occasionally a small amount of the fountain solution needs to be disposed of, this should be done as hazardous waste mainly because of this biocide content.

Technical considerations relevant to applicability

The applicability may be limited by technical and product quality requirements or specifications:

The water film brought onto the offset plate must be very thin (0.5-1 g/m^2 or 0.5-1 µm). Where the film is too thin, it breaks and parts of the plate 'run dry'. Where the film is too thick, it is not removed adequately from the hydrophilic parts of the plate. In both cases, the result is an unrecognisably coloured and smudged paper web.

In order to reduce the IPA consumption and to apply additives that are not volatile or have a low volatility, the press must be properly equipped with for example ceramic, metal or hydrophilic distribution and plate rollers (see Section 11.4.2.2). The rollers must be adjusted with precision and the press must be well maintained. Temperature control is essential.

The required state of the press and operator training for successful reduction of the IPA to maximum 3 % w/w do not differ largely from what is necessary to apply only additives that are not volatile or have a low volatility.

In some cases, the complete avoidance of the use of IPA may have qualitative drawbacks. The use of substitutes increases the amount of water that needs to be brought onto the plate for adequate wetting by 30 % to 50 % compared to when IPA is the sole wetting agent. This unavoidably reduces the sharpness of the printed dots because of the less than perfect separation of the ink-water emulsion on the plate. As a result, there are limits to the achievable quality when printing without IPA, even on modern presses with well-trained operators, good maintenance and adequate quality control.

In spite of the above, in most cases the print quality is still fit for purpose, but there may be some quality issues, for example images with lots of detail (human faces, woodgrain), with large variation in the lighting of objects, very dark unsaturated colours or subtle grey balances. As a result, the use of isopropanol may be required for certain products that need a better than normal printing quality. Examples of these products are museum art catalogues and high-quality annual reports.

Economics
A learning curve applies to both the achievement of a low IPA concentration and the application of additives that are not volatile or have a low volatility. During the learning curve, production is down because of lower press speeds and quality problems. It may take several years to achieve a situation in which under all circumstances a low IPA concentration can be maintained or the use of IPA can completely be avoided.

In the long run, a saving on the consumption of wetting agents is attained and also a saving occurs due to the avoidance of costs associated with the flammable properties of IPA.

No specification of the cost and savings is available.

Driving force for implementation
IPA use is generally reduced for reasons of worker exposure and to reduce fugitive emissions.

Example plants
All plants that submitted data.

Reference literature
[1, INTERGRAF and EGF 1999] [155, TWG 2016] [186, INTERGRAF 2017] [212, TWG 2018]

11.4.2.2 Ceramic, metal and hydrophilic distribution and plate rollers

Description
Applying a ceramic, chromium-plated or hydrophilic distributing roller in combination with hydrophilic plate rollers. Hydrophilic plate rollers are made of soft rubber. These rollers can form a particularly thin and unbroken dampening film on the plate roller with lower IPA concentrations.

These rollers are also successfully applied in situations where IPA is partly substituted. See also Section 11.4.2.1.

Achieved environmental benefits
Lower VOC emissions as IPA concentrations can be reduced to less than 2–3 % w/w, depending on the starting concentration.

Environmental performance and operational data
Whether ceramic or chromium-plated distributing rollers give better results, depends on the type of press. Ceramic rollers require more maintenance and cleaning time.

In one offset plant in Norway where IPA is partly substituted, the level of IPA could be reduced from 15 % to 4 %, which resulted in a reduction of the IPA concentration in the air above the press in the range 77–90 %.

Cross-media effects
Soft rubber is damaged sooner than plate rollers made of hard rubber and needs to be replaced more often, resulting in more waste. Also, ceramic rollers need to be replaced more frequently than chromium-plated steel ones.

Technical considerations relevant to applicability
This technique is commonly applied and is applicable in all printing plants applying IPA. However, ceramic or metal rollers are now used less. Hydrophilic rollers are used, have the same effect, and are cheaper.

Economics
The costs for hydrophilic plate rollers are the same as for hard rubber rollers and vary from EUR 250–1 000 each. However, they need to be replaced more often. Ceramic rollers cost EUR 2 500–3 000 each. The total costs of replacing distributing rollers for ceramic ones depend on the size of the press. Also ceramic rollers need to be replaced more frequently than chromium-plated ones (costs are from approximately 1997).

Driving force for implementation
No data submitted.

Example plants
Norwegian plant.

Reference literature
[1, INTERGRAF and EGF 1999] [8, Nordic Council of Ministers 1998]
[14, Aminal et al. 2002] [38, TWG 2004]

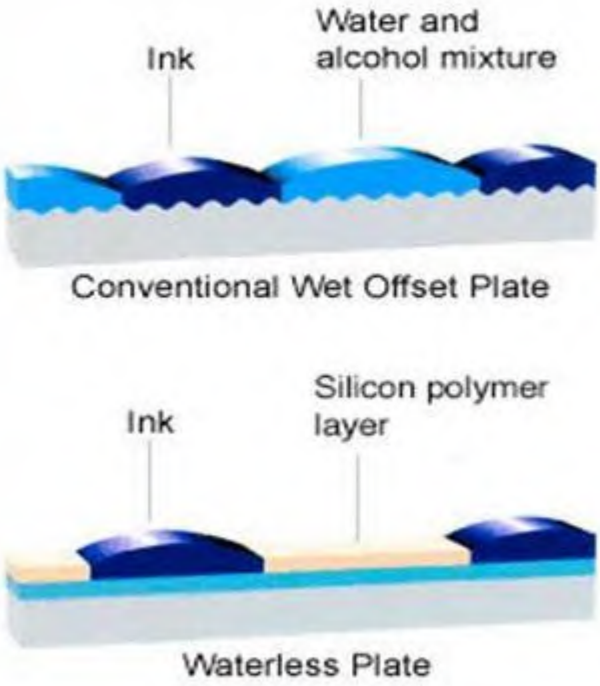
11.4.2.3 Waterless offset

[186, INTERGRAF 2017] [212, TWG 2018]

Description
Modification of the press and the pre-press processes to enable the use of specially coated offset plates, eliminating the need for dampening.

Technical description
On special offset plates, a layer of silicones is laser-hardened on the non-ink-carrying parts or alternatively hardened silicones are burnt away to produce ink-carrying areas. The hardened silicones have the same effect as the fountain solution on traditional offset plates: they locally keep the plate clear of ink (see Figure 11.11). There is only one manufacturer worldwide.

The application of waterless offset requires considerable changes to the printing process, additional cooling of the press, and the use of special inks.



Source: [186, INTERGRAF 2017]

Figure 11.11: Conventional wet offset plate and waterless plate

Achieved environmental benefits

Since no fountain solution is used, there is also no need for any additives such as isopropanol or other wetting agents and there are therefore no fugitive emissions from those additives. In addition, there is less paper loss during make-ready.

Environmental performance and operational data

Waterless offset plates do not last long. Where traditional offset plates can be treated in order to last long enough for longer runs, the plates for waterless plates need to be replaced during such a long run. This results in the production of additional plates and more frequent make-ready and paper losses. The cost of these significantly reduces the economic advantages of waterless offset. This is also the reason why waterless offset is more often encountered in sheetfed offset than in webfed offset.

Cross-media effects

Additional energy consumption is necessary for cooling the press. The plates cannot be as easily recycled as conventional offset plates.

Technical considerations relevant to applicability

The application of waterless offset requires considerable changes to the printing process, additional cooling of the press, and the use of special inks.

The special plates need to be replaced after considerably fewer prints than traditional offset plates, making the technique less applicable for long print runs such as those usually carried out in IED-sized heatset web offset printing plants.

Application of waterless offset reduces the flexibility of the printing plant. Pre-press activities by the customer may need to be adapted. The process is for example reported to have difficulty printing large areas of black ink, which may need to be circumvented by using all four colours instead.

On the other hand, in waterless offset, dot sharpness may improve and allow a somewhat sharper print quality.

It is applied for newspapers, magazines, brochures, flyers, etc.

Economics

In an existing installation, the investment is considerable since large changes have to be made to the presses.

On short runs, the reduction in make-ready constitutes a saving. There are however additional costs for cooling the press and more expensive plates.

Driving force for implementation

The reduction of paper losses due to the shorter make-ready periods results in an economic advantage in the case of short runs.

In the past, the lack of operator exposure to isopropanol vapours was also considered an advantage, but this no longer applies due to the drastic reduction of isopropanol usage in the industry.

This technique achieves very high-quality work. The reduction in chemical usage improves workplace health and safety.

Example plants

Based on the current knowledge of the STS TWG, it is not used in Europe.
For possible applications, see www.waterless.org, the website of the International Waterless Printing Association

Reference literature

[186, INTERGRAF 2017]

11.4.3 Off-gas extraction and treatment

Thermal off-gas treatment techniques (recuperative and regenerative oxidation) are widely applied in the sector due to the offensive smell of off-gases. For further information on thermal off-gas treatment techniques, see Section 17.10.5.

11.4.3.1 Extraction and treatment of air from the press room or the press encapsulation

Description

Routing of extracted air from the press room or the press encapsulation to the dryer. As a result, a part of the solvents evaporated in the press room or press encapsulation are abated by the thermal oxidiser downstream of the dryer. This reduces the fugitive emissions.

Technical description

Heatset presses are often encapsulated for reasons of climate control and noise reduction and, where necessary, to avoid excessive exposure of personnel to solvent vapours. A stable offset printing process needs a constant temperature and low velocity of the air streams around the press. The noisy parts of the printing process are the print rollers, the dryer and the folding and cutting machine. These are often encapsulated together with the press itself.

In other cases, encapsulation is not applied for technical or economic reasons. This may for instance be the case where flying imprint units are used. These necessitate numerous plate changes and operator presence at the running press. In these cases, the press is not encapsulated but operated as much as possible from a separate control room.

Temperature-controlled air is fed into the press room or the encapsulated area. The total press room ventilation flow is generally considerably larger (at least five times) than the dryer airflow. The inlet air for the dryer serves as a part of the exhaust air ventilation stream. A proportion of the air is thus not exhausted to the atmosphere, but to the dryer and the oxidiser. As a result, a part of the solvent vapours in the room or the encapsulation is treated. This reduces the fugitive emissions.

The airflow of modern dryers and integrated dryer-oxidisers is between 5 000 m^3/h and 20 000 m^3/h. The total airflow needed for controlling conditions inside the press room or the encapsulation depends on factors such as the number, the size and the speed of the presses and is generally larger than the amount evacuated by the dryers. Additional exhaust ventilation to the atmosphere is needed. The solvent concentration in the press room or encapsulation is low. Due to the low solvent concentration in the additionally ventilated air, its treatment is not economically viable. The highest concentrations will be found where isopropanol is used as an additive in the fountain solution. But even in those cases the concentration will, for health and safety reasons, be well below the occupational exposure limit for isopropanol (e.g. in Germany the maximum permissible concentration (MAK) is 200 mg/m^3). As a result of this low concentration, it is not possible to increase the dryer airflow such that it alone could provide enough exhaust ventilation for the encapsulation.

Achieved environmental benefits
Reduction of fugitive emissions.

Environmental performance and operational data
An approximate calculation for the proportion of the solvent vapours in the encapsulation that are treated is given by the following formula:

$$\frac{\text{Airflow dryers (or integrated dryer} - \text{oxidiser)}}{\text{Airflow dryers + additional exhaust ventilation}}$$

Cross-media effects
No negative environmental effects.

Technical considerations relevant to applicability
Applicable in all heatset web offset printing plants.

Economics
No additional cost.

Driving force for implementation
Ventilation of the press room or the encapsulated area is necessary for reasons of climate control and to avoid excessive exposure of personnel to solvents. Taking the inlet air for the dryers from the press room or the encapsulated area aids this ventilation.

Example plants
All or almost all heatset web offset printing plants across Europe.

Reference literature
[155, TWG 2016] [186, INTERGRAF 2017] [212, TWG 2018]

11.4.3.2 Web offset dryer integrated with off-gas treatment

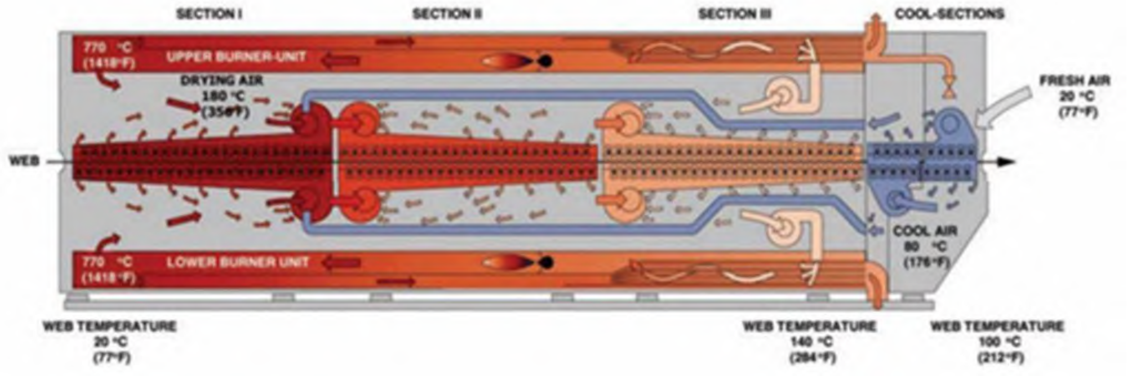
Description
A web offset dryer with an integrated off-gas treatment unit, enabling incoming dryer air to be mixed with a part of the waste gases returned from the off-gas thermal oxidation system.

Technical description
This technique consists of a hot air dryer for the printed web of heatset presses, where the incoming drying air is heated by mixing it with a part of the exhaust gases from the burner or burners that oxidise the VOC content of the outgoing drying air.

The outgoing drying air is fully fed to these burners. The part of the burner exhaust that is not recirculated and used for heating the incoming drying air is emitted.

The cool ingoing dryer air is used to cool the web where it exits the dryer and stop the evaporation of VOCs from the ink on the web. Cooling may also be achieved with the help of metal rollers that are internally cooled with water.

The maximum web temperature is adjustable and will generally be between 140 °C and 190 °C. There is a limit to the recirculation of the air from the oxidiser to the dryer part since the maximum temperature of the paper web is limited.



Source: [186, INTERGRAF 2017]

Figure 11.12: **Integrated off-gas treatment at the dryer of the heatset web offset press**

Achieved environmental benefits
The main benefit is the avoidance of VOC emissions from the drying of the mineral oils in the heatset inks.

In addition, malodorous smells are avoided. Untreated exhaust gases from heatset dryers are notoriously malodorous.

Energy consumption is considerably lower than in the case of separate dryers and oxidisers. The energy consumption of a separate dryer is saved and, due to the recirculation, the energy consumption of the oxidiser is reduced. This can be illustrated by the fact that the exhaust airflow from these integrated dryer-oxidisers is half the airflow of a separate dryer for the same press.

Environmental performance and operational data
Integrated dryer-oxidisers are generally capable of attaining values lower than the IED (Annex VII to Directive 2010/75/EU) emission limit value.

The destruction efficiency depends not only on the emission value, but also on the amount of mineral oil evaporated, which in turn depends on the ink coverage of the web and drying temperature.

Typically the VOC concentration in the drying air is some 2 g VOCs/m^3, and the emission value is well below 20 mg C/m^3. As a result, the destruction efficiency will be over 99 %. Values of 99.9 % are also achievable.

Dryer-oxidisers are designed and produced by specialist companies experienced in supplying the heatset web offset printing market. Their dimensions depend on the width and speed of the press and the usual ink coverage of the web.

The reliability of these machines is outstanding. This is of course necessary because, in case of a defect, no further printing production is possible: the thermal oxidiser cannot be bypassed.

Technical considerations relevant to applicability
In existing buildings, there may be restrictions to the applicability due to the size of the integrated dryer-oxidiser.

Replacement of existing dryers and their separate oxidisers without replacement of the press is not worth the savings in energy consumption.

Driving force for implementation
Decreased energy consumption and abatement of VOC emissions.

Example plants
Widely used.

Reference literature
[186, INTERGRAF 2017]

11.4.4 Cleaning

11.4.4.1 Non-VOC and low-volatility cleaning agents for manual cleaning

Description
The input of VOCs for manual cleaning activities can be reduced by combining the following techniques:

- careful handling of the cleaning agent, e.g. closing containers after use;
- applying -HBS (high-boiling solvent) or VOC-free vegetable-oil-based cleaning agents (VCAs) (see Section 17.9.5) for all cleaning activities;
- using cleaning agents with low environmental impact, see Section 17.6.1.

Achieved environmental benefits
The VOC input for cleaning can be reduced to < 5 % of the ink input or the overall environmental impact including OFP (ozone formation potential) can be reduced.

Cross-media effects
Using the above solvents may mean that more spent solvent will require treatment and/or disposal, as less solvent evaporates.

Technical considerations relevant to applicability
Vegetable cleaning agents (VCAs) are not applicable in heatset web offset printing, because the rinse water can break the paper web.

Only the sheetfed letterpress process can easily use VCAs, but in offset printing, vegetable cleaning agents are not an efficient solution in cleaning blanket cylinders and rubber blankets. The VCAs that are currently available work as swelling agents on rubber blankets and the blankets become unfit for use. It must be taken into consideration that even though VCAs have considerable environmental benefits, VCAs are considered BAT for only some production methods.

Low-volatility cleaning products require new working practices. Products with low volatility often do not work immediately when applied to the surface to be cleaned. They have to be rinsed off using water - as a second step. Therefore, switching to non-volatile substances for cleaning will require workers to adjust their working practices.

When non-volatile cleaners are manually applied they have to be used sparingly because if dripped into the machine they may cause printing errors [148, COM 2009].

Economics
Smaller quantities are needed for effective cleaning and they can be diluted with up to 50 % water. The resulting reduction in consumption fully compensates for their higher price [148, COM 2009].

Driving force for implementation
Occupational health (exposure to solvent vapours) and occupational safety (avoiding explosions in the dryer when the paper web with a cleaning agent reaches the dryer).

Reference literature
[7, Germany 2003] [38, TWG 2004] [78, TWG 2005] [148, COM 2009]

11.4.4.2 Use of VOC-free solvents or solvents with low volatility for automatic blanket cleaning

Description
Use of organic compounds which are not volatile or have a low volatility as cleaning agents for automatic blanket cleaning.

Technical description
Automatic blanket cleaning in heatset web offset printing concerns the cleaning of the rubber blanket cylinder during printing jobs. Paper fibres and ink stick to the rubber blanket and reduce the quality of the printed product. During production the press is occasionally slowed down or stopped, according to the cleaning cycle for the rubber blankets, which are generally eight per heatset press (four colours on each side of the paper web). The cleaning agent consists of a solvent which is often mixed with water. Where water is used, it makes the paper fibres swell and the solvents detach both the fibres and the ink from the rubber blanket.
The length and frequency of the cleaning cycles vary widely, depending on the press, the paper and the print job. The wrong length cleaning cycle may result in a web break. Cleaning cycles are reported to take generally between 15 and 40 seconds, but may sometimes take up to 3 minutes. One cleaning cycle may use between 10 ml and 700 ml of cleaning agent.

Three types of automatic cleaning exist:

- Brush system: A brush wetted with the solvent-water mixture is briefly held against the blanket. The brush is wiped clean: some 10 % of the cleaning agent is collected together with the dirt removed and some 90 % is transferred to the paper web.
- Tissue system: Tissue is pressed against the rubber blanket a few times. Both the tissue and blanket cylinder are sprayed with cleaning agent. Some 20 % of the cleaning agent and the loosened dirt is absorbed by the tissue. The remainder of the cleaning agent is transferred to the paper web. In other cases, the tissue is pre-wetted with a cleaning agent.

- Spray system: The blanket cylinder is sprayed with cleaning agent. Cleaning agent and loosened dirt are transferred to the paper web.

In all three systems, the paper web transports all or almost all the cleaning agent to the dryer where it evaporates. The VOCs absorbed by the paper web are subsequently abated in the oxidiser. The remainder is collected and disposed of as waste. Therefore the fugitive emissions are negligible.

Since most of the cleaning agents end up in the dryer, the whole system of cleaning method, cleaning agent, dryer and oxidiser must be designed and operated in such a way that no explosion risk can occur due to the temporary increase of the solvent concentration in the dryer and oxidiser during the cleaning cycle. The dryer manufacturer generally specifies limits within which the cleaning agents must fall. These limits may be expressed in different ways, (flammability, vapour pressure, LEL, etc.) but they always result in a very low vapour pressure for the solvents used.

Achieved environmental benefits
This technique results in the avoidance of fugitive emissions due to negligible evaporation of solvents from cleaning agents used for automatic cleaning. In addition, these automatic cleaning systems reduce the amount of manual cleaning and subsequently the use of more volatile solvents.

Environmental performance and operational data
The combination of low-volatility solvents that are used, the short duration of the cleaning cycle and the construction of the cleaning systems mean that almost all VOCs are either collected or absorbed in the paper web. As a result, no fugitive emissions worth mentioning result from automatic cleaning when only low-volatility solvents are used in the cleaning agent.

Cross-media effects
The amount of paper waste is influenced by the effectiveness of the cleaning agent used. In particular, VOC-free cleaning agents may be less effective than low-volatility cleaning agents. Where this is the case, the use of these VOC-free cleaning agents must be avoided to prevent an increase in paper losses.

Technical considerations relevant to applicability
All automatic cleaning systems used in large heatset web offset printing plants are suitable for the application of low-volatility solvents in cleaning agents.

Economics
There is no additional cost. All large modern heatset presses are equipped with automatic blanket cleaning systems.

Driving force for implementation
The main driving forces for implementation are economic advantages (faster cleaning, higher productivity, less manual cleaning), improved working conditions (less manual cleaning, lower exposure to solvent vapours) and increased safety (fewer flammable liquids in use).

Example plants
All plants that provided data.

Reference literature
[186, INTERGRAF 2017]

12 FLEXOGRAPHY AND NON-PUBLICATION ROTOGRAVURE PRINTING

In flexible packaging plants, a combination of two or more of the following processes is used:

- packaging rotogravure (non- rotogravure);
- flexography;
- lamination;
- varnishing;
- digital printing.

Solvents may be used in all of these processes.

12.1 General information on the flexography and non-publication rotogravure printing industry

[194, Technavio 2017] [196, ERA 2015] [197, FPE 2017]

The flexography and non-publication rotogravure printing market in Europe is continuously growing and is envisaged to continue to grow steadily in the coming years. One of the key factors for this trend is the increasing demand for plastic-based flexible packaging products.

The main product types of the flexography and non-publication rotogravure printing industry are:

- confectionary products;
- pharmaceutical;
- personal care;
- pet food;
- meat products;
- dairy products;
- frozen food products;
- fruits and vegetables.

During 2015, the confectionary products segment dominated the market and accounted for more than 22 % of the market share in terms of revenue.

The basic raw materials used are:

- plastic;
- paper;
- aluminium foil.

The European flexography and non-publication rotogravure printing industry is estimated to have a total of 320 printing plants, operating 820 rotogravure presses. They produce, for example, the following:

- Flexible packaging material (film-based foil packaging as a monolayer or composite to pack foodstuff, confectionery, pharmaceuticals, etc.). Flexible packaging material is used by the large multinational brand owners, as well as by large supermarket chains to pack their own brand products.
- Labels for bottles of the large soft drink manufacturers.
- Lids for dairy products (e.g. yoghurt).

- Beverage cartons for milk and juice.

The turnover of the flexography and non-publication rotogravure printing industry in Europe amounts to around EUR 15 billion per year. This number is a rough calculation. The turnover of the individual printer varies according to the product and the substrate that it prints.

There are also about 85 decorative rotogravure printing plants in Europe, operating 300 rotogravure presses. They produce primarily:
- base paper for laminate flooring, furniture, kitchen units, etc.;
- gift wrap;
- wallpaper.

The turnover of decorative rotogravure in Europe amounts to around EUR 2.5 billion per year.

Many flexography and non-publication rotogravure printers do not have engraving facilities of their own and subcontract the cylinder manufacturing and engraving. This has become an important industry with an annual production of more than 600 000 gravure printing cylinders. Additionally, there are a significant number of cylinders engraved for the embossing of packaging, wallpaper, hygiene paper, decorative products, etc. The turnover is estimated to be around EUR 0.5 billion per year. By subcontracting the cylinder manufacturing and engraving, the emissions to water from the electroplating of cylinders are therefore transferred to specialist suppliers.

12.2 Applied processes and techniques in flexography and non-publication rotogravure printing

[197, FPE 2017]

12.2.1 Flexography

Flexographic printing employs direct rotary printing using resilient relief plates such as rubber or, as is more likely these days, photopolymers and fast-drying solvent- or water-based inks.

Flexography is almost exclusively a reel or webfed process. It is a simple method of printing, normally with a very easy inking system using one main dispensing roller with a rough surface.

Specially designed flexography presses now produce a wide range of printed products. It is particularly suitable for long-run web printing, and is very adaptable to a wide range of substrates – from thin paper to heavy corrugated cardboard, thin cellophane to thick flexible sheeting, vinyls and foils. The main applications of the process are flexible packaging, cartons for liquids, some newspapers, paperback books, labels, paper/plastic bags, cartons/packaging and wall coverings.

Plants producing and printing corrugated cardboard use sheetfed presses. The corrugated cardboard is cut into rigid sheets which go through the whole press horizontally. The presses are either ‘bottom printers’ or ‘top printers’, i.e. print on the underside or top side of the substrate.

Inking unit

Many different products and substrates may be printed on the same press and, therefore, inks may have to be changed regularly. Food packaging inks have changed over the years from those based on aromatic solvents to aliphatics, i.e. from toluene and xylene to ethanol, MEK, acetone and ethyl acetate. These inks dry by evaporation; however, UV-cured inks are also used [38, TWG 2004].

The ink has low viscosity, is fluid and traditionally held in an inkpan from where it is picked up by a rotating rubber fountain roll. The fountain roll subsequently delivers the ink to the metering roll. Excess ink is removed from the metering roll with a doctor blade before it is transferred to the printing plate.

A more modern system is the chamber doctor blade where the ink reservoir is connected to a fountain head from which the ink is supplied directly onto the ink-metering (anilox) roll. As the ink is circulated by pumps in the box-like construction, the transfer of ink onto the anilox roll is independent of the press speed. Two doctor blades, connected to the fountain head, fit closely against the anilox roll.

Ink-metering (anilox) roll

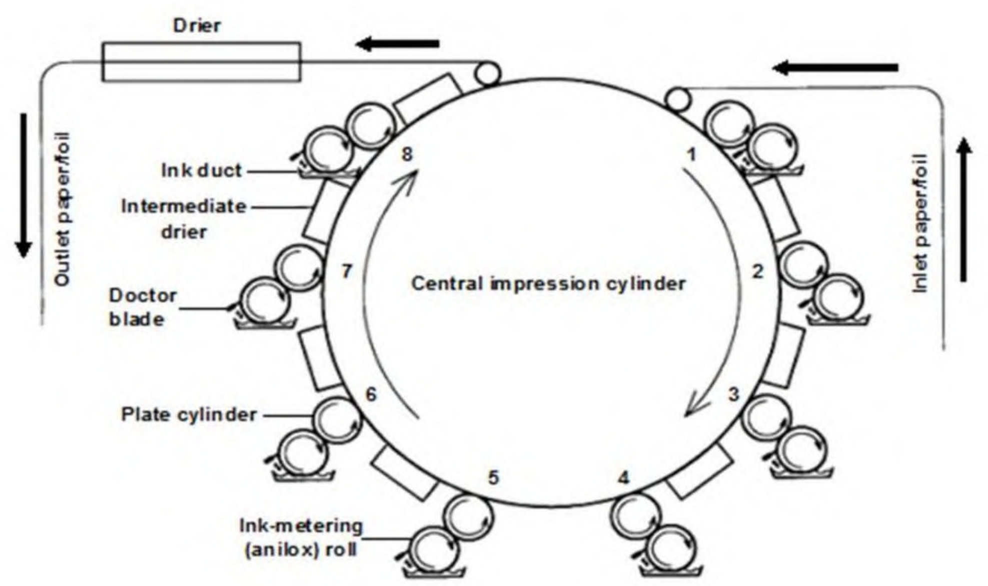
In a flexography press, the ink is transferred from the ink-fountain to an ink-metering (anilox) roll. The ink-metering roll is ceramic and covered with cells by which the ink is metered out onto the printing plate; how much depends on the depth and structure of the cells, the pattern formation and the screen count. The cells can be mechanically or laser-engraved, and if necessary can be re-engraved.

Plate cylinder

The plate cylinder is usually a steel cylinder onto which the printing plates are mounted with a double-sided adhesive. Flexography printing plates are usually made of UV-sensitive polymers or rubber, and are resilient and flexible, which has given the technique its name.

Impression cylinder

Flexography printing machines may be designed as a series of units, or in compact form. In series construction, each printing unit has its own impression cylinder and are lined up in stands one behind the other. In compact form, several printing units may be supported on both sides or, in the case of small presses, hung from one side (cantilever type) of a central impression cylinder. This is also known as a satellite press [38, TWG 2004].



Source: [14, Aminal et al. 2002]

Figure 12.1: Eight-colour flexography press with a central impression cylinder (satellite press)

Cleaning

Cleaning of printing plates and machine parts is done with solvents similar to those in the inks or varnishes. Ultrasound cleaning and cleaning with high-pressure powder can also be used.

12.2.2 Rotogravure

[1, INTERGRAF and EGF 1999] [3, IMPEL 2000] [8, Nordic Council of Ministers 1998] [78, TWG 2005] [197, FPE 2017]

In rotogravure printing, the image consists of small indentations in a smooth surface of a cylinder. This consists of a steel base which is plated with copper and covered with a thin layer of hard chromium. It tends to be a more specialised process than either relief or litho printing. In this process, the cylinder is flooded with ink, and the surface scraped clean to leave ink only in the recessed, image areas.

Rotogravure is used for printing two major graphic products: publications, which is discussed in Chapter 13 of this document, and flexible packaging (e.g. packaging for tobacco industry). Minor graphic applications are labels, wrapping paper, cardboard packaging, banknotes and postage stamps. Outside the graphic industry, this method is used for the printing of wallpaper, imitation wood (laminates) and imitation tiles for floors and walls.

Table 12.1: Main technical characteristics of packaging rotogravure presses

Parameter	Technical characteristics
Web width	Up to 2 000 mm
Printing units	Generally between 6 and 10, often 8 colour units + one lacquering unit and/or laminating unit
Production speed	Generally some 250-400 m/min; also dependent on diameter of cylinders in use
Construction	Units in line, each printing a separate colour
Colours	All colours, often also white basis
Substrates	Paper, many different kinds of plastic films, metallised paper and plastic, aluminium foil; often multi-material, multilayer substrate
Solvents in use	Ethyl acetate, ethanol, MEK and others. Mostly in mixtures in northern Europe
Abatement techniques	RTO mostly and solvent recovery

Most packaging rotogravure presses have a web width wider than one metre. They print eight or even more colours, with each press unit printing one colour [15, CITEPA 2003].

Today, rotogravure is an almost entirely webfed process, although sheetfed presses are available running at up to 10 000 sheets per hour. These have hot air dryers and are aimed at the specialised markets of high-quality decorative effects using metallic inks on metallised papers and foils. They are, however, seldom used at present, presumably because of the high costs of cylinder making, which make high (web) run lengths more economical [1, INTERGRAF and EGF 1999].

Inking unit
[8, Nordic Council of Ministers 1998] [38, TWG 2004]

The high speed of rotogravure presses requires the use of fast drying inks, which are dried between colours in dryers. Therefore, in rotogravure, inks are low in viscosity and nearly all of them are solvent-based. In packaging printing inks, ethanol and ethyl acetate are used almost exclusively. The solvents are evaporated by heat and air in drying sections [38, TWG 2004].

Solvent vapours from the inks in the rotogravure printing are normally treated with RTO or recovered.

Water-based rotogravure inks are used for printing wallpaper and imitation wood (laminates) [8, Nordic Council of Ministers 1998] [38, TWG 2004].

12.2.3 Laminating and varnishing in flexible packaging

Flexible packing materials are often multilayer materials built up by lamination and with a protective coating called varnish. The processes are technically similar to packaging gravure printing. While no image is printed, the substrate is usually totally covered (i.e. 100 % covered). Solvent-based or solvent-less adhesives (one- or two-component), water-based adhesives and resins are used [38, TWG 2004] [197, FPE 2017].

12.3 Current consumption and emission levels in flexography and non-publication rotogravure printing

[155, TWG 2016] [197, FPE 2017]

The specific consumption and emission values are significantly dependent upon the manufactured products and will increase with:

- decreasing print volume;
- increasing number of colour change sequences;
- extremely high demands on the printing quality, or difficult printing images;
- decreasing paper quality;
- increase in surface to cover.

Data for 33 flexography and non-publication rotogravure printing plants were received in the data collection and they are analysed in the following sections [155, TWG 2016].

12.3.1 Consumption

12.3.1.1 Organic solvents

[1, INTERGRAF and EGF 1999] [155, TWG 2016]

Reported values of total organic solvent consumption show a range from 40 g up to 390 g solvent per kg of printed surface. The relevant range of reported values for total solvent consumption expressed against the printed surface is from 1 kg up to 30 kg solvent per 1 000 m^2. It was not possible to differentiate on the basis of substrate material as most of the reported plants use a range of substrate types, e.g. polypropylene, polyethylene, polyester, polyamide, aluminium or paper foil, cardboard [155, TWG 2016].

Table 12.2 shows a choice of typical organic solvents that are employed in packaging printing processes together with their field of application (information from 2004). Table 12.3 shows an overview of typical organic solvents that can be found in packaging printing processes applying water-based inks, adhesives or varnishes.

Table 12.2: Typical solvents used in solvent-based packaging flexography and non-publication rotogravure printing processes

Solvent	Vapour pressure (kPa)	Field of application
Ethyl acetate	9.2	Thinner, cleaning agent
Ethanol	5.9	Solvent in ink, cleaning agent
Mixtures of ethanol and ethyl acetate	NI	Mix depends on required drying time
Isopropanol	4.3	Solvent in ink, cleaning agent
Isopropyl acetate	6.1	Viscosity adjuster
Methyl ethyl ketone	10.5	Siccative; often used as solvent in adhesives and some varnishes
n-Butanol	1.2	Retarder
Methoxy propanol	1.1	Retarder
n-Propanol	2.5	Retarder
Ethoxy propanol	0.65	Retarder
Various esters	NI	Plasticiser

Source: [7, Germany 2003] [38, TWG 2004]

Table 12.3: Typical solvents used in water-based packaging flexography and non-publication rotogravure printing processes

Solvent	Vapour pressure (kPa)	Field of application
Ethanol	5.9	Solvent in ink, siccative, cleaning agent
Isopropanol	4.3	Solvent in ink, cleaning agent
n-Propanol	2.5	Solvent in ink
Special naphtha	4.0-8.5	Cleaning agent (rarely used as most packing is for food)
White spirit	0.15-1.0	Cleaning agent (rarely used as most packing is for food)

Source: [7, Germany 2003]

Apart from organic solvents in purchased printing inks, other relevant solvent quantities are used in ink thinning (viscosity control) and for several cleaning jobs. Especially in the area of viscosity control, the rotogravure and flexography processes are different.

Table 12.4 presents typical mean values of specific VOC uses.

It is important to note that the solid to solvent ratio in inks 'as bought' will vary enormously from plant to plant. Ink is delivered to certain specifications. In one extreme, it is delivered 'almost press-ready', with a solvent content of close to 75 % (a small final dilution is done at the press). At the other extreme, ink is delivered as a 'paste' with a solvent content of about 30 %. The pastes are mixed and diluted in the ink department to 'almost press-ready'. Again, the final dilution is carried out at the machine in order to give the operators the flexibility (by adding solvent) to achieve a particular drying time. Ready-to-use solvent-based inks contain ~ 80 % solvent [148, COM 2009]. In addition, a few years ago the 'normal' percentage of solvent in ink 'as bought' was between 50 % and 60 %; this is now no longer the case. In larger plants, inks are today bought as 'paste' and diluted in-house [78, TWG 2005]:

Table 12.4: Specific VOC use in packaging flexography and non-publication rotogravure printing processes

Printing process	VOCs used expressed as % of purchased ink (wt-%) in the following areas:						Total VOCs used as % of purchased ink (wt-%)	
	Printing inks (1)		Thinners for inks		Cleaning agents			
	Average	Range	Average	Range	Average	Range	Average	Range
Rotogravure solvent-based	6	4-7	10.1	7-12	1.7	NI	17.8	12.7-20.7
Flexography solvent-based	6	4.5-7.5	8.1	5-9.5	1.4	NI	15.5	10.9-18.4
Rotogravure water-based	5	0-20	2	0-5	10	0-15	17 (2)	0-40
Flexography water-based	5	0-20	2	0-5	10	0-15	17 (2)	0-40

(1) The machine-ready ink will always contain about 80 % solvent. An ink bought with a higher solvents content will require less solvent for thinning (viscosity adjustment). Averages for solvent-based inks: gravure tends to be slightly over 80 % and flexography tends to be slightly under 80 %.
(2) Average for water-based inks of 17 % is too high [38, TWG 2004] [78, TWG 2005].
Source: [7, Germany 2003]

12.3.1.1.1 Printing inks and varnishes

[1, INTERGRAF and EGF 1999] [7, Germany 2003] [8, Nordic Council of Ministers 1998] [9, VITO 1998] [78, TWG 2005] [212, TWG 2018]

Types of inks used – solvent-based
The most common solvents used in solvent-based packaging printing are ethanol and ethyl acetate. Furthermore, flexography printing plants use isopropanol, n-propanol, methoxy propanol and ethoxy propanol, while gravure printing plants also use methyl ethyl ketone (MEK), isopropyl acetate and n-propyl acetate. The choice of solvent used in the ink depends on the printing substrate.

During printing, the viscosity of the ink is adjusted as required, or is kept at its preset level by adding compatible solvents. Newly mixed inks are always produced slightly too viscous to allow exact adjustment to be made at the press.

Flexographic ink is either solvent-based or water-based. Gravure ink is almost always solvent-based and water-based inks are rarely used.

Table 12.5 shows the average composition of a basic recipe for solvent-based inks. The ink solvent concentration varies. Machine-ready inks might contain up to 80 % solvent and 20 % solids. Varnishes also contain about 80 % solvents [38, TWG 2004] [78, TWG 2005].

Table 12.5: Average basic recipe for solvent-based flexographic printing inks

Component	Contents	Concentration (wt-%)
Binding agent:		
- solvent component	Normal drying solvents: e.g. ethanol, n-propanol, isopropanol	60-80
	Fast drying solvents: e.g. ethyl acetate, i- and n-propyl acetate, MEK, naphthas	
	Slow-drying solvents: e.g. methoxy propanol, ethoxy propanol	
- binding agent component	Cellulose derivates (e.g. nitrocellulose), polyvinyl butyrates, PVC, polyamides	2-10
Colourants	Inorganic and/or organic pigments	5-10
Colour auxiliary agents	e.g. softeners, waxes, slide agents, EDTA (no longer used in Germany)	1-6

NB: Physical properties: solids content: 25-40 %; net calorific value: > 20 MJ/kg; flashpoint < 21 °C.
Source: [7, Germany 2003] [19, Austria 2003]

A typical formula for a flexographic ink to be printed on paper is shown in Table 12.6 and a typical formula for a hydrocarbon solvent-free ink for paper is shown in Table 12.7.

Table 12.6: Typical flexographic printing ink for paper as bought

Component	Concentration (wt-%)
Pigment	20
Maleic resin varnish	16
Nitrocellulose varnish	38
Wax	4
Plasticiser	4
Ethanol	11
Isopropyl acetate	7

Source: [1, INTERGRAF and EGF 1999]

Table 12.7: Typical solvent-free flexographic printing ink for paper as bought

Component	Concentration (wt-%)
Organic pigment	12
Alcohol-soluble polyamide resin	22
Nitrocellulose (dry weight)	4
Wax	4
Fatty acid amine	1
Ethanol	29
n-Propyl alcohol	18
n-Propyl acetate	10
Source: [1, INTERGRAF and EGF 1999]	

Flexographic printing inks for plastic substrates and metallic foils vary considerably from inks that are used on paper. The solvents used have changed over time, partly as a result of food packaging requirements and regulations. Aromatic ink solvents have been replaced by ethanol and ethyl acetate and some MEK in adhesives and varnishes [1, INTERGRAF and EGF 1999] [93, COM 2002].

Apart from the general basic recipe shown in Table 12.5, other examples of typical inks used in the rotogravure printing process can also be found; one of these is shown in Table 12.8. Of course, the ink formulation will vary considerably depending on the printing substrate, the press parameters and the end use of the finished product.

Table 12.8: Typical recipe of a rotogravure ink as bought

Component	Concentration (wt-%)
Pigment	4-12
Extender pigment	0-8
Resin	10-30
Plasticiser/wax/additives	2-10
Solvents	40-60
Source: [1, INTERGRAF and EGF 1999] [38, TWG 2004]]	

In general, the solvent choice will depend on many aspects, such as a need to avoid a solvent attack on a film or solvent coating, and to ensure that as little solvent as possible remains in the product, especially with food packaging. Only very rarely is it necessary to deviate from ethanol, ethyl acetate and mixtures of the two. MEK, acetone, toluene (packaging for medical purposes) or isopropanol (non-food paper product) may be found [1, INTERGRAF and EGF 1999] [78, TWG 2005].

Types of inks used – water-based

Table 12.9 shows the average composition of a basic recipe for water-based inks applied in rotogravure printing. In water-based inks, the water concentration in the purchased printing inks might normally be in the range of 50-60 %. Aqueous dispersions, such as styrene-acrylate copolymer, are mainly used as binding agents. According to the purpose and the desired resistances, acid resins, which are transformed into a water-soluble form by saponification with alkaline substances (ammonia or amines), are employed for modification. During the drying process, the amines or ammonia escape and the binding agent resins once more become insoluble in water [7, Germany 2003].

As drying additives, ethanol and isopropanol are added in low concentrations [7, Germany 2003].

In most cases, the recipes contain additives such as anti-foam agents, wetting agents and biocides. Dilution can be made with water [7, Germany 2003].

Table 12.9: Average basic recipe for water-based rotogravure inks

Component	Contents	Concentration (wt-%)
Binding agent:		
- aqueous solvent component	Water	50-75
- organic solvent component	Alcohols (e.g. ethanol, isopropanol)	0-13
- other binding agent component	e.g. polyester and acrylate resins, polyvinyl acetate	10-20
- other binding agent component	Ammonia, amino acids	1-5
Pigments	Inorganic and/or organic pigments	10-20
Colour auxiliary agents	e.g. waxes, (softeners and complex formers are not used in Germany)	1-5
	Saponification agents	1-5
NB: Physical properties: solids content: 25-40 %; net calorific value: > 10 MJ/kg; approx. pH value: 8. *Source*: [7, Germany 2003] [19, Austria 2003] [38, TWG 2004]		

A typical recipe of a water-based rotogravure ink for printing on coated paper might be as shown in Table 12.10.

Table 12.10: Typical recipe of a water-based rotogravure ink for coated paper as bought

Component	Concentration (wt-%)
Acrylic resin	32
Water	30
Pigment	15
Acrylic dispersed phase polymer	15
Alkali	2
Anti-foam	1
Isopropanol	3
Wax dispersant	2
Source: [1, INTERGRAF and EGF 1999] [7, Germany 2003] [78, TWG 2005]	

A typical composition of a well-performing, water-based flexographic ink used for printing on paper and cardboard is shown in Table 12.11.

Table 12.11: Typical recipe of a water-based flexographic ink for paper and cardboard as bought

Component	Concentration (wt-%)
Acrylic emulsion	50
Water	20
Pigment	25
Monoethylamine	2
Polyethylene wax	3
Organic anti-foam	< 1
Source: [1, INTERGRAF and EGF 1999]	

Water-based inks for printing onto polyethylene and polypropylene would typically have much higher acrylic dispersed polymer contents (40 %) and much lower acrylic resin percentages (between 5 - 10 %).

Cartons are almost always varnished, increasingly with water-based overprint varnishes. A water-based heat-seal-resistant varnish, suitable for overwrapping with film, might have the formula shown in Table 12.12.

Table 12.12: Typical recipe of water-based varnish for cartons in rotogravure printing processes

Component	Concentration (wt-%)
Hard acrylic resin	15
Isopropanol	20
Water	15
Acrylic emulsion	35
Amine or ammonium hydroxide	2
Wax emulsion	5
Wax dispersion	5
Release agent	2
Anti-foam	1
Source: [1, INTERGRAF and EGF 1999]	

Types of inks used – UV

UV printing inks are increasingly applied in flexographic printing. These inks consist of binders, additives, photoinitiators and the dyestuff which are all solid materials and contain no solvent. Drying, or more correctly, curing is the consequence of the cross-linking or polymerisation of the printing film resulting from the printed surface being exposed to short-wave UV light.

Amounts of inks used

The amount of both solvent- and water-based ink consumed depends largely on the colour of the ink and only slightly on the printing substrate or printing method. Table 12.13 shows some average values.

Table 12.13: Average ink application values

Colours	Ink application (for theoretical complete coverage) (g/m^2)
White	1.5-2.0
Spot colours	1.0-1.5
Half tone	0.5-1.0
Source: [38, TWG 2004]	

Information received from industry indicates that ink application values of up to 12 g/m^2 may also occur [ERA comment #12 in [212, TWG 2018]].

Most of the reported values for total ink and varnish consumption show a variation from 0.33 g/m^2 up to 45 g/m^2 of finished product [155, TWG 2016].

The surface that is covered with ink, especially in flexible packaging, is determined by several complex customer requirements, such as:

- the quality of the image that has to be printed and the type of printing substrate;
- the need to prevent light reaching the product inside (usually food);

- the need for an airtight barrier and prevention of migration of smells;
- for printing materials that are difficult to moisten (e.g. foils), a primer is applied that acts as an adhesive agent and is applied in the first print run;
- for improvement of the effect of the printed colours on transparent plastic or metal foils, the surface is first printed in matt white before applying the final colours;
- for improving the characteristics of the coloured surface, e.g. UV or abrasion resistance, full-surface varnishing is employed as a last step in the printing job.

For example, on corrugated cardboard the surface covered with ink is usually < 20 %, while for high-quality consumer goods (e.g. chocolate packaging) a surface coverage of > 400 % is achieved by using a series of coatings. ‘Flat tints’ reach 100 % coverage for white ink on plastic, and varnishes and adhesives also have a large impact on the total surface covered [38, TWG 2004].

12.3.1.2 Cleaning agents

For cleaning the presses, primarily the same solvents as those employed in the inks are used. Plants using water-based ink systems are usually cleaned with water, partly with admixtures of alkaline substances, such as sodium bicarbonate, and tensides. Mixtures of water with water-dilutable organic solvents are also used. In order to remove dried inks from the small cavities in gravure cylinders and anilox rollers, ultrasonic equipment or other solvent-free cleaning techniques may be used. High-pressure water jets are also used on anilox rollers [1, INTERGRAF and EGF 1999] [7, Germany 2003] [38, TWG 2004].

12.3.1.3 Adhesives in lamination

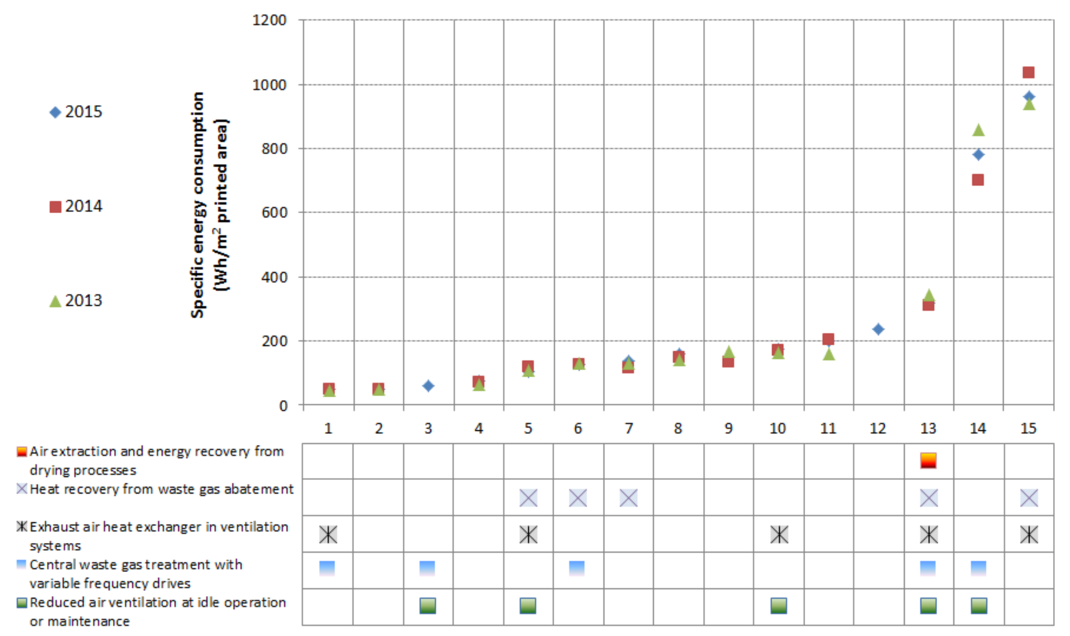
Laminating is done with solvent-based and solvent-free systems. The adhesives are based on epoxy or urethane systems, in which two constituents react to form a very tough film. The difference of both systems is that in one case solvent is used to steer viscosity and in the other case heat is used to control viscosity.

Mixing of the two components is required but there will be no solvent emissions. Solvent-free adhesives or UV-curing laminating adhesives are also applied [1, INTERGRAF and EGF 1999], [38, TWG 2004], [197, FPE 2017].

12.3.1.4 Energy and resources

[155, TWG 2016]

The reported values for specific energy consumption expressed as total energy consumption (electrical and thermal) per square metre of printed area from flexography and non-publication rotogravure printing installations are presented in Figure 12.2.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Air extraction and energy recovery from drying processes													■		
Heat recovery from waste gas abatement					✕	✕	✕						✕		✕
Exhaust air heat exchanger in ventilation systems	✳				✳					✳			✳		✳
Central waste gas treatment with variable frequency drives	■		■			■							■	■	
Reduced air ventilation at idle operation or maintenance			■		■					■			■	■	

Source: [155, TWG 2016]

Figure 12.2: Specific energy consumption expressed in Wh/m² of printed area for the period 2013-2015

The main energy-saving techniques that were reported are:

- air extraction and energy recovery from drying processes;
- heat recovery from off-gas treatment;
- use of waste heat from the thermal oxidiser for thermal oil heating;
- exhaust air heat exchanger in ventilation systems;
- central off-gas treatment with variable frequency drives;
- thermal insulation of tanks and vats with heated liquids, oil valves and flanges;
- CCHP (combined cooling, heat and power) – trigeneration;
- reduced air ventilation during idle operation or maintenance;
- optimisation of dryer efficiency in printing and laminating.

More information on possible energy efficiency options for the printing sector in general can be found on the EMPSI project webpage[38].

UV- and water-based inks need more energy to dry than solvent-based inks. UV inks need UV light to cure them and special equipment on the press. As the high energy supply to the lamps is turned into heat, large installations for cooling are also needed [8, Nordic Council of Ministers 1998]. For water-based inks, an increase in the energy consumption of the dryers of some 10 % is often found [1, INTERGRAF and EGF 1999].

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[38] EMPSI: Energy management standardisation in printing industry, http://www.emspi.eu/index.html

12.3.2 Emissions

A report [77, VROM 2004] showed VOC emissions from flexography and non-publication rotogravure printing plants using good practices to be in the order of 7.5 % to 12.5 % of the reference emissions as those are calculated according to Annex VII (Part 5) to Directive 2010/75/EU (IED). Older plants that have connected only the more concentrated VOC sources to off-gas treatment achieve 10-25 % of the reference emission. Lower values may be associated with the extensive use of solvent-free products. Similarly, some plants without abatement equipment can achieve less than 25 % of the reference emission, but, as a consequence, not many of these will use more than 200 tonnes of solvent per year.

In total, 29 different emission sources were distinguished. These include not only sources for fugitive emissions but also some sources for waste gas emissions. Distinction was made between four different groups of emission sources: press room (P), oxidation (O), cleaning (C) and ink preparation (I).

Table 12.14 below gives, for many sources, a typical emission value for fugitive emissions (F) expressed as a percentage of solvent input, possible reduction measures for that source and a typical emission value after the reduction measures have been taken. The following points should be borne in mind:

- ‘Typical’ emission values are provided to give an impression of the order of magnitude. The emission is expressed as a percentage of the solvent consumption of the plant. Actual emissions values may vary widely.
- ‘n.a.’ means that no typical emission value can be given. Emissions from sources such as ‘defects in bypasses’ or ‘solvent content water-based products’ obviously vary enormously from plant to plant.
- ‘Very small’ means that the total emissions of all the ‘very small’ sources may be less than 1 % of the solvent consumption.
- ‘Negligible’ means that the emission is either zero or an order of magnitude smaller than the ‘small’ emissions. Their total volume is smaller than the margin of error in the larger emissions.

Table 12.14: Reduction of fugitive emissions from flexography and non-publication rotogravure printing

Group	Activity or source	Typical emission	Possible reduction measures	After reduction
P	Evaporation from the ink fountains during production	5 %	1. Adequate coverage of the ink fountains 2. Use of chamber doctor blades 3. Encapsulation of varnishing or lamination units 4. Use of adhesives with reduced solvent content 5. Floor extraction through dryers 6. Floor extraction sent to incinerator	< 2.5 %
	Evaporation from open viscosity adjustment units	Very small	Encapsulation	Negligible
	Leaking dryers through defects or dryer pressure higher than atmospheric	n.a.	Proper maintenance, correct operation, periodic checks (see Section 17.10.2.4)	Negligible
	Defects in the bypass of the dryers (off-gases sent to atmosphere rather than to the incinerator)	n.a.	High priority, proper maintenance, correct operation, periodic checks, instruction for manual operation if possible, speedy repairs	n.a.
	Waste gas emissions from presses when these are filled with ink, but not yet printing	n.a	Automatic closure of bypass before make-ready speed is reached	Negligible
	Waste gas emissions from presses in the case of defects to production machines	n.a	Proper maintenance, correct operation, periodic checks (see Section 17.2.6)	Very small
	Waste gas emissions from presses when printing at make-ready speed. (30–60 m/min)	3-8 %	Automatic closure of bypass before make-ready speed is reached	Very small
	Cleaning floors	1 %	1. Prevention of soiling 2. Use of squeezable sweeps 3. Use of non-volatile cleaning agents (see Sections 17.8.6 and 17.9.6)	Very small
	Evaporation from open drums	Very small	Keep closed as much as possible (see Section 17.2.2)	Negligible
	Residual solvent packaging materials for food	Negligible	None	Negligible
	Residual solvent in printed materials that are not packaging for food	n.a	Improve drying	< 0.1 %
O	Emissions from the incinerator	0.5-1.5 %	(May increase if additional solvent-laden air streams are sent to incinerator)	0.5-1.5 %
	Defects in the oxidiser causing off-gases to be sent to the air	n.a.	High priority: proper maintenance, correct operation, periodic check, instruction for manual operation if possible, speedy repairs Equip with computer techniques, connect to supplier	Very small
	The use of solvent-based inks, varnishes and adhesives on machines not attached to the incinerator	n.a.	Connect to incinerator at times when incinerator has enough capacity	0.5-1.5 %
	The use of solvent-based inks, varnishes and adhesives on dryers not attached to the incinerator	n.a.	Refrain from using these dryers for solvent-based inks Connect to incinerator at times when incinerator has enough capacity	0.5-1.5 %
C	Drying process and ventilation in automatic washing	5 %	1. Ventilation to incinerator 2. Use non-volatile cleaning agents	0.5-1.5 %

	machines using solvents		(see Sections 17.8.6 and 17.9.6)	
	Evaporation during manual cleaning operations - Cleaning and drying by hand after washing automatically - Cleaning with machines other than automatic washing machines -Evaporation from open drums (solvent, waste etc.)	1 %	1. Prevent useless evaporation 2. Prevent cleaning and drying by hand after washing automatically 3. Use automatic washing machine as much as possible 4. Use non-volatile cleaning agents as much as possible 5. In press room, prevent contamination of objects that cannot be cleaned in washing machine as much as possible 6. In-depth cleaning of anilox rollers and cylinders with solvent-free methods (see Sections 17.8.6 and 17.9.6)	0.5 %
I	Evaporation resulting from the mixing of inks	Very small	Automatic ink mixing systems, drum close to nozzles, quickly close drums after filling (see Sections 17.2.5 and 17.2.2)	Very small
	Evaporation resulting from making colour tests	Negligible	None	Negligible
	Cleaning of the floors and other cleaning	1 %	1. Prevention of soiling 2. Use of squeezable sweeps 3. Use of non-volatile cleaning agents (see Sections 17.8.6 and 17.9.6)	0.5 %
	Evaporation losses from tanks	Negligible	None	Negligible
	Evaporation from open drums	Very small	Keep closed (see Section 17.2.2)	Negligible
Source: [77, VROM 2004] updated by [197, FPE 2017]				

The emissions caused by defects in dryers, bypasses or in the oxidiser itself may be considerable. The same is true for machines and dryers not attached to the oxidiser and the solvent content of water-based inks. No typical emission values are given, but the total of the emissions from these sources may easily be several per cent of the annual solvent consumption. It can be seen that the total of the emissions from all the other sources may vary enormously. If none of the reduction measures mentioned in Table 12.14 are applied, this total may amount to well over 25 % of solvent consumption. If all possible reduction measures are applied, the total of these emissions may be well below 15 % of solvent consumption.

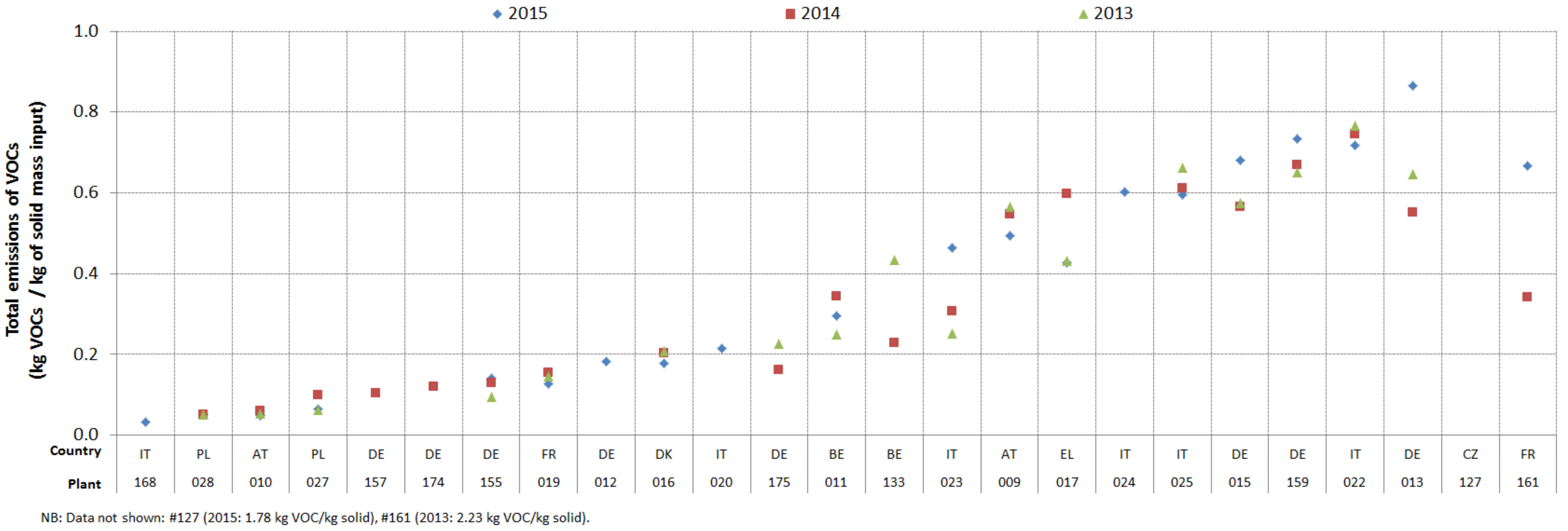
Allowing for several per cent of emissions due to defects and the solvent content of water-based inks, the total emissions can be expected to vary between 10 % and 30 % in most plants.

In order to attain low total emission values, it is necessary to carry out all or most of the following:

- prevent defects to the oxidiser, bypasses, dryers, etc.;
- send off-gases from the dryers to the oxidiser automatically before the make-ready press speed is reached;
- connect the ventilation exhaust of the automatic washing machines to the oxidiser);
- reduce emissions due to evaporation from ink fountains during production;
- avoid the use of solvent-based products in machines not connected to the abatement equipment;
- reduce the residual solvent in printed materials not intended to be used as packaging for food;
- reduce the use of volatile solvents for cleaning floors (see Sections 17.8.6 and 17.9.6).

12.3.2.1 Total emissions of VOCs

In the original BREF (2007), total emissions of VOCs were expressed as a percentage of the reference emissions which are calculated by using the methodology proposed in Annex VII (Part 5) to Directive 2010/75/EU. As this methodology includes the use of a multiplication factor for the total mass of solids (included in inks, varnishes or adhesives) which depends on the type of process and the substrate, this multiplication factor is to be considered and decided on a plant-by-plant basis. A more objective way to express total emissions of VOCs is expressed in kg VOCs per kg of solid mass input. Reported values using the latter approach are presented in Figure 12.3.



Source: [155, TWG 2016]

Figure 12.3: Total emissions of VOCs expressed as kg VOCs per kg of solid mass input for the period 2013-2015

The basic parameters for the production features of the reporting plants are presented in Table 12.15 below. An explanation of abbreviations used for the packaging and non-publication gravure data is provided in Table 12.16.

Table 12.15: Main production and contextual information of installations reporting VOC emission data

Installation	Unit(s) type	Abatement system	Machines' encapsulation	Production hall outline	Ink piping	Ink type	Press washing system	Cleaning material type	Machines connected to abatement
168	4Fl	RTO/ 2WS/CA	EN	EN-T	Auto	SL	Auto	SB	4/4
028	3PG/2Fl/ 1L/1PL	RTO	EN	EN-nT	NI	6SB 1UV	Auto-man	SB	6/7+W
010	1Fl/2PG/ 3L	2CO/ RTO	EN	EN-T	NI	SB	Auto-man	SB	6/6+W
027	2PL/1L	RecTO/ BWGT	NI	NI	NI	SB	NI	NI	NI
157	3Fl/2L	RTO	NI	NI	NI	NI	NI	NI	NI
174	2PG/1L	RTO	EN	EN-T	Auto	2SB/ 1SL	Man	SB	3/3
155	2Fl/2PG/ 1L/3PL	RTO/ RTO-5	2EN/ 6OP (nT)	NI	2 auto/ man	SB	2 auto/ 6 man	SB	NI+W
019	3PG	2RTO	OP	EN-nT	Pump	SB	Man	SB	3/3+W
012	4FL/5PG/ 2PL/3V/ 5L/1LC	4RTO/ AAC-Z	4EN/ 16OP	EN-nT	P-auto	17SB/ 1WB/ 2UV	Man	17SB/ 3WB	17/20
016	2PG/4L/1 Fl	AAC-Z/ TO	4EN/ 4OP	EN-T	Auto	SB	2 auto/ 6 man	SB/ WB	7/7+W
020	8PG	AAC-Z	OP	EN-nT	NI	SB	Man	DI	8/8
175	4Fl/2L	RTO/CO	OP	EN-nT	Auto	4SB/ 2SL	Auto-man	SB	5/6
011	7PG	RTO	OP	EN-nT	Pump	2SB/ 5WB	Man	2SB/ 5WB	2SB
133	2PL/1PG/ 1Fl/1L	RTO/TO	7OP/ 1EN	NI	NI	SB/ 2SL	Man	SB	5/5
023	2Fl/3PG	AAC-Z		EN-T	Auto	SB	Auto	SB	5/5
009	4PG/8V/ 10L	2RTO	3OP/ 5EN	EN-nT	NI	SB	Man	14SB/ 8UV	17/22
017	4PG	AAC-Z	OP	pEN	NI	3SB/ 1SL	Man	SB	4/4
024	2PG/2Fl/ 4L	AAC-Z	OP	EN-T	Auto	SB	Auto	SB	6/8
025	3L/2EPL/ 2PL/4P	AAC-Z	3EN/ 8OP	EN-nT	Pump	SB	Man	SB	11/11
015	2PG	RTO	OP	En-T	NI	SB	Man	SB	2/2
159	9PL/1Fl/ 3IJ	RTO	12OP/ 1EN	En-nT	NI	SB	Man	SB	10/10 +W
022	4PG/4L	AAC-Z	OP	EN-T	Auto	SB	3 auto/ 5 man	SB	8/8
013	5PG	RTO-3	OP	EN-T	Cont	SB	Auto	SB	5/5
127	2Fl/1PG	RTO	EN	pEN	Auto	SB	Man	SB	3/3
161	2PG/1Fl/ 2PL	TO	OP	EN-nT	Pump	4SB/ 1FlUV	Man	SB	5/5+W
005	3Fl/ 1PG	RTO-3	EN	EN-T	Auto	NI	NI	SB	4/4
006	NI	RecTO/ 2AAC-Z	NI	NI	NI	NI	NI	NI	NI
007	2PG/1L	RTO-3/ AAC-Z	NI	NI	NI	NI	NI	NI	3/3

008-F	2Fl	TO	EN	EN-nT	NI	NI	NI	NI	2/2
008-L	1L	TO	EN	EN-nT	NI	NI	NI	NI	1/1
014	3PG	2 RTO/ AAC-Z	OP	EN-nT	auto	SB	1auto/ 2 man	SB (2016: alkaline)	3/3
018	3PL	AAC-Z	2pEn/ 1EN	pEN	man to mixing/ auto to machines	SB	Auto	SB and DI (1/y)	3/3
021	4Fl	RTO-3	EN	NI	Auto	SB	3 auto/ 1 man	SB	4/4
NB: NI: No information provided. *Source*: [155, TWG 2016]									

Table 12.16: Explanation of abbreviations used for the flexography and non-publication rotogravure printing data

Unit type		**Ink type – cleaning material type**	
Fl	Flexography	SB	Solvent-based
PG	Packaging gravure	SL	Solvent-less
L	Lamination	WB	Water-based
PL	Printing & Lamination	UV	UV-cured
IJ	Ink jet printing	DI	Dry ice
V	Varnishing	**Machines' encapsulation / production hall layout**	
LC	Lamination & Coating	OP	Open
Ink piping		EN	Enclosed
man	Manual	EN-nT	Enclosed with air extraction but without subsequent treatment
auto	Automatic	EN-T	Enclosed with air extraction and subsequent treatment
cont	Continuous	**Machines connected to abatement**	
pump	Direct pumping	W	Washing machine connected to abatement

Some basic statistical figures of the reported levels for total emissions of VOCs are presented in Table 12.17.

Table 12.17: Statistical parameters of reported values of total emissions of VOCs expressed in kg VOCs per kg of solid mass input for the period 2013-2015

Parameter	**2015**	**2014**	**2013**	**Average (2013-2015)**
Average	0.45	0.33	0.44	0.41
Median	0.43	0.27	0.25	0.30
25th percentile	0.14	0.13	0.12	0.12
75th percentile	0.67	0.55	0.61	0.61
Source: [155, TWG 2016]				

Lower values were reported from installations applying thermal VOC destruction while slightly higher values were reported from installations applying solvent recovery techniques.

The statistical parameters of the reported data according to the abatement method applied are presented in Table 12.18.

Table 12.18: Statistical parameters of reported values of total emissions of VOCs expressed in kg VOCs per kg of solid mass input in relation to the applied abatement technique for the period 2013-2015

Parameter	**2015**		**2014**		**2013**		**Average (2013-2015)**	
	RTO	Recovery	RTO	Recovery	RTO	Recovery	RTO	Recovery
Average	0.42	0.50	0.27	0.57	0.41	0.53	0.38	0.50
Median	0.18	0.53	0.18	0.61	0.23	0.55	0.18	0.54
25th percentile	0.10	0.44	0.12	0.53	0.08	0.39	0.10	0.38
75th percentile	0.67	0.60	0.39	0.65	0.57	0.69	0.57	0.62
Source: [155, TWG 2016]								

Most of the installations use solvent-based inks while the use of solvent-free inks is reported for a small number of machines.

12.3.2.2 Fugitive emissions of VOCs

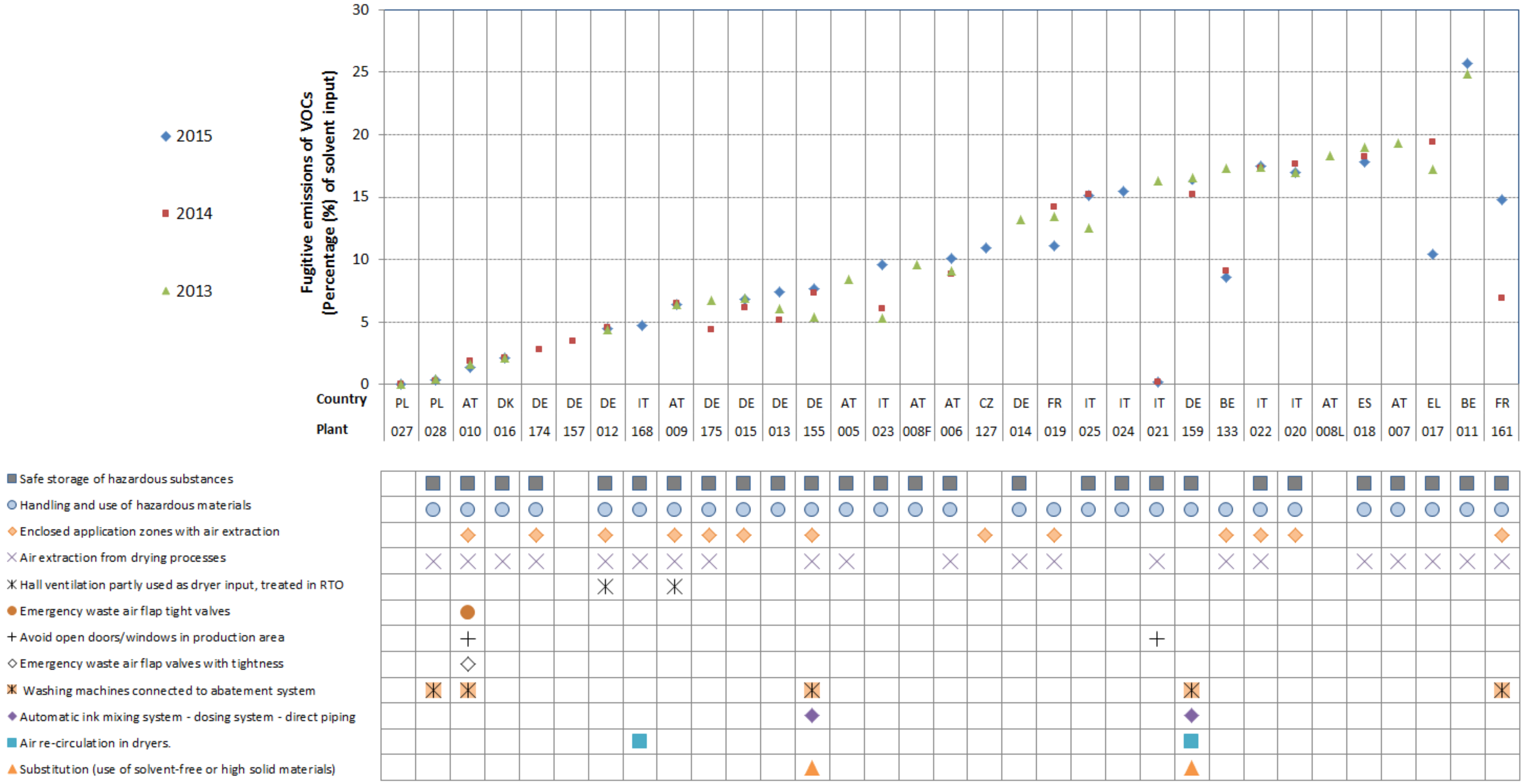
The reported values for fugitive emissions of VOCs expressed as a percentage of the solvent input are presented in Figure 12.4.

Almost all of the reported values for fugitive emissions of VOCs are below the IED limit value of 20 % of the solvent input and more than the half of reported values are below 10 % of the solvent input.

In most plants, the production hall is totally enclosed and the air is extracted from it with or without subsequent treatment (see Table 12.15). Machine parts cleaning is mainly solvent-based and there are a significant number of installations that have installed a dedicated cleaning machine and have connected its extraction to the abatement system.

The main reported techniques for the minimisation of fugitive emissions are:

- safe storage of hazardous substances and measures to prevent unplanned releases;
- handling and use of hazardous materials;
- air extraction from drying processes;
- enclosed application zones with air extraction;
- hall ventilation partly used as dryer input, treated in RTO;
- air recirculation in dryers;
- overpressure management with installed waste air pipes to minimise leakages caused by overpressure;
- ink management techniques that include an automatic ink mixing system and management of ink residues;
- automatic hardener dosing using enclosed piping system (two-component systems);
- air extraction from washing machines, adhesive mixing and ink mixing area;
- automatic parts cleaning machine (solvent-based, connected to ‘smoothener’ and common waste gas extraction for treatment in a RTO);
- solvent-free adhesives (hot melts);
- ultrasonic cleaning machine for anilox rollers.



	PL 027	PL 028	AT 010	DK 016	DE 174	DE 157	DE 012	IT 168	AT 009	DE 175	DE 015	DE 013	DE 155	AT 005	IT 023	AT 008F	AT 006	CZ 127	DE 014	FR 019	IT 025	IT 024	IT 021	DE 159	BE 133	IT 022	IT 020	AT 008L	ES 018	AT 007	EL 017	BE 011	FR 161
■ Safe storage of hazardous substances		■	■	■	■		■	■	■	■	■	■	■	■	■	■	■		■		■	■	■	■		■	■		■	■	■	■	■
○ Handling and use of hazardous materials		○	○	○	○		○	○	○	○	○	○	○	○	○	○	○		○	○	○	○	○	○	○	○	○		○	○	○	○	○
◆ Enclosed application zones with air extraction			◆		◆		◆		◆	◆	◆		◆					◆		◆					◆	◆	◆						◆
× Air extraction from drying processes		×	×	×	×		×	×	×	×			×	×			×		×	×			×		×	×			×	×	×	×	×
⚹ Hall ventilation partly used as dryer input, treated in RTO							⚹		⚹																								
● Emergency waste air flap tight valves			●																														
+ Avoid open doors/windows in production area			+																				+										
◇ Emergency waste air flap valves with tightness			◇																														
⚹ Washing machines connected to abatement system		⚹	⚹										⚹											⚹									⚹
◆ Automatic ink mixing system - dosing system - direct piping													◆											◆									
■ Air re-circulation in dryers.								■																■									
▲ Substitution (use of solvent-free or high solid materials)													▲											▲									

NB: Data not shown: #011 (2014: 40.3 % of total solvent input), #161 (2013: 48.65 % of total solvent input).

NB:
1. For Plant #021, 2013 high values are attributed to the fact that an elevated quantity of organic solvent remained in the product (O3 parameter of the solvent mass balance).
2. #008L is the lamination unit of Plant #008 for which a separate solvent mass balance was submitted.
Source: [155, TWG 2016]

Figure 12.4: Fugitive emissions of VOCs expressed as percentage of the solvent input for the period 2013-2015

12.3.2.3 TVOC emissions in waste gases

The majority of reported data concerns periodic monitoring of TVOC emissions in waste gases with monitoring frequencies that vary from two times a year up to once every 3 years. At the majority of installations with periodic monitoring, annual measurements (once every year) occur.

The reported values for periodic monitoring of TVOC emissions expressed in mg C/Nm^3 are presented in Figure 12.5 and Figure 12.6.

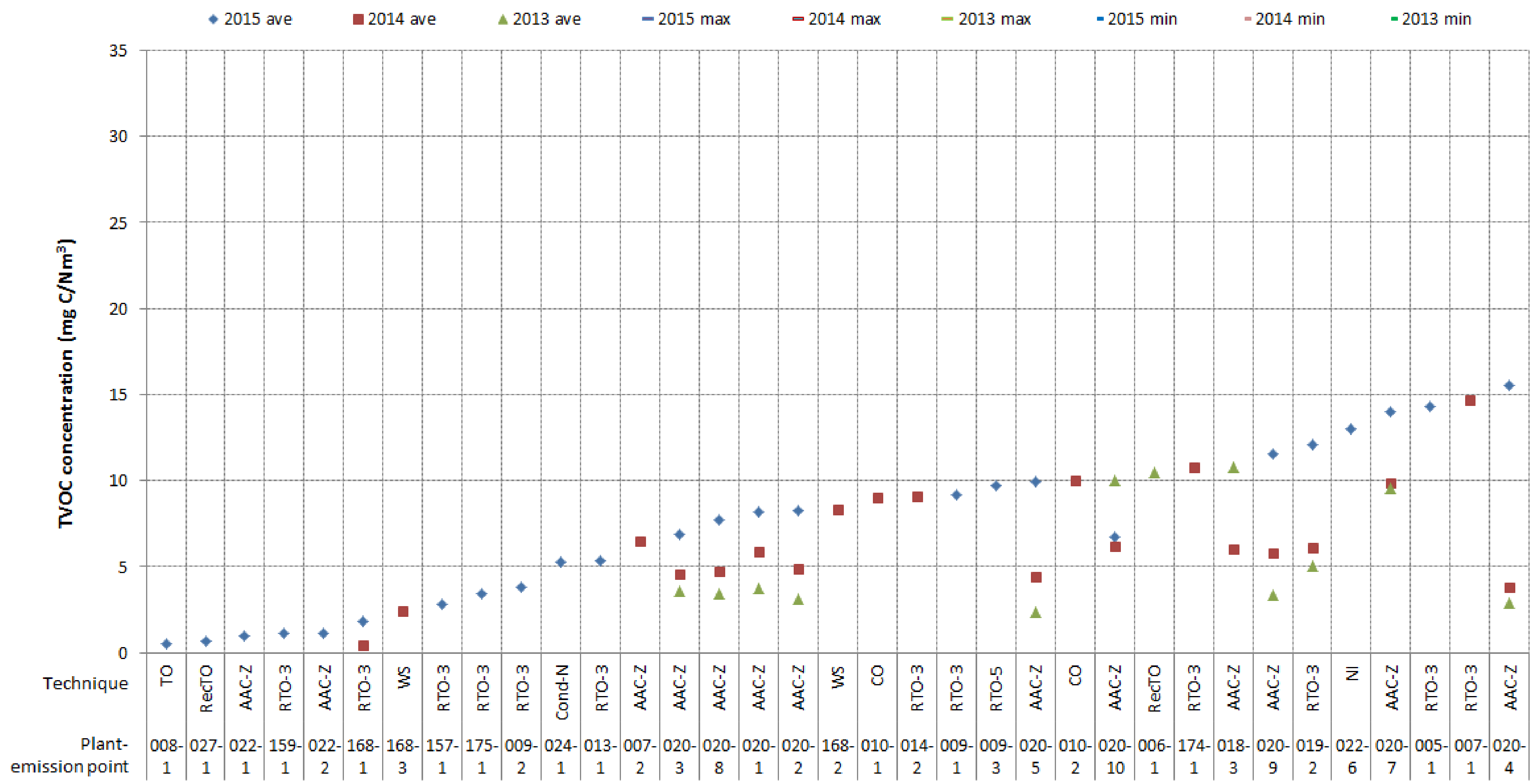
Some basic statistical parameters of the reported data for TVOC emissions in waste gases from periodic monitoring are presented in Table 12.19.

Table 12.19: Statistical parameters of the reported data for periodic monitoring of TVOC emissions in waste gases for the period 2013-2015

Applied technique	2015				2014				2013			
	No of values	Average	Max.	Min.	No of values	Average	Max.	Min.	No of values	Average	Max.	Min.
		mg C/Nm^3				mg C/Nm^3				mg C/Nm^3		
TO	2	7.8	15.0	0.5	1	19.9	NA	NA	1	45.6	NA	NA
RecTO	1	0.6	NA	NA	NA	NA	NA	NA	1	10.5	NA	NA
RTO-2	1	18.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
RTO-3	13	14.0	61.5	1.1	7	12.2	27.0	0.4	2	18.0	31.0	5.0
RTO-5	2	14.5	19.2	9.7	NA	NA	NA	NA	NA	NA	NA	NA
CO	NA	NA	NA	NA	2	9.5	10.0	9.0	NA	NA	NA	NA
AAC-Z	24	46.8	298.0	1.0	25	18.3	83.5	3.8	23	10.3	45.6	2.4
AAC-Z+ TO	NA	NA	NA	NA	1	32.0	NA	NA	1	23.0	NA	NA
WS	NA	NA	NA	NA	2	5.4	8.3	2.4	NA	NA	NA	NA
Cond-N	1	5.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CA(OD)	1	18.0	NA	NA	1	2.5	NA	NA	NA	NA	NA	NA
BWGT	1	63.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NI	7	149.0	297.0	13.0	NA	NA	NA	NA	NA	NA	NA	NA

NB:
NA: Not available/applicable.
NI: No information provided.
Source: [155, TWG 2016]

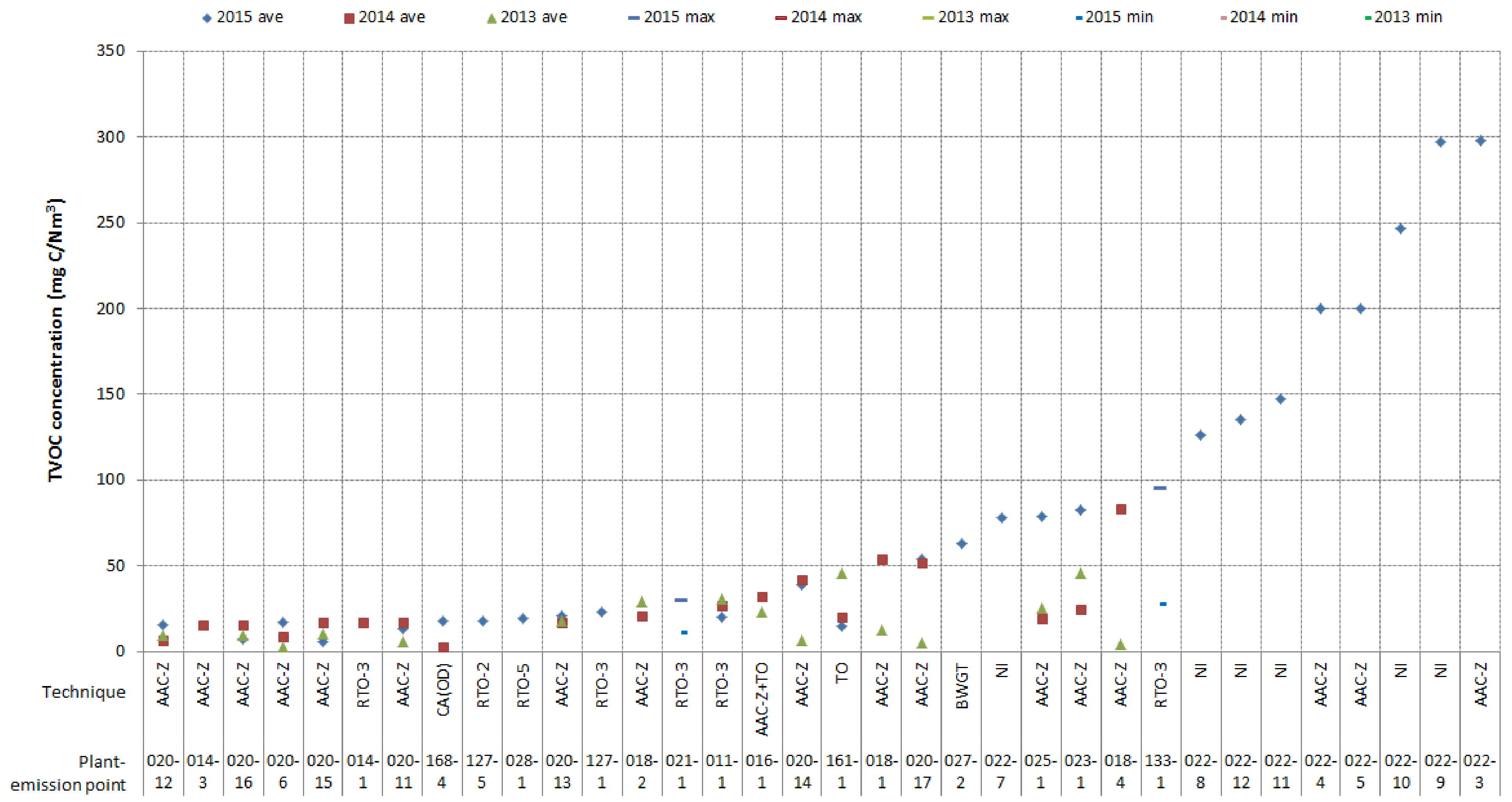
The reported values underline the efficiency of the applied end-of-pipe abatement techniques which on average achieve low TVOC concentration values.



NB: #009 data for 2016 instead of 2015. #008 data for 2010 instead of 2015.

Source: [155, TWG 2016]

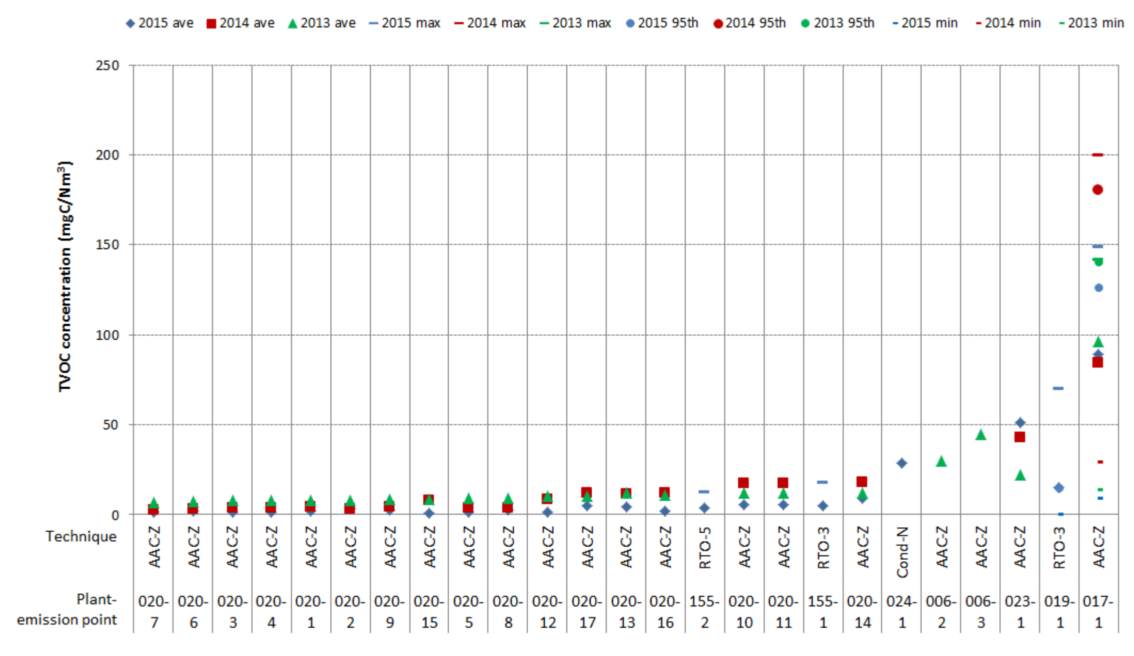
Figure 12.5: TVOC emissions in waste gases (periodic monitoring) for the period 2013-2015 (1/2)



Source: [155, TWG 2016]

Figure 12.6: TVOC emissions in waste gases (periodic monitoring) for the period 2013-2015 (2/2)

A small number of installations reported data for continuous monitoring of TVOC emissions in waste gases. These data are presented in Figure 12.7.



Source: [155, TWG 2016]

Figure 12.7: TVOC emissions in waste gases (continuous monitoring) for the period 2013-2015

Some basic statistical parameters of the reported data for TVOC emissions in waste gases from continuous monitoring are presented in Table 12.20.

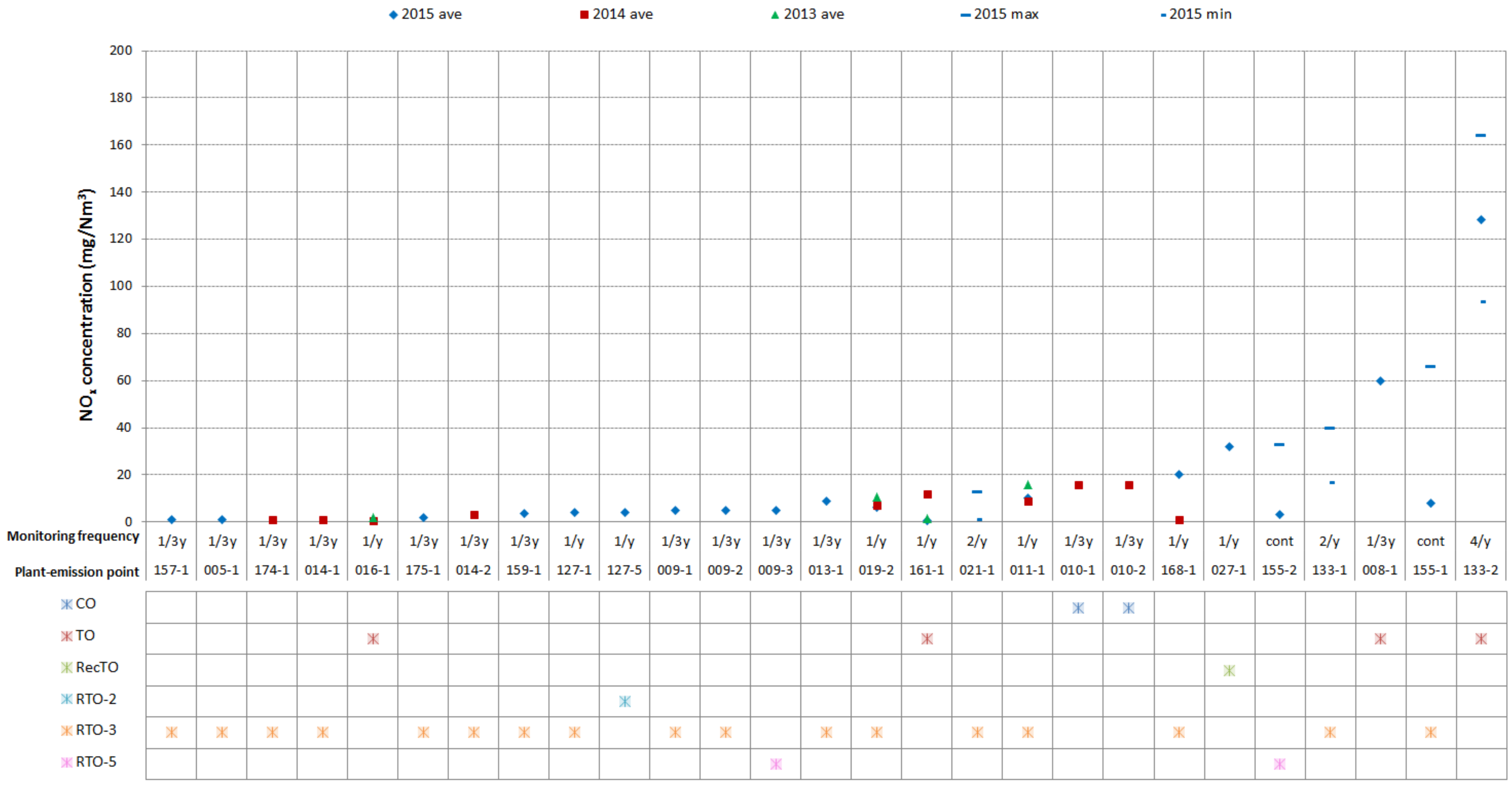
Table 12.20: Statistical parameters of the reported data for continuous monitoring of TVOC emissions in waste gases for the period 2013-2015

Applied technique	**2015**				**2014**				**2013**			
	No of values	Average	Max.	Min.	No of values	Average	Max.	Min.	No of values	Average	Max.	Min.
		mg C/Nm^3				mg C/Nm^3				mg C/Nm^3		
AAC-Z	19	10.2	89.4	1.1	19	14.0	84.6	2.7	21	17.0	96.4	7.0
RTO-3	2	10.0	15.0	5.0	NA	NA	NA	NA	NA	NA	NA	NA
RTO-5	1	4.0	4.0	4.0	NA	NA	NA	NA	NA	NA	NA	NA
Cond-N	1	28.9	28.9	28.9	NA	NA	NA	NA	NA	NA	NA	NA

NB:
NA: Not available/applicable.
Source: [155, TWG 2016]

12.3.2.4 NO_X and CO emissions in waste gases

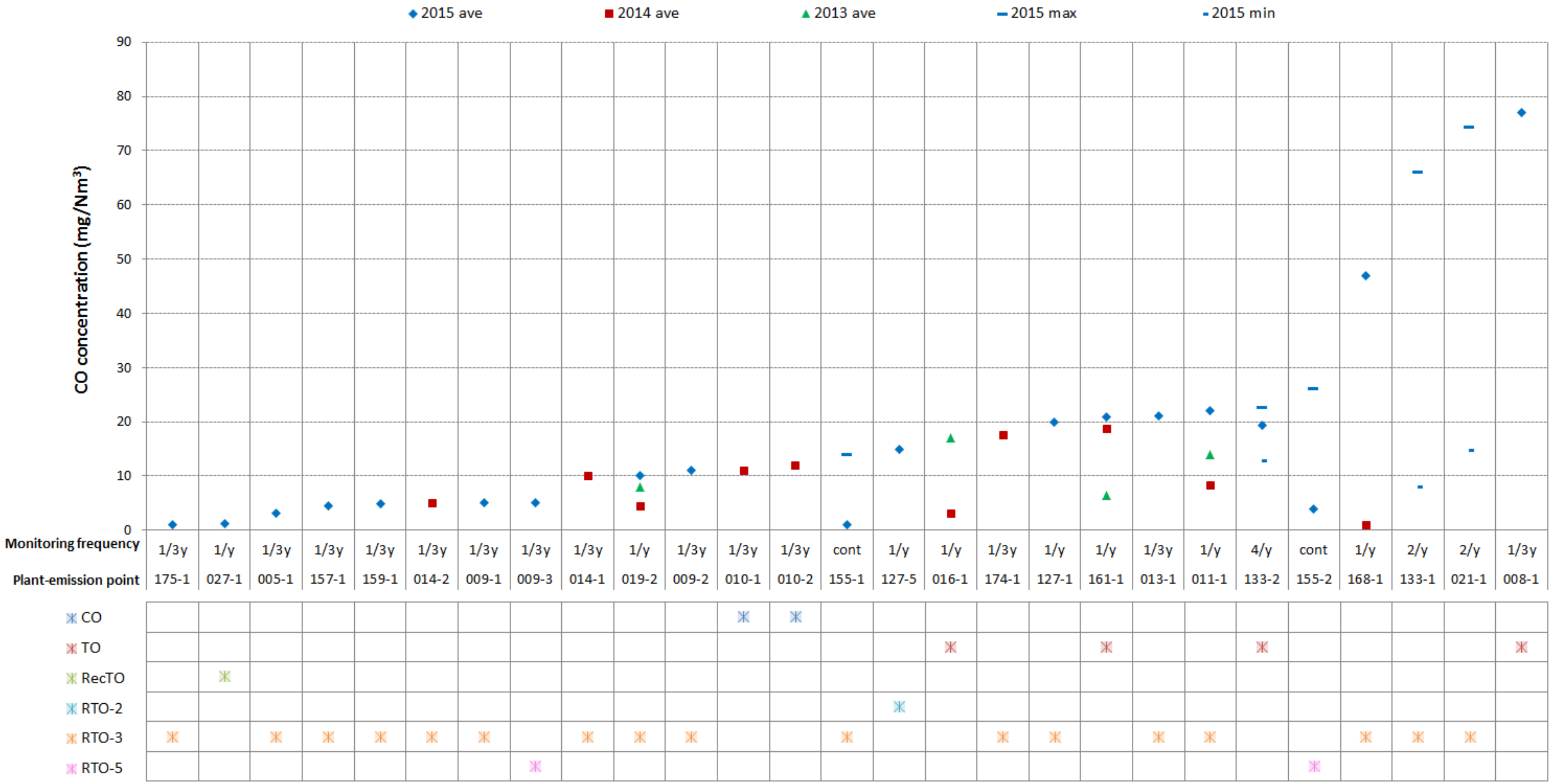
Nitrogen oxides (NO_X) and carbon monoxide (CO) emissions result from the thermal oxidation of off-gases from the dryer. Reported values for NO_X and CO concentrations are presented in Figure 12.8 and Figure 12.9.



NB: #009 data for 2016 instead of 2015.#008 data for 2010 instead of 2015.

Source: [155, TWG 2016]

Figure 12.8: NO$_X$ emissions in waste gases for the period 2013-2015



NB: #009 data for 2016 instead of 2015. #008 data for 2010 instead of 2015.

Source: [155, TWG 2016]

Figure 12.9: CO emissions in waste gases for the period 2013-2015

The reported values demonstrate that it is possible to achieve low NO_X levels with no significant offset for the relevant CO concentration values. In general for both parameters, levels below 60 mg/Nm^3 were reported.

12.3.2.5 Waste generation

[78, TWG 2005] [155, TWG 2016]

Printing substrate
Printing substrate is wasted when starting a new printing job and also arises from misprints because of defects and when the edge of the printed web roll requires trimming. The quantity depends on the product produced [7, Germany 2003] [38, TWG 2004].

Ink
Ink losses arise from three areas [1, INTERGRAF and EGF 1999]:

- The amount of ink prepared always exceeds the need to avoid presses running out of ink.
- Ink supplied to the inking unit, but not used, is stored and later used on a repeat job for the same client. Most plants have a large stock of these ready-made inks waiting for repeat jobs. Periodically, inks that are not expected to be used again are removed.
- The mixing of the ink results in the wrong colour. To correct this mistake, more ink has to be added and, as a result, too much ink is prepared.

Surplus inks are disposed of as waste or alternatively are distilled in-house. Their solvent content is then recovered and used for cleaning purposes; the ink sludge is disposed of as waste.

However, modern practice with computerised colour-matching systems enables better first-time quality, resulting in very little ink wastage and minimal leftover batches, which can be used again in slightly different colours (see Section 17.6.2.1).

Varnish and ink sludge
Solvent, ink and varnish sludges result from the production process and often from the distillation process for the recovery of solvent content which can be reused for cleaning processes. When there is not a previous distillation step, significant solvent contents have been reported (up to 70 %) [197, FPE 2017].

Cleaning
Dirty wipes containing solvents, absorbents, filters, cloths, protective clothing, dirty cleaning mixtures of water and solvent, and ink residues stem from interim cleaning. When the cleaning agents are distilled, the resulting waste, i.e. ink sludge, is far less than without recovery [7, Germany 2003].

When cleaning is done with water-based cleaning agents, the waste water might be treated and discharged. Cleaning solutions with solvents are normally treated as hazardous waste [1, INTERGRAF and EGF 1999] [38, TWG 2004].

Solvent-based cleaning agents can be successfully recovered by distillation.

Others
Other wastes include [1, INTERGRAF and EGF 1999] [38, TWG 2004]:

- photopolymer and rubber printing plates: the steel, polyester or aluminium sleeves are reused repeatedly: the polyester or rubber materials are glued to these;
- non-returnable metal containers;
- reel cores;
- glue and adhesive wastes;

- film wastes.

12.3.2.6 Emissions to water

Waste water from water-based ink processes can be treated and disposed of to the sewerage system or disposed of as waste. The total amount of waste water is highly dependent on the working methods, and on average 2-3 m^3/t of ink is used and discharged, mainly from interim cleaning and cleaning the machinery after a job. If treated, the water may be reused and the sludge disposed of as waste [1, INTERGRAF and EGF 1999] [38, TWG 2004]. The characteristics of this waste water before and after treatment are shown in Table 12.21. Copper is not present to the extent shown in Table 12.21 in inks, and is likely to come from the paper [38, TWG 2004].

Table 12.21: Characteristics of waste water from water-based ink processes

Contaminant	Before treatment (mg/l)	After treatment (mg/l)
AOX	1 500	1
Cu	20	-
Hydrocarbons	1 000-5 000	10
COD	1 000	200
Source: [7, Germany 2003]		

The amount of ink sludge resulting from the waste water treatment differs depending on the treatment applied. Treatments such as coagulation and flocculation, which are most commonly applied, result in high quantities of sludge compared to ultrafiltration for example [7, Germany 2003].

A study by the TWG identified the main parameters and other substances of interest that may be discharged in waste waters (including those mentioned above) and therefore to be considered for the data collection[39]. These are identified in Table 12.22 below, with the results of the data-gathering exercise. The sources of waste waters are diverse, with various combinations of treatment and discharge type. The main concern for this sector is possible emissions from rotogravure cylinder preparation; however, only one data set was submitted, showing low values. COD values varied significantly according to the source.

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[39] COM working document EIPPCB 09/06/2016: Assessment of Technical Working Group (TWG) data submitted on metals and other emissions to water for their consideration as Key Environmental Issues for installations carrying out IED Annex 1 6.7 activities.

Table 12.22: Emissions to water data for flexography and non-publication rotogravure printing installations

Plant	WWTP	Source	Discharge type	Average concentration (mg/l) - 2015					
				COD	TOC	Cu	Cr_{total}	Cr(VI)	Zn
006	NI	Mainly from distillation	NI	1933	NI	NI	NI	NI	NI
023	NI	Cooling (evap.) system for solvent recovery	NI	60	NI	NI	NI	NI	NI
025-1	None	Cooling	Direct	16	NI	0.035	0	NI	0.12
025-2	None	Cleaning	Indirect	5	NI	0	0	NI	0.16
020	Combined	Steam (regeneration of activated carbon)	Indirect	807	276	NI	NI	NI	NI
022-1	Dedicated	Gravure roller processing	Indirect	NI	NI	0.01	0.01	0.01	NI
022-2	NI	Cooling	NI	300	NI	NI	NI	NI	NI
024	None	NI	Indirect	23	NI	0.05	NI	0.001	0.43

NB:
NI: No information provided.
Source: [155, TWG 2016]

12.4 Techniques to consider in the determination of BAT for flexography and non-publication rotogravure printing

[78, TWG 2005] [227, TFTEI 2017]

In Chapter 17, techniques are discussed which might also be applicable to flexography and non-publication rotogravure printing. In Table 12.23, the general techniques relevant for flexography and non-publication rotogravure printing are shown. These techniques are not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 17.1.

The TFTEI report for flexible packaging printing provides useful data on the costs and benefits at the European level of applying primary and secondary measures for the reduction of VOC emissions as well as techniques for minimisation of fugitive emissions [227, TFTEI 2017].

Table 12.23: Reference to techniques generally applicable to the sector

Technique	Section number
Environmental management techniques	17.1
Storage and handling of raw materials	17.2
Monitoring	17.3
Water use and waste water generation	17.4
Energy management and energy efficiency	17.5
Raw material management (including substitution)	17.6
Coating processes and equipment	17.7
Drying and/or curing techniques	17.8
Cleaning techniques	17.9
Off-gas extraction and treatment	17.10
Waste water treatment techniques	17.11
Waste management techniques	17.12
Odour emissions	17.13

12.4.1 Solvent mass balance for flexography and non-publication rotogravure printing

For a general description and the general principles of the solvent mass balance, see Section 17.3.1. An exemplary SMB for this sector is also presented in Annex 21.5.4.

12.4.2 Material-based techniques

12.4.2.1 UV-radiation-cured inks

Description
UV-radiation-cured inks do not contain organic solvents. Curing is achieved by UV radiation. See also Sections 17.7.2.3 and 17.8.5.4.

Achieved environmental benefits
A significant reduction in solvent emissions can be achieved.

Environmental performance and operational data

Printing with UV-cured inks in flexography requires ‘kiss printing’. UV-cured inks have much stronger pigments than other inks. The amount of ink to be transferred must be much smaller. Where in ‘normal’ flexography the substrate is forcefully locked between the image carrier and the impression cylinder, in UV printing this must be far less. Only very little pressure is used. This is one of the main reasons why retrofit is not possible on most existing flexography presses. In flexography, in the case of web breakages, the end of the broken web may, on its way to the end of the press, pass a few inkpans and transport ink from one inkpan to the next. This must, of course, be cleaned before printing can restart. In ‘normal’ flexography this is cumbersome, but in UV flexography this is nearly impossible because of the heavy pigmentation and the fact that the ink does not dry. When printing with UV flexography, the press design must be such that in case of web breakages, the web is immediately stopped, before the end of the web can drag through any inkpan.

A major problem is presented by the difficulty in cleaning presses where UV-cured inks are used. The strong pigmentation and the fact that UV inks do not dry anywhere other than on the substrate means that the smallest amount of contamination makes for serious quality problems. Cleaning is very labour-intensive because the inks do not easily dissolve in any solvent. The problem is larger where colours need to be changed between jobs, which is the case with printing packaging materials.

In a Dutch plant, cleaning between jobs was prohibitively time-consuming and caused unacceptable quality problems. In order to limit cleaning, a patented system was developed that reduces the number of colour changes drastically. Seven standard colours are used to build up the required colours. This means that seven out of eight printing units do not need to be cleaned between jobs. The eighth printing unit is used to add an additional colour if still necessary. For every job that is switched from ‘normal’ flexography to UV flexography, all image carriers need to be replaced. In publications, colour photographs are built up from four standard colours. This system, however, cannot produce every colour and brightness necessary in packaging printing.

UV-cured inks were originally introduced for the printing of labels and show a continuous rising use. UV-cured inks are used for flexographic printing on paper, cartons and self-adhesive paper labels, especially when a high-quality result is required [148, COM 2009].

Use of UV-radiation-cured inks in flexographic printing was reported for three plants in the frame of the data collection [155, TWG 2016].

Cross-media effects

In some circumstances, the energy consumption of the UV curing lamps may exceed the usual dryer consumption, although one plant reports overall energy savings. The UV lamps contain mercury and require special management as a waste.

UV-cured inks contain reactive acrylates, monomers and oligomers, some of which are allergenic.

Technical considerations relevant to applicability

UV-cured inks can be applied in flexographic processes for printing paper packaging materials, labels, and carton packaging materials for dairy products. However, manufacturers of packaging materials for food are often reluctant to employ UV-cured inks since the migration of minute quantities of some of the ingredients of these inks into the packed food may lead to non-compliance with food contact legislation. One solution to this problem can be overlacquering of the print in order to protect ingredients (like residual monomers, etc.) from migrating.

Most paper can be printed with UV inks. The limitation is, however, not the substrate but the existing machinery. UV-curing flexography is used for several applications (e.g. self-adhesive labels, beverage cartons). In both cases, presses are used that are built specifically for the purpose: labels on small narrow web presses (up to 25 cm) and beverage cartons on presses with a width of between 100 cm and 150 cm.

Not all solvent-based inks can be substituted by UV-cured alternatives due to the need for specific application properties.

Economics
In the case of flexography for beverage cartons, the machines are considerably more expensive than 'normal' flexographic presses. Better quality can however be obtained, which is needed in answer to market demands.

Where otherwise increased quality requirements tend to lead to a switch from flexography to rotogravure, the combination of the run length, customer requirements for regular changes in the printed image and the special substrates used for these cartons make UV-curing flexography an appropriate technique in this case.

Driving force for implementation
Workplace health and safety.

Example plants
Thomas Grafishe Veredelung GmbH & Co, KG, Germany. Elopak (Terneuzen, the Netherlands). Plants #012, #028 and #161 in [155, TWG 2016].

Reference literature
[7, Germany 2003] [8, Nordic Council of Ministers 1998] [14, Aminal et al. 2002] [38, TWG 2004] [78, TWG 2005] [148, COM 2009] [155, TWG 2016] [197, FPE 2017]

12.4.2.2 Electron beam (EB-) radiation-cured inks

Description
EB-radiation-cured inks consist of low-molecular-weight polymers that react with a stream of electrons from a vacuum tube. These inks contain no solvents and do not cure until exposed to light and may, therefore, remain in ink fountains for long periods of time, reducing clean-up needs. The electrons drive the reaction, forming polymers and setting the ink. See also Sections 17.7.2.3 and 17.8.5.5.

Electron beam dryers use polymerisation by electron bombardment to dry liquid and powdered coatings.

Achieved environmental benefits
VOC emissions from ink are reduced to zero.

Environmental performance and operational data
Problems reported with EB-curable inks include paper degradation and worker exposure to radiation. They are sometimes used for higher-quality gloss coatings and metal decorating applications.

Technical considerations relevant to applicability
Only applicable to new presses.

Economics
These dryers have high initial costs and low to moderate operating costs.

Example plants
Not widely used.

Reference literature
[18, US EPA et al. 2003] [38, TWG 2004] [197, FPE 2017] [212, TWG 2018]

12.4.2.3 Water-based inks

Description
Water-based inks contain reduced amounts of organic solvents. Conventional water-based inks rely on relatively highly acidic resins for water dispersibility; more recently developed inks are based on water-dispersible polyester resins. The latter do not need neutralising agents such as ammonia or amines to maintain their dispersibility properties, and therefore meet flexography requirements. See also Section 17.7.2.2.

Achieved environmental benefits
In flexography and non-publication rotogravure printing, press-ready inks contain up to 80 % solvents. These are always mixtures of several solvents, e.g. ethanol and ethyl acetate. Substitution with water-based inks can result in significant reductions in solvent emissions, particularly of fugitive emissions. Where off-gases are efficiently treated and excessive fugitive emissions are avoided, little further gain is made by switching to water-based inks. Another potential problem is the possible lack of efficiency when running thermal oxidation techniques for the treatment of off-gases (non-autothermal operation).

Cleaning of water-based inks can be done with water as long as the ink or varnish is not dry.

Water-based inks may require more energy for drying; however, the total plant energy consumption will be reduced because an off-gas treatment system may not be required (see Section 17.7.2.2. and Annex 14 to the ECM REF).

Environmental performance and operational data
In flexography, most paper packaging materials can be successfully printed with water-based inks. Simple plastic packaging materials such as carrier bags, refuse bags, bread bags and heavy-duty bags may also be printed successfully with water-based inks in flexography. Applying ceramic anilox cylinders improves the printing quality.

Flexible food packaging materials may be required to be resistant against acids, solvents, fats or oils coming from the food that is to be packed. High-quality products meeting these requirements are often printed in packaging rotogravure, applying solvent-based inks. However, sometimes white ink, the colour that is used most, can be substituted.

Switching from solvent-based inks to water-based inks in flexography or non-publication rotogravure usually requires a different pretreatment of the carrier material and always new printing plates and cylinders.

Cross-media effects
Water-based inks used in flexography and non-publication rotogravure printing processes still contain ethanol, isopropanol and/or n-propanol.

The amount of energy needed for drying of water-based inks is higher than for solvent-based inks. However, the lack of solvents makes it possible to recirculate the drying air more often and thus reduces the effect. In practice, the increase in energy consumption for drying purposes may be about 10 %.

More waste ink is generated. The quantity of recovered solvent is less and not enough for cleaning purposes.

Technical considerations relevant to applicability

Water-based inks (not varnishes) are successfully applied in flexography and non-publication rotogravure printing processes for printing paper sacks, plastic refuse sacks and carrier bags. However, in these processes conventional inks still also need to be applied in some exceptional situations, e.g. for fluorescent effects, gold or silver colours, or where very high gloss is required.
Where water-based products (inks, varnishes, etc.) are applied on existing presses, the dryer systems are often found to lack capacity. This reduces the applicability on old, existing presses. Modern dryers have sufficient capacity to dry not only solvent-based but also water-based inks, thus no additional investment is needed [148, COM 2009].

Water-based inks are applicable in non-publication rotogravure printing and reported for two plants in the data collection [Plants #011 & #012 in [155, TWG 2016]].

Economics

Changing from solvent-based to water-based inks involves substantial changeover costs. For new presses applying water-based inks, the investment is approximately the same as for presses for solvent-based inks. In the case of retrofit, substantial investment may be needed if the dryer capacities need to be enlarged.

Since water-based inks are more highly pigmented, less ink is needed and the operational cost per m^2 of printed material will generally be somewhat lower than the cost of solvent-based inks.

Where, in the case of water-based inks, printing speed and flexibility can be maintained and other solvent-related costs can be avoided, substantial savings may result.

Example plants

Plants #011 and #012 in [155, TWG 2016].

Reference literature

[1, INTERGRAF and EGF 1999] [3, IMPEL 2000] [8, Nordic Council of Ministers 1998] [14, Aminal et al. 2002] [18, US EPA et al. 2003] [78, TWG 2005] [155, TWG 2016] [197, FPE 2017]

12.4.2.4 Water-based varnishes and adhesives

Description

Water-based varnishes and adhesives are generally solvent-free (see also Section 17.7.2.2).

Achieved environmental benefits

Press-ready varnishes and adhesives contain about 80 % solvents. They may be mixtures of several solvents, e.g. ethanol, ethyl acetate and MEK, or single-solvent systems. Substitution with water-based products can result in significant reductions in solvent emissions, particularly fugitive emissions. Where off-gases are efficiently treated and excessive fugitive emissions are avoided, little further gain is made by switching to water-based varnishes and adhesives. Another potential problem is the possible lack of efficiency when running thermal oxidation techniques for the treatment of off-gases (non-autothermal operation).

Cleaning of water-based varnishes and adhesives can be done with water as long as they are not dry. However, ethanol, IPA, etc. have to be used if they are dry.

Water-based varnishes and adhesives require more energy for drying; however, the total energy consumption may be reduced if no off-gas treatment system is required (see water-based inks in Section 12.4.2.3, see also Section 17.7.2.2).

The same is valid for the amount of waste water that will on the one hand increase, but in situations where a waste gas adsorption and solvent recovery system is no longer used the overall amount of waste water will decrease.

Environmental performance and operational data
There are a large number of different quality requirements and resistances that apply to a packaging material and therefore the applicability of alternatives for traditional solvent-based inks, varnishes and adhesives is never obvious. For example, the varnish may be required to have a certain resistance against slip in order to accommodate the specifics of the packaging machines, which may only be achieved by applying specific solvent-based varnishes. They also show a lower chemical resistance compared to solvent-based adhesives besides the lower adhesive starting and composite strength; for these reasons, water-based inks may not be used for all types of applications.

In the special lamination process where a thin paper is attached to plastic or aluminium, water-based products are suitable because the water can evaporate through the paper. For the lamination of two non-porous films, water-based products are less suitable because they require a longer drying time before the films can be put together. In these situations, solvent-based or two-component solvent-free adhesives are used.

Cross-media effects
The energy consumption for increased drying of the water-based products is somewhat higher and more waste is generated. The amount of energy needed for drying water-based inks is higher than for water-based varnishes and adhesives. However, the lack of solvents makes it possible to recirculate the drying air more often and thus reduce the effect. In practice, the increase in energy consumption for drying purposes may be about 10 %.

Technical considerations relevant to applicability
This technique is applicable in all printing and laminating processes in the manufacturing of flexible packaging. It is commonly applied in flexography and non-publication rotogravure printing plants. However, they cannot replace the solvent-based varnishes in all situations.

Where on existing presses water-based products (inks, varnishes, etc.) are applied, the dryer systems are often found to lack capacity. This reduces the applicability in existing presses.

Driving force for implementation
Occupational health and safety.

Example plants
Plant #012 in [155, TWG 2016].

Reference literature
[6, DFIU et al. 2002] [8, Nordic Council of Ministers 1998] [14, Aminal et al. 2002] [78, TWG 2005] [197, FPE 2017]

12.4.2.5 High-solids varnishes and adhesives

Description
Use of high-solids varnishes and adhesives that contain 40 % or more solids, resulting in the reduction of solvent consumption and emission. See also Section 17.7.2.1.

Technical description
Traditional solvent-based adhesives contain up to 80 % solvents, where high-solids adhesives contain up to 60 % solvent. Where the original adhesives need 4 kg solvent for each kg of solids, the alternative only need up to 1.5 kg. In this case, a reduction of solvent consumption of

more than 60 % is attained if no solvent recovery is in place; with solvent recovery, the reduction in solvent consumption is up to 90 %.

Achieved environmental benefits
Reduction of emissions of VOCs, reduction of solvent consumption.

Environmental performance and operational data
High-solids adhesives are applied in lamination processes for flexible packaging. They are applied in the high-performance sector for mechanically, thermally or chemically stressed packages and in the production of composites with variable material composition.

Cross-media effects
Off-gas treatment techniques may still be necessary.

Technical considerations relevant to applicability
Applicable in new and existing plants.

Economics
This varies from site to site.

Example plants
Plant #174 (adhesive with ~ 60 % solids content) in [155, TWG 2016].

Reference literature
[6, DFIU et al. 2002] [38, TWG 2004] [155, TWG 2016] [197, FPE 2017]

12.4.2.6 UV-radiation-cured varnishes and adhesives

Description
UV-cured varnishes and adhesives used for lamination do not contain organic solvents.

Achieved environmental benefits
Where varnishes or adhesives based on volatile solvents are used, a significant reduction in solvent emissions can be achieved. See also Section 17.7.2.3.

Environmental performance and operational data
In the flexography and non-publication rotogravure printing industry, in addition to printing, laminates containing a number of different plastic films and aluminium foil are often made. UV-cured adhesives are applied here, however only for standard composites up to a medium-quality level.

Cross-media effects
UV-cured varnishes and adhesives require energy to be dried by specific UV dryers. However, this is unlikely to be more than for drying conventional solvent-based systems. In addition, the lamps used contain mercury and require special treatment as waste.

UV-cured varnishes and adhesives contain reactive acrylates, monomers and oligomers, some of which are allergenic.

Technical considerations relevant to applicability
Applicable in new and existing plants.

Example plants
Plant #012 in [155, TWG 2016].

Reference literature
[6, DFIU et al. 2002] [8, Nordic Council of Ministers 1998] [14, Aminal et al. 2002] [38, TWG 2004] [78, TWG 2005] [155, TWG 2016] [197, FPE 2017]

12.4.2.7 Solvent-free two-component adhesives

Description
Solvent-free adhesives are two-component adhesives with a 100 % solids content, often containing isocyanates.

Achieved environmental benefits
Solvent emissions from adhesive application are reduced to zero.

Environmental performance and operational data
These are commonly applied in the flexography and non-publication rotogravure printing industry in the lamination processes on non-porous substrates such as plastic and aluminium.

As opposed to the solvent-based adhesives where layer thickness can be controlled by the viscosity, the thickness has to be controlled by mechanical rolling processes. The adhesive layer might show slightly increased surface irregularities compared to solvent-based adhesives.

Many complex laminates can be produced with two-component systems. They require special machinery.

Cross-media effects
Risk of isocyanate emissions in workplaces.

Technical considerations relevant to applicability
Widely used.

Economics
Depends on product requirements/specifications.

Driving force for implementation
Client’s product specifications.

Reference literature
[6, DFIU et al. 2002] [8, Nordic Council of Ministers 1998] [14, Aminal et al. 2002] [197, FPE 2017]

12.4.2.8 Co-extrusion

Description
The printed substrate is coupled with a warm, liquefied plastic film and subsequently cooled down. This film replaces the necessary additional coating layer. It may be used between two different layers of different carriers acting as an adhesive.

Achieved environmental benefits
Solvent emissions are eliminated.

Environmental performance and operational data
Applied in flexible packaging.

Cross-media effects
Co-extrusion requires energy.

Technical considerations relevant to applicability
This technique is case-specific and is not applicable when high bond strength or resistance to sterilisation temperature is needed.

Driving force for implementation

- Occupational health and safety.
- Product requirements/specifications.

Example plants
Widely used in flexography, example plant: #133 in [155, TWG 2016].

Reference literature
[14, Aminal et al. 2002] [78, TWG 2005] [155, TWG 2016] [180, COM 2017] [197, FPE 2017] [212, TWG 2018]

12.4.3 Off-gas extraction and treatment

The following techniques are commonly applied:

- Oxidation: recuperative, catalytic and regenerative oxidation, see Section 17.10.5.
- Adsorption using activated carbon or zeolites, see Section 17.10.6.2.
- Condensation (using nitrogen), see Section 17.10.6.1. Industry comments that condensation is not widely in use in the sector (see FPE comment #14 in [212, TWG 2018]); however, this technique is applied in Plant #024 with six machines connected to the recovery system.
- Wet scrubbing, see Section 17.10.6.3.
- Biological off-gas treatment, see Section 17.10.7.

12.4.3.1 Extraction and treatment of air from the presses and other production areas

Description
Solvents evaporating from the presses and other production areas such as from containers for ink, varnishes and adhesives, from venting automatic cleaning machines (see Section 17.10.2) and escaping capture by the dryers, are extracted locally and subsequently treated.

Technical description
Solvents not only evaporate in the dryer; they also evaporate from ink fountains, viscosity adjusters, containers, etc. These solvents should be extracted locally for health and safety reasons, in order not to exceed occupational exposure limits (OELs).

The following can be applied:

- Encapsulating the laminating and varnishing machines.
- Sending local extraction from the area around the production machinery to abatement.
- Relevant fugitive emissions from ink fountains are captured and treated. This reduces the need for local extraction of open areas.
- Installation and use of chamber doctor blades.
- Sending washing machine ventilation to abatement (see Section 17.9.7).

Achieved environmental benefits

Less solvents are consumed and more solvents are directed to the abatement equipment. There is a reduction in VOC emissions, especially fugitive ones as it assures the capture and treatment of emissions from ink fountains and washing machines.

Environmental performance and operational data

Modern non-publication rotogravure presses are equipped, apart from extraction of the dryers, with floor extraction and/or extraction from the ink containers to the off-gas treatment system. This solvent content of the extracted air depends on applied measures taken to reduce fugitive emissions. These additional extraction systems are placed between the printing units. For flexography presses equipped with a central impression cylinder, there might be some restrictions related to the available space between the printing units, which may be too small to install a local extraction system (see Figure 12.1). In this case, total enclosure of the flexography presses may be applied as also indicated in the data collection [155, TWG 2016].

Modern stand-alone varnishing and lamination units are usually equipped for this.

Automatic cleaning machines need to be ventilated before unloading. During a few minutes, a relatively small airflow (a few thousand m^3/h) is heavily laden with solvent vapours. This airflow is sent to the abatement equipment.

Cross-media effects

Extraction requires energy, but this local extraction takes place to prevent high occupational exposure levels. The issue is whether or not to send the extracted air to the off-gas treatment. However, since the abatement may need to be larger, the main fan of the oxidiser would also be much larger. This would substantially increase the amount of energy required. The increased airflow with a low solvent content will increase the amount of support fuel required by the abatement.

Technical considerations relevant to applicability

Local extraction may not be applicable on existing flexography presses equipped with a central impression cylinder. It is in-built in new stand-alone varnishing and lamination units.

This technique is generally applicable to automated machines. Enclosure of ink fountains, viscosity adjusters, containers, etc. is increasingly used. Retrofit is possible (machine control needs to be completely automated). Dryers are always enclosed.

Economics

The cost depends mainly on the capacity of the off-gas treatment system. Enclosure or encapsulation reduces the volumes of air to be extracted and therefore reduces the size of extraction fan motors and off-gas treatment where applied.

Example plants

Widely applied. Almost all plants that submitted information (see Table 12.15).

Reference literature

[1, INTERGRAF and EGF 1999] [8, Nordic Council of Ministers 1998]
[14, Aminal et al. 2002] [38, TWG 2004] [78, TWG 2005] [155, TWG 2016]
[197, FPE 2017]

12.4.3.2 Inspection and maintenance to reduce solvent emissions during OTNOC

Description
Ensure planned maintenance and speedy repairs are carried out, see also Section 17.2.6

Achieved environmental benefits
Defects in oxidation equipment can give rise to VOC emissions of up to 0.4 % of the annual input per day (assuming 250 working days a year).

Environmental performance and operational data
In seven IED-size Dutch flexible packaging plants, the downtime of incinerators varied between 1 and 14 working days. The average was almost 7.5 days, i.e. about 3-8 % of the total annual input. These data are from 2004.

Technical considerations relevant to applicability
Applicable to all plants.

Example plants
Widely applied.

Reference literature
[38, TWG 2004]

12.4.4 Cleaning techniques

12.4.4.1 Replacement of VOCs with less volatile solvents for cleaning floors

Description
For a general description, see Section 17.9.5.

Achieved environmental benefits
A reduction in the emission of VOCs of 1-2 % can be achieved compared to a situation where floors are cleaned by wetting with buckets of solvents. However, where some preventative measures are already taken, such as reducing the dirtying of the floors and controlling solvent use, the reduction in emissions is less.

12.4.4.2 Cleaning of machine parts and equipment in enclosed washing machines

For a general description, see Section 17.9.7.

Example plants
Several plants that submitted information (see Table 12.15).

12.4.4.3 Cleaning of machine parts with high-pressure water spray

For a general description, see Section 17.9.9.

12.4.4.4 Dry ice cleaning

Description

Pellets of dry ice are blown, using pressurised air, at about 300 m/s onto the surface to be cleaned. A high degree of cleanliness is achievable and no residue is left [148, COM 2009]. See also Section 17.9.11.

Example plants

Several plants that submitted information (see Table 12.15)

13 PUBLICATION ROTOGRAVURE PRINTING

13.1 General information on publication rotogravure printing

[148, COM 2009] [149, ERA 2016] [196, ERA 2015]

The European publication rotogravure printing industry uses 180 000 tonnes of ink annually (data from 2006). This consists of 30 kt pigments, 50 kt resins and 100 kt toluene. More than 95 % of the toluene is reused: this is possible because rotogravure uses a mono-solvent system. The formation of azeotropes (constant-boiling mixtures, which hinder purification) is not possible, so it is not necessary to distil the recovered solvent. This saves time, costs and energy. The recovered pure toluene can be reused on site or delivered back to the ink-maker.

The productivity of rotogravure printing is very high. Advanced presses can print on a 4.32 m wide paper web at speeds of up to 16 m/s. Even with smaller units, the energy used per square metre of printed product is less than in alternative printing methods. However, this advantage increases the longer the print run.

The main environmental advantages of publication rotogravure printing are:

- the use of easily recyclable raw materials;
- the usage of renewable raw materials;
- the production of a very easily recyclable product.

There are currently 32 printing plants in Europe, operating 125 rotogravure presses (2017 data). Publication rotogravure is applied to print magazines, catalogues and supplements with high print runs:

- news magazines, TV magazines, women's magazines, etc.;
- publications;
- catalogues;
- supplements, inserts and flyers published by large department stores and supermarket chains, etc.

The turnover of the publication rotogravure printers currently amounts to around EUR 3.5 billion per year (2017 data).

Compared with other printing techniques, publication rotogravure is associated with the highest investment costs for machinery and the highest costs of producing the image carrier. Therefore, publication rotogravure printing is generally used by large companies, sometimes also operating heatset web offset in the same plant to be able to print different runs [148, COM 2009].

About 60 % of all magazines and 50 % of all catalogues are printed using the publication rotogravure technique; the remainder are produced with heatset web offset printing [148, COM 2009].

Products printed with publication rotogravure have a circulation of at least 200 000 copies, substantiating the extra costs of making rotogravure cylinders over those of making printing plates for heatset web offset printing. Most runs are of more than 500 000 copies [148, COM 2009].

A cylinder can print more than 10 million copies without quality loss. Publication rotogravure generally prints on paper. Compared with heatset web offset, publication rotogravure can also print with very good results on partially coated or uncoated paper surfaces [148, COM 2009].

Publication rotogravure printing is characterised by the use of engraved cylinders, toluene-based inks and a solvent recovery system for toluene in the off-gases.

13.2 Applied processes and techniques in publication rotogravure printing

[1, INTERGRAF and EGF 1999] [3, IMPEL 2000] [8, Nordic Council of Ministers 1998] [78, TWG 2005] [149, ERA 2016]

The image carrier in the rotogravure printing process is generally a steel cylinder with a copper-plated surface in which small recesses, called ‘cells’, are made which carry the ink. The surface is normally then plated with hard chromium to improve its wearing properties.

In the press, there is a printing unit for each cylinder. The surface of the rotating cylinder dips into an inkpan which fills the cells with ink (the inks for rotogravure printing are very fluid, whereas offset lithographic ink is paste-like). Surplus ink is then wiped off the cylinder surface by the squeegee action of the doctor blade, leaving only ink in the cells. The impression roller then presses the paper web onto the cylinder and the ink transfers onto the paper.

Rotogravure applies the ink in controlled doses from different sizes of cell. The larger the volume of the printing cells, the more ink is transferred and the stronger the tone which is reproduced by them.

Rotogravure is used for printing two major graphic products: publications and flexible packaging, which is discussed in Chapter 12 of this document. Minor graphic applications are labels, wrapping paper, cardboard packaging, banknotes and postage stamps. Outside the graphic industry, this method is used for the printing of wallpaper, imitation wood (laminates) and imitation tiles for floors and walls.

Table 13.1: Technical characteristics of publication rotogravure presses

Parameter	**Technical characteristics**
Web width	900-4 320 mm
Printing units	Mostly 8 units, sometimes 9 or 10 units
Production speed	15 m/sec = 900 m/min
Construction	Mostly 4 units per side of paper
Colours	Four inks in 8 units, five inks in the case of 9 or 10 units possible
Substrates	Paper
Solvents in use	Toluene > 99.9 % pure
Abatement techniques	Solvent recovery plant

Publication rotogravure printing is best known for being capable of producing very high-quality colour printing on lower-quality, cheaper grades of paper. The press web width can be anything from 900 mm up to 4 320 mm. Most publication gravure presses have eight printing units, one for each of the four process colours: cyan, magenta, yellow and black (CMYK) for each side of the paper. Occasionally a fifth printing unit per side is included (i.e. 10 units altogether) to allow a ‘spot colour’ such as a metallic or fluorescent ink for special effects [149, ERA 2016]. After printing one colour, the paper web is transferred into the dryer to evaporate the ink solvent (toluene) before entering the next colour unit. The drying usually takes place without heating the airflow to prevent dimension changes of the paper web. Today’s rotogravure presses for publication rotogravure run at 15 m/s and more.

Rotogravure printing is an almost entirely webfed process, although sheetfed presses are available running at up to 10 000 sheets per hour. These have hot air dryers and are aimed at the specialised markets of high-quality decorative effects using metallic inks on metallised papers and foils. They are, however, seldom used at present, presumably because of the high costs of cylinder making, which make high (web) run lengths more economical [1, INTERGRAF and EGF 1999].

Other similar processes are copperplate printing and die-stamping. Both employ the filling of recessed image areas with ink, but, in these cases, the ink is thick and dries by oxidation and adsorption rather than relying on solvent evaporation. Copperplate is used for the printing of banknotes and other security documents, while die-stamping is employed for letter headings.

Cylinder preparation

[149, ERA 2016]

In the past, rotogravure printing cylinders were produced with photographic films and etching. This was a complex process which needed time, raw materials and energy and led to some chemical waste. Nowadays, these production steps have been completely replaced by digital data handling. The final step of producing the cells in the surface of publication rotogravure printing cylinders is done either electromechanically or with a laser installation, so etching is no longer necessary. The surface is then plated with a hard chromium layer to improve its wearing properties. Nowadays, most rotogravure printers buy the necessary chromium compounds in dissolved form, which means that dust occurrence is no longer possible. As a sideline, the surface has a higher quality because the continuous flow of the solution holds the concentration of the chromium ions during the galvanisation constant.

Inking unit

[15, CITEPA 2003] [38, TWG 2004] [148, COM 2009] [155, TWG 2016]

The high speed of rotogravure presses requires the use of fast-drying inks, which are dried between colour changes in dryers. Therefore, in rotogravure, inks are low in viscosity and nearly all of them are solvent-based. Publication printing inks contain 25-55 % toluene when leaving the ink factory. A dilution with toluene is carried out in the printing plant to obtain the proper toluene concentration: ink that is ready for use contains 70-80 % toluene. The solvents are evaporated by heat and air in drying sections; see Figure 13.1 which shows that each printing unit is equipped with a dryer on top [38, TWG 2004].

One plant reported the application of electrostatic assistance (ESA) for ink transfer in printing units. An electric field is generated in the region of the nip between the impression roller and the rotogravure printing cylinder (where ink transfer takes place). This technique has as its main benefits: improvements in print quality, especially on less expensive stock, less waste, reduced need for high impression pressures, faster press speeds, decreased impression roller heat build-up and a resultant increase in roller life [Plant #030 in [155, TWG 2016]].

Most of the toluene content of the inks evaporates in the dryer and is routed to the solvent recovery system. Recovery is realised with adsorption on several activated carbon units (e.g. for 70 minutes), desorption of toluene by passing hot steam (~ 45 minutes) and carbon drying with extracted air (1-7 minutes). Hot steam is cooled, advantageously with heat exchange, and toluene – as it is lighter than water – can be separated in a gravitational separation system [148, COM 2009].

All installations in the publication rotogravure printing industry in Europe are equipped with activated carbon adsorbers to recover the toluene that is evaporated [15, CITEPA 2003]. The presses are normally encapsulated. The recovered toluene is reused either on site to dilute the ink or sold to the ink supplier.

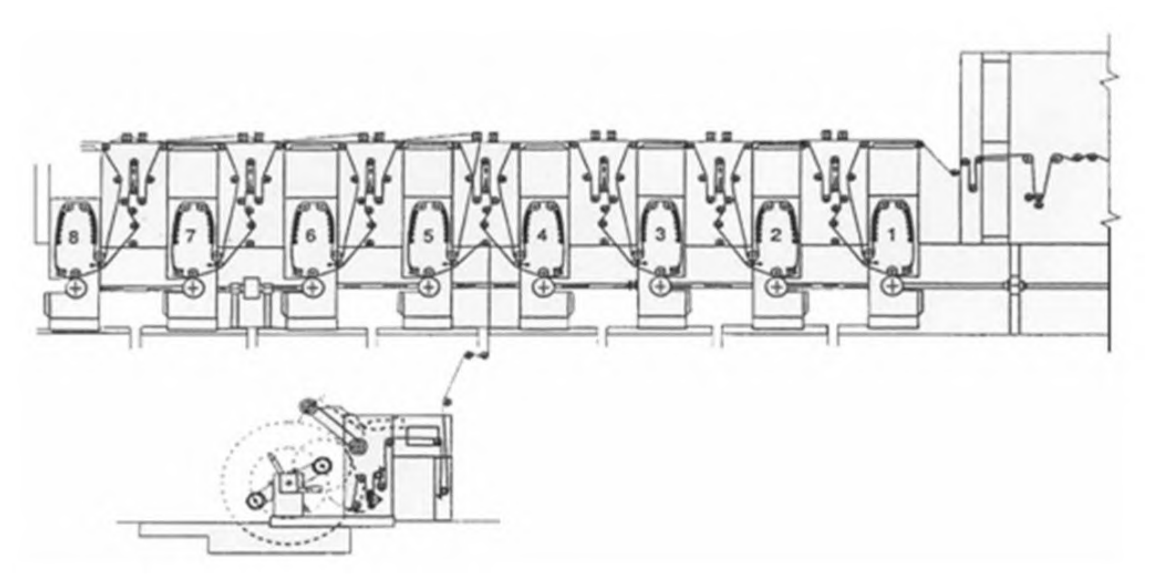


Figure 13.1: 4 + 4 colour publication rotogravure press

Printing ink

[149, ERA 2016]

Some toluene is lost as traces in the printed products. This amount has been significantly lowered in recent years. This was mainly achieved though modification of the ink composition. The surface of the printed ink takes slightly more time to solidify. In this short time period (around 10 milliseconds), additional toluene evaporates in the printing unit and is caught by the recovery system. When the printed matter leaves the production site, the toluene traces are in any case lower than 0.04 %. As a result, the airborne toluene concentration in nearby sensitive areas is far below 260 µg/m^3 of air. The figure of 260 µg/m^3 is the maximum limit accepted by the WHO for private homes. At the workplace, and already including a high safety margin, the maximum concentration allowed is 190 mg/m^3 as an average over an 8-hour working day.

The pigments in the rotogravure printing inks are synthetic, mostly based on petrochemicals. Ink providers (European Printing Ink Makers Association) have established an ‘Exclusion List for Printing Ink and Related Products’ which excludes toxic and other very harmful materials as ingredients. The resins of the rotogravure inks are based approximately 80 % on natural materials, for example rosin, gum rosin, tall oil resin. The last is a by-product of chemical pulp production in the paper industry.

Paper

[149, ERA 2016]

Years ago it seemed impossible that high-quality publication rotogravure products could be printed on paper which contains recycled fibres. Recent developments in the paper production industry have changed this situation and allow the production of high-quality products and for the customers’ demands to be met.

At the same time, it was possible to reduce the paper basis weight (grammage) without losing the optical properties. The recycling rate for printed matter in Europe is 55 % (2005): if the European recovered paper that is recycled outside Europe is included, the rate reaches 63 % (2005).

Cleaning

Cylinders are automatically or manually cleaned with the same solvent as the ink. If the job is expected to be repeated, the cylinders might be saved; otherwise they are made ready for the next printing job by replacing the engraved copper/chromium layer with a new one [38, TWG 2004].

Finishing

[1, INTERGRAF and EGF 1999] [8, Nordic Council of Ministers 1998]

Print finishing services are provided by printing companies themselves and also by a number of specialised, independent plants (purely print finishing plants).

The most important print finishing services include the processing of:

- books by folding, collecting, stitching, binding and trimming;
- magazines, leaflets, catalogues and printed advertising products (e.g. brochures, sample cards, etc.) by folding, gathering, gluing and perfect binding;
- other printed matter, printed papers or cardboard (e.g. forms, labels, packaging, calendars) by folding, punching, embossing, gluing and laminating.

Each of these steps will involve guillotining and collating. These mechanical processes, as well as folding, binding and punching, do not use solvents and therefore are not described any further in this document. In processes such as gluing and laminating, however, solvent-based products are sometimes used, and so these are further described.

Laminating

Traditionally, most laminating was done with solvent-based systems, where the adhesive-coated film was passed through an oven to drive off the solvent before being pressed onto the printed surface. Two-component adhesives are also used, often of the epoxy type containing solvents such as ethanol and ethyl acetate, or of the urethane type. The emissions from this process are significant. In some places, the vapours are directed to the oxidiser or recovered for reuse. Water-based and solvent-free adhesives or UV-cured laminating adhesives are also applied [38, TWG 2004].

Binding by using adhesives (gluing)

Gluing is part of many working processes in bookbinding and print finishing. For the processing of the book block and the production of, for example, the cover for hard case books, adhesive binding is the most frequently used binding technique, both for books and multiple-page leaflets. Adhesive binding is often referred to as ‘perfect binding’.

The adhesive used can be based on natural products or can be synthetic. The latter may be dispersion, hot melt or polyurethane. Natural products mainly comprise starch adhesives, dextrines and animal glues.

Traditionally, most glues used are water-based or hot melt and some are solvent-based.

Varnishing

‘Coating’, ‘varnishing’ and ‘overprinting’ are synonyms for the coating that is spread over the printed surface for protection or decoration. The overprint varnish is a colourless, transparent ink without pigments. Varnishes dry by evaporation, oxidation or by UV curing, and varnishes can be applied in line on the press or on a separate machine [8, Nordic Council of Ministers 1998] [38, TWG 2004].

13.3 Current consumption and emission levels in publication rotogravure printing

13.3.1 Mass balances

[7, Germany 2003] [78, TWG 2005] [148, COM 2009] [155, TWG 2016]

In 1999, the results of an inventory amongst publication rotogravure printing plants in Germany were reported. One of the results of this inventory was that the performance data from different units of different plants were compared and used to simulate a virtual plant that could meet the legal requirements, especially those of the then applicable Solvent Emissions Directive (SED). In this section, a mass balance for a good practice plant (selected from the inventory) is reported, followed by data for the virtual plant and complemented by data from the recent data collection [155, TWG 2016].

A good practice plant

In this section, data of a good practice plant from this inventory are reported along with the mass balances of the virtual plant. The good practice plant is a modern publication plant with five presses containing 40 ink units in total. The products are mainly magazines and catalogues which both need to be of high quality. The operational data of this good practice plant are as shown in Table 13.2.

Table 13.2: Mass balance of a good practice publication rotogravure printing plant

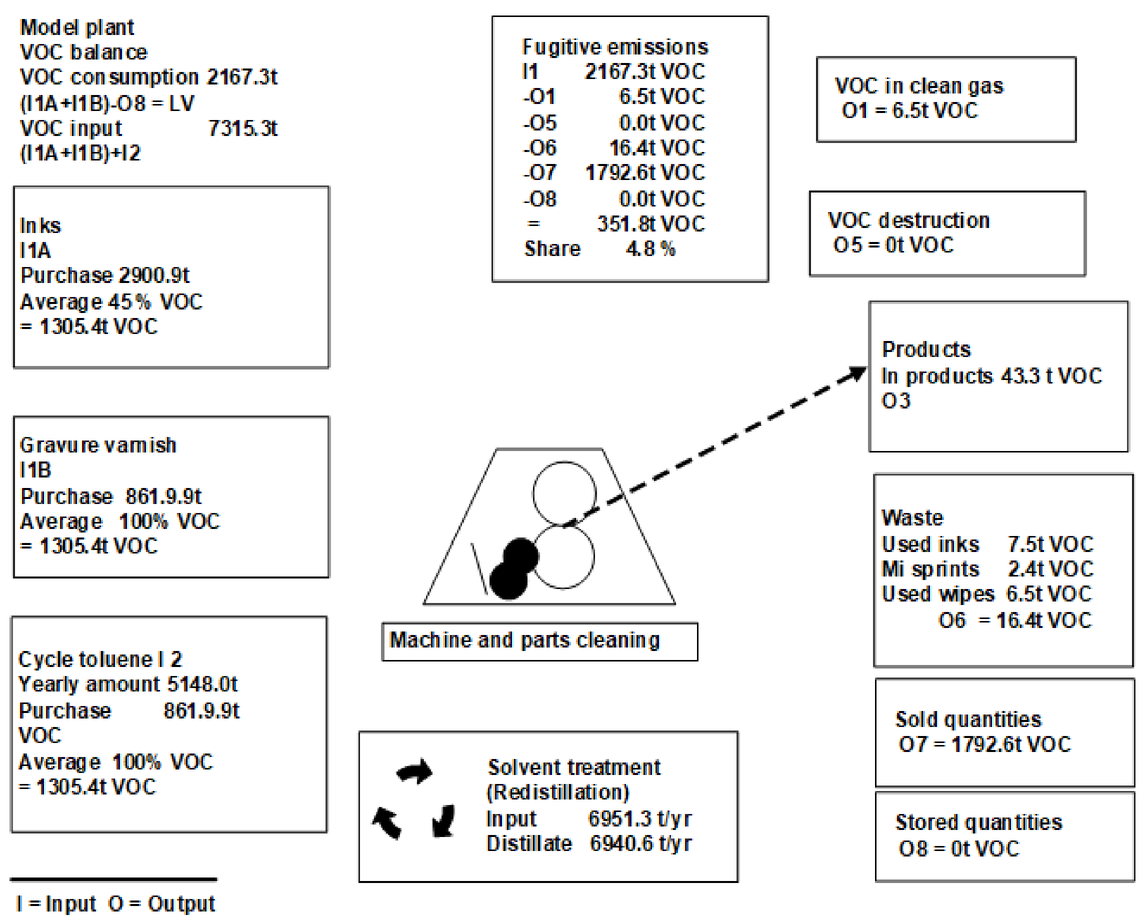
Input	Amount	Unit	Comments	Output	Amount	Unit	Comments
Material				*Products*			
Pre-products	3 100	t/yr		Pre-products	86 367	t/yr	Paper and ink
				Waste			
Printing substrate	91 300	t/yr		Substrate/ misprints	8 005	t/yr	
Printing inks	2 210	t/yr	Including varnish	Ink/varnish residues	15.7	t/yr	Hazardous
Water: of which	158 150	m^3/yr	Well water	Sludge	7.5	t/yr	Hazardous
	123 100	m^3/yr	Cooling				
	9 000	m^3/yr	Cylinder preparation	Activated carbon	2.6	t/yr	From adsorbers
	6 500	m^3/yr	Heating	*Waste water*			
Wipes	600 125	Items/yr that are cleaned	Reusable wipes	To sewage	33 200	m^3/yr	2 418 m^3/yr from electro-varnishing
Energy				*Waste gas*			
Energy in total	67 509	MWh/yr		VOCs in purified gas	7.2	t/yr	Average 35 mg C/m^3
Gas energy	44 051	MWh/yr		NO_X from combustion plant	7.6	t/yr	Natural gas combustion
Electric energy	24 011	MWh/yr		CO from combustion plant	0.2	t/yr	Natural gas combustion
				Fugitive			
				Fugitive VOCs	365	t/yr	

Source: [7, Germany 2003][38, TWG 2004]

The virtual plant

The virtual plant is, as explained above, not an existing plant, but made up of well-performing units from different existing plants. The VOC balance of the virtual plant, by employing emission factors that are typical for the branch, gives the following results shown in Figure 13.2 below. Inks, when bought, contain on average 50-55 % toluene rather than 45 % (gravure varnish contains 45-55 % VOCs). However, it does not affect the calculations, as after dilution the figures approximately balance.

VOCs in 'clean gas' equals a recovery efficiency of 99.9 %, which is exceptional and far higher than usual good practice, and is technically very difficult to achieve and would create a large energy demand. The average airflow is 19 000 Nm^3/h, which is unusual in practice; 100 000 m^3/h would be much more likely [38, TWG 2004].



NB: 'Gravure varnish' should read 'Gravure extender'. Gravure extender contains 45-55 % toluene, not 100 %. This affects the calculations.
Source: [7, Germany 2003] [78, TWG 2005]

Figure 13.2: VOC balance of a virtual publication rotogravure printing plant

This mass balance is, in theory, achieved by applying the following reduction measures:

- the applied printing inks are retention inks (see explanation below and Section 13.4.1.1);
- air extraction is applied at collecting places of ink residues and solvent wipes;
- periodic cleaning of persistent contaminants is done with dry ice instead of solvents;
- the performance of the toluene adsorber is continuously monitored;
- the drying air from the toluene adsorber is led through the waste gas scrubber.

In 'retention inks', formation of a skin on the ink surface is delayed by a modified recipe. In this way, a higher percentage of the toluene contained in printing ink can be expelled directly into the ink-drying unit of the printing plant [7, Germany 2003].

Some key VOCs in illustration rotogravure are shown in Table 13.3. From this table it can be calculated that for each tonne of purchased ink, 1.86 tonnes of toluene (partly recovered and partly fresh) are used. Data from two plants show a specific toluene input of 1.96 tonnes and 1.48 tonnes respectively for each tonne of purchased ink (see Table 13.4). However, it is not clear if this refers to the ratio of toluene to solids; this is the only accurate basis to compare toluene input with ink input [38, TWG 2004].

Table 13.3: VOCs in publication rotogravure printing

Substance	Vapour pressure at 20 °C (kPa)	Specific input (wt-% of purchased ink input)	Use
Toluene	2.9	54.7	Solvent in ink and gravure varnish
		100	Thinner in the printing process
		2.5-7.5 (1)	Cleaning agent (2)
Ethanol	5.9	< 1	Siccative for cylinder correction
Turpentine substitute	0.04	< 1	Cleaning agent for cylinder correction
Acetone	24.0	< 1	Cleaning agent for cylinder correction
Source: [7, Germany 2003], (1) [78, TWG 2005], (2) [38, TWG 2004]			

Table 13.4: Specific toluene input of two plants in Flanders, Belgium

Plant number	Purchased ink input (t/yr)	Total toluene input (fresh and recovered) (t/yr)	Specific toluene input (wt-% of purchased ink input)
Plant 1	1 312	2 571	196
Plant 2	1 475	2 179	148
Source: [13, Aminal et al. 2002]			

More recent data from the data collection [155, TWG 2016] indicate significantly higher levels of toluene input, expressed either in relation to the purchased inks and varnishes or in relation to the solid mass content of purchased inks and varnishes (see Table 13.5).

Table 13.5: Specific toluene input data

Plant	Specific toluene input (fresh and recovered) (t/yr) per purchased inks and varnishes (t/yr)			Specific toluene input (fresh and recovered) (t/yr) per solid mass content of purchased inks and varnishes (t/yr)		
Year	2015	2014	2013	2015	2014	2013
1	2.68	2.74	2.65	5.88	6.04	5.75
2	2.49	2.68	2.89	-	-	-
3	2.25	2.24	2.26	5.74	5.35	5.28
Source: [155, TWG 2016]						

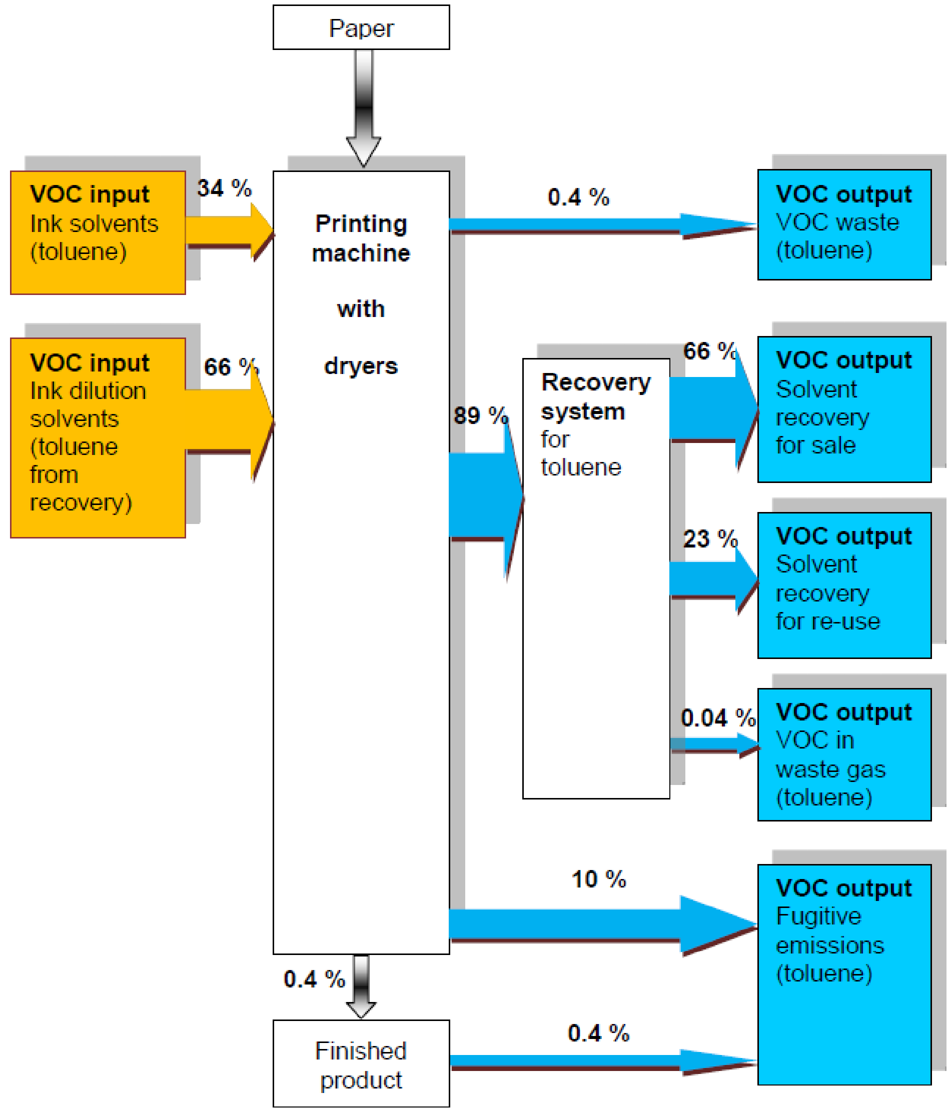
The toluene balances of the two rotogravure printing plants with a total of five presses situated in Flanders (Belgium) are shown in Table 13.6. The fugitive toluene emissions are 10 % and 6 % of the solvent (toluene) input respectively. The technique for achieving zero toluene in the waste of Plant 2 has not been identified [38, TWG 2004].

Table 13.6: Toluene balances of two rotogravure printing plants

Parameter	Plant 1	Plant 2	Unit
Total toluene consumption (fresh and recovered)	2 571	2 179	t/yr
Toluene in waste	11	0	t/yr
Toluene in solid product	10	10	t/yr
Toluene recovered and reused on site	1 694	1 428	t/yr
Toluene recovered and sold	599	613	t/yr
Emissions			
Toluene emissions after treatment	1.1	4	t/yr
Fugitive toluene emissions (1)	265	133	t/yr
Total toluene emission	266.1 (10 %)	137 (6 %)	t/yr (% of consumption)

(1) Inclusive of 10 tonnes of toluene in the sold product.
Source: [13, Aminal et al. 2002]

In Figure 13.3, the main relevant solvent inputs and VOC outputs are shown. Arrows indicate the relevance of the VOC amount [148, COM 2009].



Source: [148, COM 2009]

Figure 13.3: Main solvent inputs and VOC outputs for a publication rotogravure printing plant

Data from four publication rotogravure printing plants were submitted in the frame of the data collection [155, TWG 2016].

13.3.2 Consumption

[7, Germany 2003] [155, TWG 2016]

13.3.2.1 Printing inks

The European publication rotogravure printing industry uses 180 000 tonnes of ink annually (data from 2006). This consists of 30 kt pigments, 50 kt resins and 100 kt toluene [149, ERA 2016].

All inks used in publication rotogravure are toluene-based. Table 13.7 shows an average basic recipe for publication rotogravure printing. In the printing plant, inks of this type of recipe are significantly thinned before being used. The toluene concentration of the press-ready ink is in the range of 70-80 wt-%.

Table 13.7: Average basic recipe of purchased publication rotogravure ink

Component	Contents	Concentration (wt-%)
Binding agent:		
- Solvent component	Toluene	50-60
- Binding agent component	e.g. phenol resins, hydrocarbon resins, ethyl cellulose	30-40
Colourants	Organic and inorganic pigments	8-20
Colour auxiliary agents	e.g. waxes, dispersants, defoamers	1-4
Source: [7, Germany 2003]		

Reported data on the solvent content of publication rotogravure inks show a variation from 54 % to 61 % [155, TWG 2016].

The amount of ink used in the publication rotogravure printing plants participating in the data collection varies from 1 million kg up to 2.8 million kg. The solvent content in purchased ink materials as well as the reused solvent quantities are presented in Table 13.8.

Table 13.8: Ink consumption and solvent input data from publication rotogravure printing plants

Plant	Solvent content in purchased inks (%)	Solvent quantity recovered and reused as solvent input (% of the purchased inks)
1	54.3	215
2	51.9	217
3	58.7	166
Source: [155, TWG 2016]		

The reported figures for solvent consumption of substrate varies from 70 kg/t up to 92 kg/t, while the average solvent consumption per million m^2 of substrate varies from 2.1 kg up to 4.8 kg [155, TWG 2016].

Water-based inks have been the subject of experiment. A major problem is that, with the existing paper recycling processes, de-inking of the paper is not possible. This, in combination with lower press speeds, print problems with wide web widths and cross-media effects, has led to cessation of their use [1, INTERGRAF and EGF 1999] [38, TWG 2004].

A successful development of publication rotogravure inks has led to a new generation of toluene-based inks known as ‘retention inks’ (see Section 13.4.1.1). Their formulation has been modified in such a way that the toluene evaporates more efficiently in the dryers. Although they contain about 5 % more toluene when press-ready, they can lead to less fugitive emissions. These new inks are distributed by several manufacturers [7, Germany 2003] [14, Aminal et al. 2002] [15, CITEPA 2003].

13.3.2.2 Cleaning agents

All inks used in publication rotogravure printing are toluene-based. Once dry, they redissolve in toluene, which is, therefore, used as the cleaning agent. Data on the amount of cleaning agents used are not available however; only the relative value in Table 13.3 shows that for each tonne of purchased ink, 2.5-7.5 wt-% of toluene is used for cleaning [78, TWG 2005].

VOC-free systems (dry ice) are also applied for regular machine cleaning [155, TWG 2016].

13.3.2.3 Energy

[155, TWG 2016]

Reported values for specific energy consumption vary between 0.4 MWh and 0.75 MWh per tonne of substrate or from 10 MWh up to 30 MWh per million m^2 of printed area.

The toluene recovery system (local extraction, steam generation, cooling water pumping) represents a significant share (in some cases close to half) of the total energy consumption of the plant.

In addition to the general techniques (energy-saving lighting, optimisation of the pressure level), the main energy-saving techniques identified for the sector are as follows:

- heat exchanging in the ventilation systems including the toluene recovery plant, air conditioning, dust extraction lines, trimming line;
- reduced air ventilation at idle operation or maintenance;
- thermal insulation of tanks and vats with heated liquids (toluene recovery plant adsorbers, hot water tank);
- toluene recovery plant with variable frequency drives;
- heat recovery from the toluene recovery plant;
- air extraction and energy recovery from drying processes.

More information on possible energy efficiency options for the printing sector in general can be found on the EMPSI project webpage[40].

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[40] EMPSI: Energy management standardisation in printing industry, http://www.emspi.eu/index.html

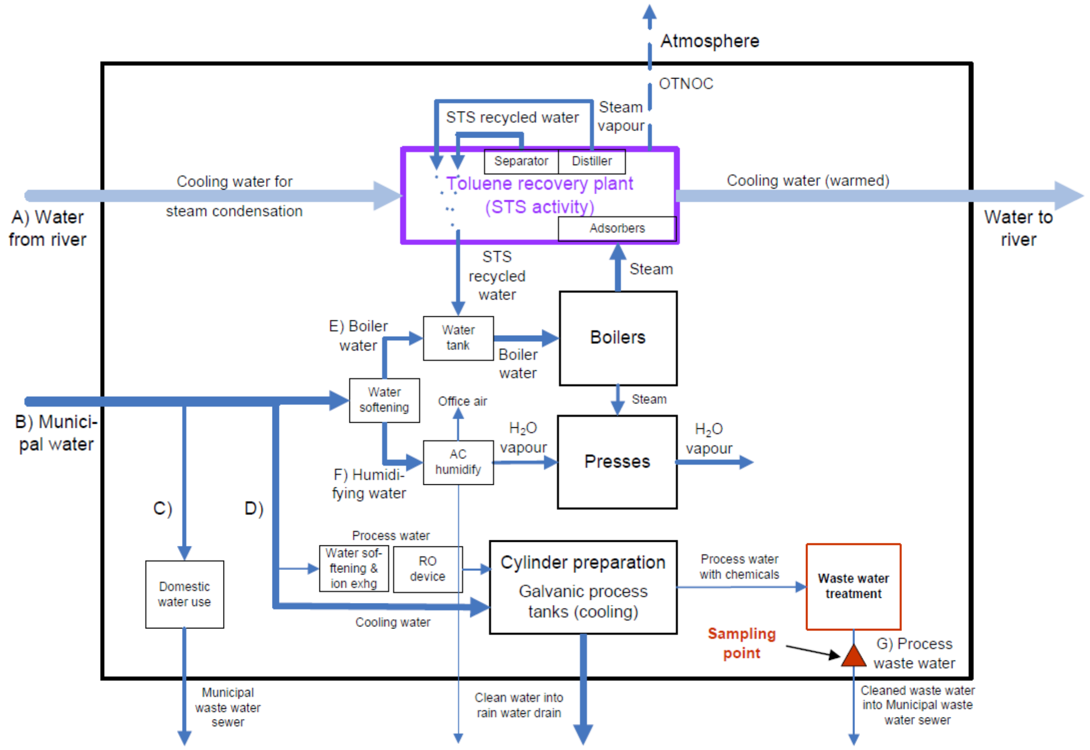
13.3.2.4 Water

[155, TWG 2016]

The toluene recovery process uses some 2-8 kg steam per kg of recovered toluene. Where, in a 'normal' four-press plant, some 7 000 tonnes of toluene are recovered yearly, some 20 000 to 30 000 tonnes of water are necessary. Normally this water is reused for cooling purposes or, in the case of new recovery installations, combined with new steam boilers and used again as steam for the toluene recovery. As cooling water, about 30-50 % water can be saved. In situations where the condensed steam is reused as boiler water, the savings are up to 100 % [1, INTERGRAF and EGF 1999] [13, Aminal et al. 2002].

Two installations reported the following specific water consumption values: 1.146 m^3/t of product and 10.15 ml/m^2 of product. Reuse of water was also reported for the cylinder preparation department after proper treatment (sedimentation, filtration, ion exchange) [155, TWG 2016].

A typical distribution of water influent and outflow is presented in the diagram of Figure 13.4.



Source: Plant #030 in [155, TWG 2016]

Figure 13.4: Diagram of water use at a publication rotogravure installation

13.3.2.5 Printing substrates and others

Reported data on annual printing substrate consumption for plants with two or three printing units show a range from 40 000 t up to 90 000 t [155, TWG 2016].

The reported values for paper substrates usage show a variation from 50 kg up to 70 kg of paper per kg of solvent or from 25 kg to 40 kg of paper per kg of ink [155, TWG 2016].

13.3.3 Emissions

All publication rotogravure printing plants nowadays have toluene recovery installations. In spite of the toluene recovery, part of the toluene input is still emitted.

The main sources of VOC emissions are:

- the printing process and its cleaning operations;
- the solvent recovery system;
- the printed product.

Toluene (CAS number 108-88-3) possesses some hazardous risks, in particular it is suspected to be toxic for reproduction (Reproductive toxicity, Category 2; H361d[41]). Toluene is included in the Community Rolling Action Plan (CoRAP, 2018 data[42]).

In order to minimise toluene emissions to air, various techniques have been identified:

- direct piping of inks;
- closed-loop distiller system at the toluene recovery for recovering the toluene residue from decanted water;
- use of retention inks;
- connection to the toluene recovery system of all potential toluene-emitting activities/processes: print units, toluene washing machines, dryers, press room air at units.

In addition, continuous air extraction from the press, the dryers and the press room is widely applied [155, TWG 2016].

13.3.3.1 Total emissions of VOCs

[155, TWG 2016]

The reported values of total emissions of VOCs expressed as a percentage of the solvent input are presented in Figure 13.5.

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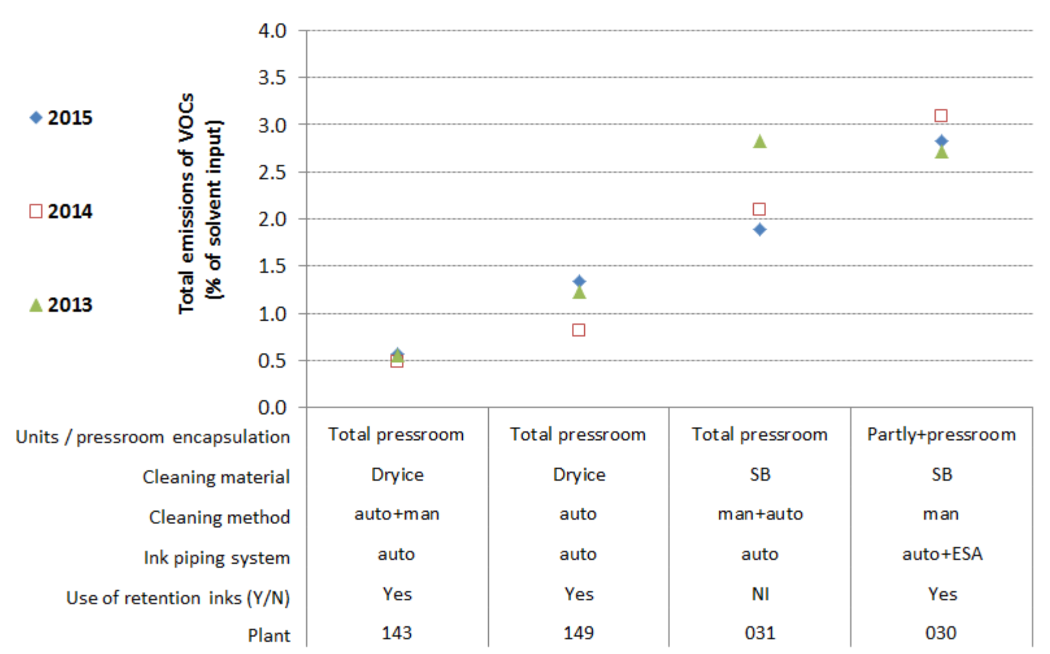
[41] See https://echa.europa.eu/es/information-on-chemicals/cl-inventory-database/-/discli/details/30426

[42] See https://echa.europa.eu/information-on-chemicals/evaluation/community-rolling-action-plan/corap-table/-/dislist/details/0b0236e1807e45ba



Source: [155, TWG 2016]

Figure 13.5: Total emissions of VOCs expressed as percentage of the solvent input for the period 2013-2015

The abbreviations used in this chapter are explained in Table 13.9.

Table 13.9: Abbreviations used in this chapter

Process	Abbreviation	Additional information
Unit(s) / press room encapsulation	Total pressroom	Pressurised press room and air extraction with subsequent treatment in the toluene recovery unit
	Partly+pressroom	Local extraction from printing units and room air ventilation with subsequent treatment in the toluene recovery unit
Cleaning material	Dry ice	Removal of dried paint or ink by blasting with dry ice pellets
	SB	Use of solvent-based cleaning agents
Ink piping	Auto	Automatic ink piping from containers
	ESA	Electrostatic assistance
Use of retention inks	Yes/No	Retention inks have a modified formulation that slows the film formation and allows evaporation of the toluene over a longer period of time. Use of retention inks could reduce fugitive emissions by 1 % of the solvent input

The reported values for total emissions of VOCs and contextual information on the layout and operation of the publication rotogravure plants that submitted data are presented in Table 13.10.

Table 13.10: Reported values of total emissions of VOCs and contextual information from publication rotogravure plants

Plant	Use of retention inks (Yes/No/NI)	Current layout since year	Unit(s) / press room encapsulation	Ink piping	Cleaning agents	Press washing system (no of presses)	Total emissions of VOCs (% of solvent input)		
							2015	2014	2013
143	Yes	2000	Total pressroom	Auto	Dry ice	Auto (2) Manual (1)	0.56	0.49	0.55
149	Yes	2009	Total pressroom	Auto	Dry ice	Auto	1.34	0.82	1.23
031	NI	2006	Total pressroom	Auto	SB	Manual (1) Auto (1)	1.89	2.10	2.82
030	Yes	2000	Partly+ pressroom	Auto + ESA	SB	Manual	2.82	3.09	2.71

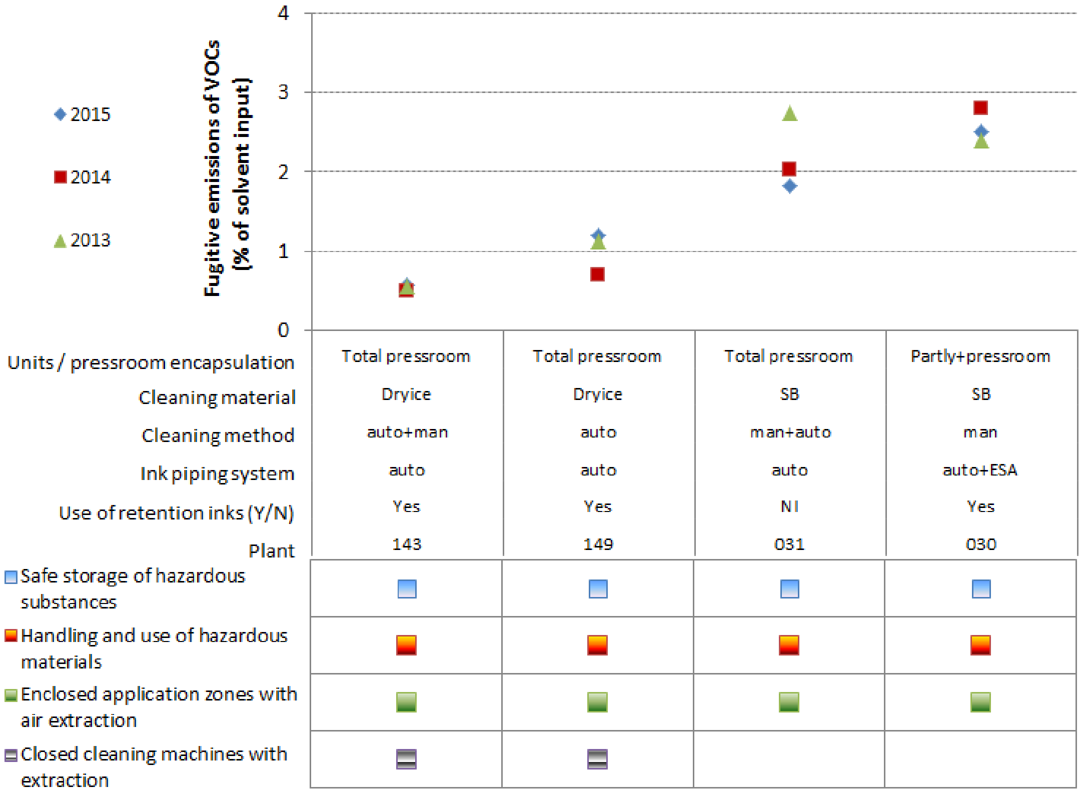
Source: [155, TWG 2016]

As can be seen in Figure 13.5, total emissions of VOCs as a percentage of the solvent input are below 3 % in all cases and close to or lower than 1 % when non-solvent-based cleaning agents are used.

13.3.3.2 Fugitive emissions of VOCs

[155, TWG 2016]

Reported values for fugitive emissions of VOCs expressed as a percentage of the solvent input for the reference period 2013-2015 are presented in Figure 13.5.



NB: The meanings of the abbreviations used in this table are given in Table 13.9.
Source: [155, TWG 2016]

Figure 13.6: Fugitive emissions of VOCs expressed as percentage of the solvent input for the period 2013-2015

The reported values for fugitive emissions of VOCs and contextual information on the layout and operation of the publication rotogravure plants that submitted data are presented in Table 13.11.

Table 13.11: Reported values of fugitive emissions of VOCs and contextual information from publication rotogravure plants

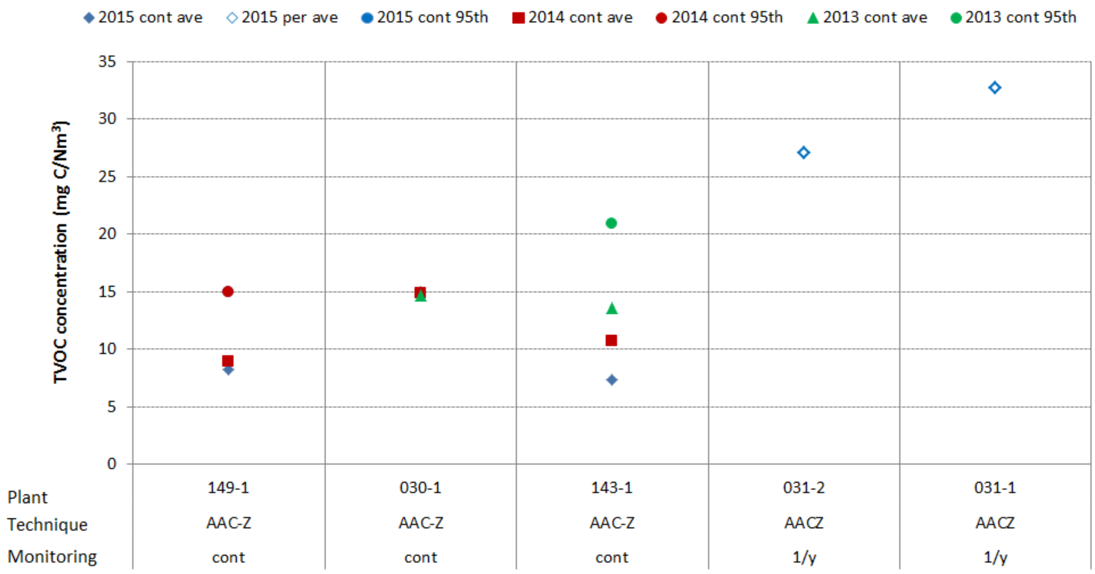
Plant	Use of retention inks (Yes/No/NI)	Current layout since year	Unit(s) / press room encapsulation	Ink piping	Cleaning agents	Press washing system (no of presses)	Fugitive emissions of VOCs (% of solvent input)		
							2015	2014	2013
143	Yes	2000	Total pressroom	Auto	Dry ice	Auto (2) Manual (1)	0.56	0.49	0.55
149	Yes	2009	Total pressroom	Auto	Dry ice	Auto	1.19	0.7	1.12
031	NI	2006	Total pressroom	Auto	SB	Manual (1) Auto (1)	1.83	2.03	2.74
030	Yes	2000	Partly+ pressroom	Auto + ESA	SB	Manual	2.5	2.8	2.4

Source: [155, TWG 2016]

13.3.3.3 Emissions in waste gases

[155, TWG 2016]

All reporting plants operate central toluene recovery systems and at three plants continuous toluene monitoring is performed at the exhaust of the recovery system. The results are presented in Figure 13.7.



NB: Plant 030-1: yearly average.
Plant 031-1 & 031-2: Reported values are related to maintenance periods (open loop). During NOC emissions are zero (close loop system).

NB:
1. For Plant #030, the presented values are the annual averages.
2. Plant #031 with periodic monitoring performs one measurement campaign per year with a sampling duration of 4 hours. It is also stated that the solvent recovery system is a closed-loop system and was designed with a zero emissions strategy. Reported values refer to maintenance activities, when the system runs in an 'open loop'. Normal operating condition lead to no emission.

Source: [155, TWG 2016]

Figure 13.7: TVOC emissions in waste gases from the toluene recovery unit for the period 2013-2015

13.3.3.4 Waste generation

[155, TWG 2016]

The main types of waste generated in the publication rotogravure printing are presented in Table 13.12.

Table 13.12: Main types of waste generated in the publication rotogravure printing industry

Waste type	Source	Final destination	VOC content (%)	Quantity
Paper waste	Production processes	Sold off site	0-0.5	6-12 % of paper input
Waste toluene	Air emission abatement	Delivered off site as hazardous waste	80-100	0.1-0.2 % of toluene input
Slurry toluene	Cleaning of ink tank	Delivered off site as hazardous waste	40-80	0.07-0.1 % of toluene input
Waste ink	Production processes	Delivered off site as hazardous waste	20-85	< 0.1 % of ink input
Metallic copper	Cylinder preparation – copper plating	Sold off site	0	< 0.4 g/kg of paper input
Solid waste containing Cr(VI)	Cylinder preparation	Delivered off site as hazardous waste	0	< 50 g/t of paper input
De-chroming acid bath electrolyte	Production processes	Delivered off site as hazardous waste containing Cr ions and 35 % sulphuric acid	0	< 0.3 g/t of paper input
Waste water treatment sludge filter pressed	Waste water (pre)treatment	Delivered off site as hazardous waste	0	< 0.02 kg/t of toluene input
Cleaning rags from press rooms	Cleaning processes	Delivered off site as hazardous waste	1	< 0.05 g/t of paper input
Carton, paper reel wrappings	Production processes	Delivered off site as non-hazardous waste	0	< 4 g/t of paper input
Oil and lubricants	Maintenance	Delivered off site as hazardous waste	0	2-4 t/yr < 0.04 g/kg of paper input
Wood	Material from delivery	Sold off site	0	< 0.4 g/kg of paper input
Scrap	Maintenance	Sold off site	0	< 0.33 g/kg of paper input
Source: [155, TWG 2016] [212, TWG 2018]				

Paper waste

Printed paper waste contains very small amounts (1 %) of toluene residue, which is released in due course to atmosphere. Printed paper waste is about 50 % of the total paper waste. In relation to the total paper quantity input to the installation, waste paper represents 6-12 % of the total.

Inks

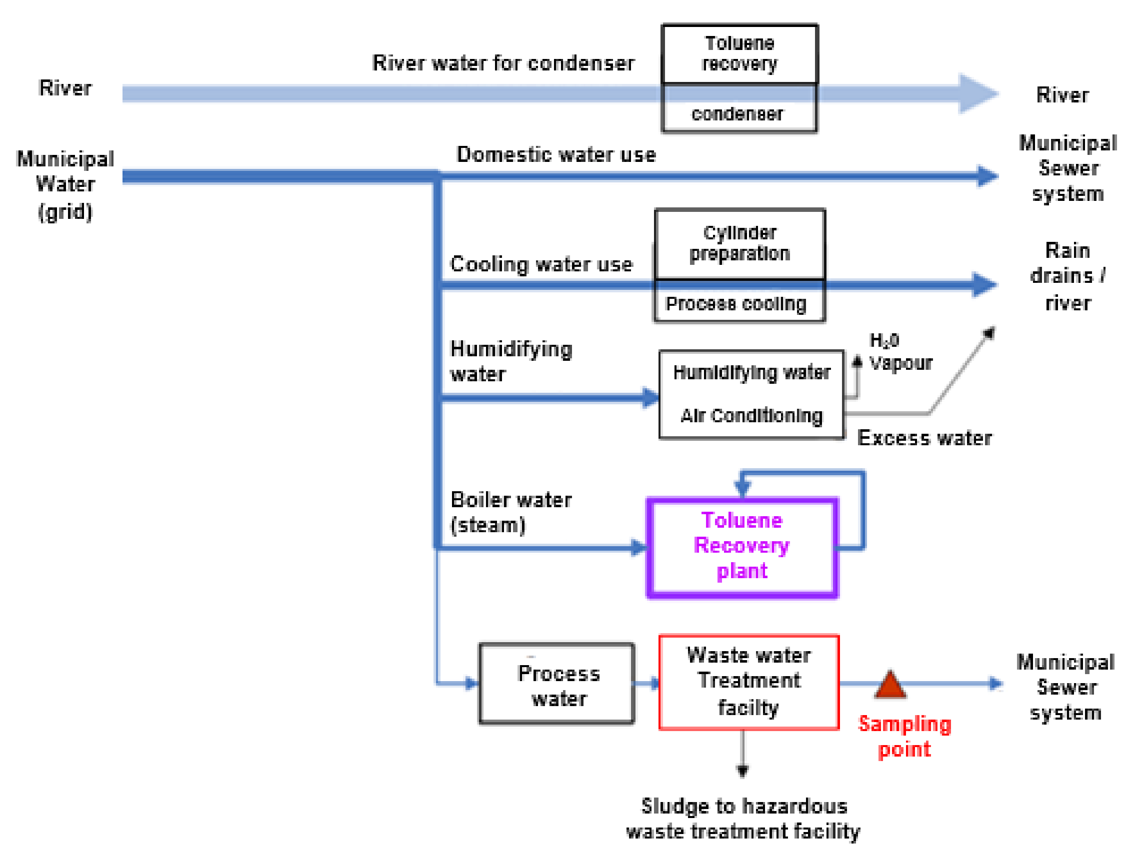
In most cases, the work is done with four standard process colour inks and very little mixing of inks takes place. Presses work in shifts and, if at all, are only stopped during the weekends and for public holidays. Only a small proportion of the ink becomes waste and reusing press returns is normal practice [1, INTERGRAF and EGF 1999].

Leftover coloured ink may be mixed with black ink and thus reused, saving on black ink. Waste ink can be distilled to recover the toluene. The distillation sludge, which is about 20 % of the original weight of the waste ink, is disposed of. However, because of the small amounts of toluene recovered, distillation is not often applied because of the relatively expensive equipment needed [1, INTERGRAF and EGF 1999]. Based on data from two installations, the waste ink percentage is estimated to be less than 0.1 % of the ink input. Waste ink is delivered off site as hazardous waste [155, TWG 2016].

Cleaning materials (wipes, rags)
Used wipes and rags containing ink and toluene residues are dried in drying booths from where the extracted air is directed to the toluene recovery plant. Only very small amounts of toluene residue may remain in the rags after drying.

13.3.3.5 Emissions to water

Figure 13.8 shows the diagram of waste water generation at a publication rotogravure printing installation.



Source: [Plant #030 in [155, TWG 2016]]

Figure 13.8: Diagram of waste water generation at a publication rotogravure printing plant

Waste water resulting from the dedicated waste water treatment from the cylinder preparation department is directed to the municipal sewer system. This waste water flow represents less than 1 % of the water input for the total production needs of the installation [Plant #030 in [155, TWG 2016], see also Figure 13.7)].

Only two data sets with data for metal emissions in waste water were submitted for 2015. The results are presented in Table 13.13.

Another installation reported waste water effluent only from the sanitary facilities and desludging water from the boiler and the cooling towers. Waste water from the plating department is evaporated generating sludge (hazardous waste).

Table 13.13: Metal emissions in waste water from two publication rotogravure printing plants (data for 2015)

Plant	**#030**				**#031**			
Pollutant	**Ave.**	**Max.**	**Min.**	**No of samples**	**Ave.**	**Max.**	**Min.**	**No of samples**
Cu	0.39	0.85	0.04	100	0.144	0.538	NI	104
Cr(VI)	0.01	0.06	0.01	100	0.278	0.359	NI	104
Cr_{total}	0.08	0.2	0.01	100	0.003	0.003	NI	104

NB:
NI: No information provided.
Source: [155, TWG 2016]

13.4 Techniques to consider in the determination of BAT for the publication rotogravure printing

In Chapter 17, techniques are discussed which might also be applicable to publication rotogravure printing. In Table 13.14, the general techniques relevant for publication rotogravure printing are shown. These techniques are not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 17.1.

Table 13.14: Reference to techniques generally applicable to the sector

Technique	Section number
Environmental management techniques	17.1
Storage and handling of raw materials	17.2
Monitoring	17.3
Water use and waste water generation	17.4
Energy management and energy efficiency	17.5
Raw material management (including substitution)	17.6
Coating processes and equipment	17.7
Drying and/or curing techniques	17.8
Cleaning techniques	17.9
Off-gas extraction and treatment	17.10
Waste water treatment techniques	17.11
Waste management techniques	17.12
Odour emissions	17.13

13.4.1 Material-based techniques

13.4.1.1 Use of retention inks

Description
Retention inks slow the formation of the dried film surface, which allows toluene to evaporate over a longer time and therefore more toluene to be released in the dryer and recovered by the toluene recovery system.

Achieved environmental benefits
The remaining toluene load in the product, measured directly at the delivery area of the press, can be reduced by 30-50 %.

Diffuse emissions can be reduced by approximately 1 % of the solvent input. This corresponds to a reduction of 20 % of the total emissions from a good practice publication rotogravure printing plant (where total emissions are 5-6 % of the solvent input, including emissions from off-gas treatment; solvent input is as defined in the IED) [7, Germany 2003].

These benefits can only be achieved where the waste gas from the dryers are extracted and treated.

Cross-media effects
Where adsorption is used, more energy is reported to be needed to desorb the higher load of toluene produced from the dryers.

Technical considerations relevant to applicability
Applicable for all publication rotogravure printing processes, except where special inks are required that do not have a retention ink counterpart.

In the EU-15, 70 % of the publication rotogravure inks used are now retention inks, and in Germany 100 % (data for 2003).

Economics
The price of retention inks is the same as conventional inks; however, less ink is needed (although this is not an ink reduction technique).

The savings for each kg of toluene recovered are about EUR 0.50 (2006 data).

Driving force for implementation
Less toluene in the final product.

Example plants
Large number of plants throughout Europe.

Plants #143, #149 and #030 in [155, TWG 2016].

Reference literature
[1, INTERGRAF and EGF 1999] [7, Germany 2003] [14, Aminal et al. 2002]
[38, TWG 2004] [78, TWG 2005] [155, TWG 2016]

13.4.2 Off-gas extraction and treatment techniques

For the treatment of off-gases from all potential toluene-emitting activities/processes, adsorption and recovery of toluene (i.e. toluene recovery system) is commonly applied (see Section 17.10.6.2).

13.4.2.1 Continuous air extraction from the press, the dryers and the press room

See also Section 17.10.2.

Description
The extracted air from the press room is routed to the off-gas treatment system, along with the air from the dryers and from the encapsulated press.

There are facilities where personnel controlling the printing process are situated in separate control rooms. In these situations, the separate press room where the machines are sited can be seen as the encapsulation of the press. The air from this room is extracted and routed to the off-gas treatment system.

Achieved environmental benefits
The main benefit is low toluene emissions. Additional VOC emission reduction can be achieved if air is not only extracted from the enclosed machine and the dryer but also from the entire press room. By routing press room air to the adsorption system, the toluene content is recovered.

Three out of the four plants that submitted emission data apply total encapsulation of the press room, and the fourth plant applies local air extraction from the printing unit and press room. Emission levels, expressed as a percentage of the solvent input, in the range of 0.5 % to 3.1 % are achieved [155, TWG 2016].

Environmental performance and operational data
All publication rotogravure printing plants are equipped with an off-gas treatment system.

Cross-media effects
Increased energy consumption for air extraction and toluene recovery.

Technical considerations relevant to applicability
This system may need the activated carbon system to be adapted to be able to adsorb and desorb lower toluene concentrations effectively [148, COM 2009].

Economics
The savings for each kg of toluene recovered are about EUR 0.50. The extra investment cost, compared to the situation where only the dryers are connected to the off-gas treatment system, is about EUR 0.5 million per press. Additional operational costs are about EUR 100 000 per year per press (2006 data).

Driving force for implementation
Occupational health and safety.

Example plants
Plants #030, #031, #143 and #149 in [155, TWG 2016].

Reference literature
[12, Netherland 1996] [14, Aminal et al. 2002] [38, TWG 2004] [148, COM 2009] [155, TWG 2016]

13.4.2.2 Internal concentration of solvents (closed air loop ventilation)

For a general description, see also Section 17.10.3.2.

Description
The exhaust air from the off-gas treatment system is returned to the dryers or the press room. This requires an off-gas treatment system with a much higher capacity than normal. The frequency of the adsorption/desorption cycle is very short to achieve very low toluene levels in the recycled air stream. Before sending the exhaust air stream to the building again, the air has to be cooled.

Achieved environmental benefits
Depending on the size of the press, the total toluene emission might be reduced to 20-75 t/yr.

Environmental performance and operational data
No information submitted.

Cross-media effects
A higher frequency of the adsorption/desorption cycle creates more waste water and requires more energy. More energy is also needed because the capacity of the off-gas treatment system is higher. However, several energy reduction or reuse options are commonly installed.

Technical considerations relevant to applicability
This technique is applicable to new presses in combination with a new off-gas treatment system. The technique is also applicable to existing presses when a new off-gas treatment system has to be installed. Retrofitting an existing off-gas treatment system may be too expensive.

A three-metre press in a plant in the Netherlands, including a new off-gas treatment system, applying closed air loop ventilation achieved a toluene emission reduction of 75 t/yr. For the two Flemish plants, with presses which are smaller and slower, the achievable reduction may be

20 t/yr for each press; however, the technique is not installed at these plants because the costs of retrofitting are too high.

Economics

For a three-metre press, additional investment costs, on top of the costs for a new off-gas treatment system, are EUR 5 million. The operational costs are the same when energy-saving techniques are installed. The costs per tonne of avoided toluene emissions are about EUR 10 000, based on a loan for a period of 10 years with an interest rate of 7 % (1999).

The savings for each kg of toluene recovered are about EUR 0.50.

Driving forces for implementation

Occupational health and safety.

Example plants

Etten Leur, the Netherlands.

Reference literature

[1, INTERGRAF and EGF 1999] [7, Germany 2003] [14, Aminal et al. 2002] [38, TWG 2004]

13.4.2.3 Air knives on the printed web

For a general description, see also Section 17.10.2.3.

Description

Air knives prevent the web from carrying solvent-laden air out of the dryers.

Achieved environmental benefits

Fugitive VOC emissions are reduced.

Cross-media effects

Noise levels might increase along with an increase in energy consumption.

Technical considerations relevant to applicability

Applicable to webfed printing processes using forced air drying systems.

Economics

Relatively low cost; increased energy costs.

Driving force for implementation

Occupational health and safety.

Example plants

This technique is commonly applied in publication rotogravure.

Reference literature

[1, INTERGRAF and EGF 1999]

13.4.3 Cleaning techniques

13.4.3.1 Automatic cleaning systems connected to the toluene recovery system

Description
Automated cylinder cleaning with air extraction to the toluene recovery system.

Technical description
The printing cylinders in publication rotogravure presses are cleaned automatically. The air is extracted to the toluene recovery system.

Achieved environmental benefits
Reduction of VOC emissions.

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation
Reduction of fugitive VOC emissions and recovery of toluene.

Example plants
Plants #143 and #149 in [155, TWG 2016].

Reference literature
[1, INTERGRAF and EGF 1999] [155, TWG 2016]

13.4.3.2 Drying of used cleaning materials (wipes, rags) in drying booths connected to the toluene recovery system

Description
Used wipes and rags containing ink and toluene residues are dried in drying booths from where the extracted air is directed to the toluene recovery plant. Only very small amounts of toluene residue may remain in the rags after drying. See also Section 17.12.3.2.

Example plants
Plants #030, #143 and, #149 in [155, TWG 2016].

13.4.3.3 Dry ice cleaning

Description
See Section 17.9.11.

Example plants
Plants #143 and #149 in [155, TWG 2016]

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14 COATING OF WOODEN SURFACES

[5, DFIU et al. 2002] [38, TWG 2004] [57, VDI 2005] [78, TWG 2005]
[148, COM 2009] [162, COM 2014]

14.1 General information on the coating of wooden surfaces

Wood is a natural raw material characterised by its inhomogeneity and anisotropy, and which displays irregular properties in terms of surface structure, the varying contents of different substances (e.g. waxes, water, resins), and variable electrical resistance. Wood fibres often have the characteristic that they swell up and become erect under the influence of liquids (in particular, with water). Wooden surfaces are coated in order to conserve or strengthen the colour, surface structure and/or porosity. The coating is applied to provide, for example, resistance against:

- chemical impacts;
- mechanical stress;
- climatic impacts;
- staining.

Currently, the wood and furniture industry is facing new market requirements, as complicated product geometry and higher qualities (e.g. colour variety, new surface effects) are demanded. To meet these expanding requirements, spray application techniques are increasingly being utilised.

This industry is characterised by a strong predominance of medium-sized companies, with 75 % of enterprises having less than 100 employees. Germany, Italy, Poland, France and the UK account for over two thirds of all EU furniture production in 2012 (see Table 14.1). Half of all the European furniture manufacturing companies are located in these countries, and together they employ around 60 % of the European sector workforce (see Table 14.2) [162, COM 2014].

Table 14.1: Furniture production in the EU-28 in 2012

Country	Million EUR	Share of EU total	Average yearly growth rate 2003-2012
Germany	17 738	21 %	1.5 %
Italy	15 950	19 %	-2.1 %
Poland	8 323	10 %	7.4 %
France	7 929	9 %	0.2 %
United Kingdom	7 022	8 %	-2.5 %
Spain	4 611	5 %	-4.8 %
Sweden	3 021	4 %	2.4 %
Denmark	2 147	3 %	-2.2 %
Netherlands	2 119	3 %	-0.7 %
Austria	2 115	3 %	-0.4 %
Belgium-Luxembourg	1 953	2 %	-0.6 %
Romania	1 594	2 %	6.3 %
Czech Republic	1 459	2 %	1.5 %
Portugal	1 354	2 %	-0.4 %
Lithuania	1 090	1 %	11.2 %
Hungary	1 017	1 %	1.8 %
Finland	929	1 %	-2.6 %
Slovakia	928	1 %	6.6 %
Slovenia	619	1 %	-3.4 %
Greece	532	1 %	-7.9 %
Ireland	376	0 %	-3.5 %
Estonia	373	0 %	2.0 %
Croatia	369	0 %	1.8 %
Bulgaria	268	0 %	2.6 %
Latvia	188	0 %	-0.3 %
Cyprus	82	0 %	-4.1 %
Malta	41	0 %	-3.4 %
EU-15	**67 796**	**81 %**	**-1.0 %**
EU-13	**16 351**	**19 %**	**5.1 %**
EU-28	**84 147**	**100 %**	**-0.1 %**

Source: [162, COM 2014]

Table 14.2: The furniture sector in the EU-28

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011
Enterprises	134 557	134 879	134 577	135 266	135 902	130 750	126 061	131 077	126 000
Employees	1 178 781	1 191 393	1 162 084	1 144 611	1 151 988	1 096 161	993 919	937 247	919 311
Share of production in total manufacturing (%)	1.8	1.9	1.8	1.8	1.8	1.7	1.7	1.6	1.4

Source: [162, COM 2014]

Nowadays, the level of automation of paint application in the furniture industry has been increased significantly, mainly due to increasing quality, efficiency and environmental requirements.

A variety of materials are processed and coated in the wood and furniture industry. These can be distinguished in a number of fields of application:

- exterior construction, fittings and furniture;
- interior construction, fittings and furniture;
- commercial and public applications, e.g. schools;
- domestic applications;
- wet applications, e.g. for swimming pool decking, saunas, kitchens and bathrooms.

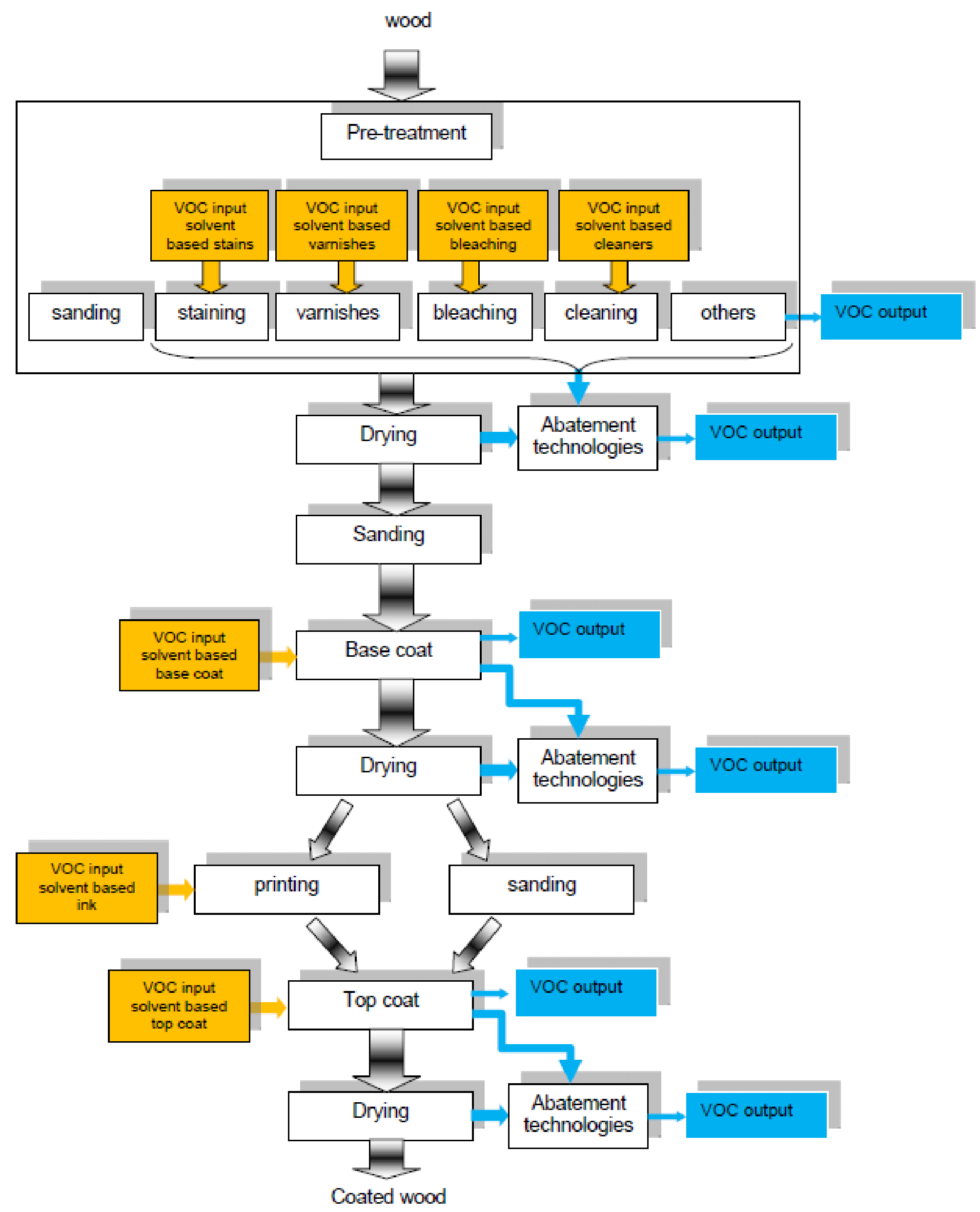
14.2 Applied processes and techniques in the coating of wooden surfaces

The application of coating materials for wooden surfaces involves:

- pretreatment of the wooden surface;
- application of a base coat;
- application of a topcoat;
- application of the paint;
- flash-off and drying/curing.

Depending on the desired surface structure (i.e. open or closed cell pore structure), different paint systems may be used. If the wooden grains need to be visible, e.g. for solid wood or veneer, uncoloured paints (i.e. clear coats), oils and waxes are used. For example, medium-density fibreboard (MDF) panels are coated with pigment paints of the desired colour. If pigment paint systems are used, a barrier layer is applied before the base coat, which restricts permeation of paint to the wooden subsurface and allows a more uniform paint layer to be applied.

An overview of the typical process steps for the coating of wooden surfaces is shown in Figure 14.1.



Source: [148, COM 2009]

Figure 14.1: Typical process steps and main VOC inputs and outputs for the coating of wooden surfaces

14.2.1 Pretreatment of the wooden surface

Due to irregular growth and the varying surface structure, and because of the differing content of certain substances such as resin or wax, proper pretreatment of the surface to be coated is essential. This pretreatment can address different aspects of the wood, such as the existing surface flatness, removal of working marks, treatment of colour differences, unevenness, fibre erections, cracks, boughs, as well as wood moisture. Typical pretreatment techniques include:

- mechanical pretreatment, e.g. sanding;
- colouring methods, such as:
  - staining,
  - glazing,
  - bleaching.

For some special kinds of wood, it is necessary to use chemical cleaning processes that utilise soap solutions, ammonia or organic solvents, together with a sanding technique for the disposal of paint-incompatible wood substances such as resin and wax.

Sanding

Usually for ideal paint results, wood and wooden base materials need an intermediate sanding to be applied after the application of a base coat or after staining or the application of other paint layers, since an erection of wood fibres is caused by the interaction with fluids. This kind of napping of the wooden surface is especially significant when water-based paint systems are used.

Staining

The aim of staining is to change the colour of the wood to a darker colouring. The wooden structure and the pore structure remain the same. Depending on the type of staining applied, the drying time varies considerably. Stains are suspensions of pigments or solutions of dyes in water or organic solvents. The most commonly applied stain is solvent-based. If chemical stains, as an example one-component positive stains, are used, longer residence times have to be taken into account. If water-based stains are processed, the swelling and roughening of the wood (napping) has to be allowed for. Also, combinations of water-dilutable organic solvents and water can be used (combi-stains). The traditionally applied stain is a water-based material. The compositions of different types of stains are listed in Table 14.3 below.

Table 14.3: Composition of different types of wood stains

Type of wood stain	Water content (%)	Content of organic solvents (%)	Proportion of pigments (%)
Water-based stain	Up to 95	0	Up to 15
Solvent-based stain	0	85-95	5-15 *
Combi-stain	65-70	25-30	5
* In some roller applications, the proportion of pigments may be up to 15 % *Source*: [38, TWG 2004]			

Application is either carried out manually (with a sponge, brush, rolls, spraying) or is automated (automated spray applications, rolling, foam rubber rolls). Subsequent drying takes place at ambient temperatures or in convection dryers, flat dryers or jet dryers.

Glazing

Modern glazes are high-liquid wood covers based on lacquer resins. The materials achieve a good penetration of the wood and often contain water-repellents and fungicide ingredients to improve the wood. They may be colourless or may be pigmented with different colourings. Different materials are used for outdoor and indoor usage. Glazes without fungicides, as well as colourless wood glazes, are only suitable for indoor usage.

Bleaching

In general, bleaching brightens the wood colour. Sometimes it is necessary to bleach several times, for example if maple is used. For bleaching, hydrogen peroxide (30-35 %) and several additives or radiation are used. The impact time has to be adjusted to the desired effects. As bleaching splits off oxygen, sufficient drying is necessary in order to avoid blistering. Bleaching is also used for wood with non-light-resistant colourings such as cherry or rosewood. After bleaching, staining with highly light-resistant pigments is used to reproduce the original wood colouring. If polyurethane-based coating systems are used, the curing agent has to be peroxide-resistant.

14.2.2 Application of a base coat

Base coat material needs to be suitable for sanding down. Application techniques include:

- spraying (manually or automatically; conventional, airless, air-assisted airless ('airmix') and electrostatically assisted);
- casting;
- rolling (e.g. using a UV-curing lacquer suitable for rolling);
- dipping (only for special workpieces).

After drying of the pretreatment stage, sanding (with material of an appropriate grain size) takes place before a colourless base coat is applied. Afterwards the surface is sanded again before a topcoat is applied. In some cases, a wooden structure is printed directly onto the base coat. As the substrate, mainly simple veneers are used or, alternatively, the surface to be coated may already incorporate a coloured base coat/stopper.

14.2.3 Application of a topcoat

For the coating of wooden surfaces, paints, foils or other panel-like coating materials, as well as textiles or leathers are used. Some specific coatings are:

- nitrocellulose paint (NC), sometimes called cellulose nitrate paint (CN);
- acid-curing paints;
- polyurethane paints (PUR);
- unsaturated polyester paints (UP):
    - open-cell UP materials,
    - thick-film layer systems;
- water-based paints;
- powder coatings;
- alkyd paints/glazes;
- combined/mixed paint systems;
- water-based UV lacquers;
- 100 % UV lacquers.

The same application techniques are used as described in Section 14.2.2.

Table 14.4 itemises the main properties of the most commonly used wood stains and paints.

Table 14.4: Overview of the properties of wood stains and paints

Wood stain or paint type	Proportion of solvent (%)	Proportion of water (%)	Components	Type of reaction	Catalyst	Remarks
Wood stain						Organic solvents; water-dilutable solvents; combi-wood stain; water-dilutable solvents; napping of wood
• solvent-based						
– type a)	95	0				
– type b)	70	25-30				
– type c)	25-30	70-80				
• water-based	0	85-95				
NC paint (CN paint)			Collodium wool (cellulose nitrate)	Physical drying		Surface resistance with limited usability
• uncoloured	Approx. 75	0				
• pigmented	Approx. 60	0				
Acid curing paint			Alkyd-melamine urea resins polyols	Forced drying	Acid	Older paint systems emitted formaldehyde; high resistance
• two-component; uncoloured	40-50					
• two-component, pigmented	20-30					
• one-component; uncoloured	20-30					
PUR paint			Isocyanates; acrylates; polyesters	Addition reaction (physico-chemical)		Generally two-component materials; high resistance
• uncoloured	65-70	0				
• pigmented	36-60	0				
• medium-solids; uncoloured	40-50	0				
UP paint			Polyester, unsaturated (organo-metallic materials)	Polymerisation • heat • radiation	Organic peroxides UV radiation; Photo-initiator	Component systems; for infrared curing UP coatings, pre-drying and curing times have to be allowed for
• conventional	Approx. 35 (15)	0				
• containing paraffin	Approx. 35 (15)	0				
• free of paraffin	Approx. 35 (15)	0				
• UV curing	Approx. 35 (15)	0				
– rolling lacquer	Approx. 20 (20)	0				
– stopper	Approx. 20 (10)	0				
• UP-spraying paint						
– uncoloured	65-70	0				
– UV curing	65-70	0				
Acrylate paint			Polyacrylate, unsaturated	Electron beam	Photo-initiator	
• UV curing	2-40					
– rolling lacquer	2-10					
– spraying paint open cell structure	65-70					
• electron beam curing	2-5					

Water-based paint • conventional drying • UV curing • PUR, two-component	5-7 Approx. 2 Approx. 9	60-65 58-60 60-65		Physically drying; polymerisation; addition reaction	UV radiation	Napping of the wood; longer drying times; possibly application of UV base coat followed by a water-based paint application; UV-cured water-based paint is becoming more and more significant. UV coating can only be applied where flat pieces can be coated separately and coating is done before the piece of furniture in assembled
Powder coating • conventional drying • UV curing	0	0	Epoxy resins Polyester-acrylate resins	Addition and condensation	UV radiation	Powder coatings with conventional convection drying are not suitable for the coating of wood at present. Application systems exist only for the coating of MDF
Alkyd resin paints	10-80	0	Alkyd resins	Oxidation in air physico-chemical drying	Organo-metallic compounds	Organic solvents

NB: Data in brackets means the solvent content emitted as % of the coating.
Source: [5, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005]

14.2.4 Application of the paint

The following application techniques are used for wooden surfaces:

- painting, rolling;
- manual spraying (partly also using electrostatically assisted processes);
- automated spraying (partly also using electrostatically assisted processes);
- automated spraying with or without the recycling of overspray (partly also using electrostatically assisted processes);
- rolling;
- vacumat technique;
- filling with stoppers;
- curtain coating;
- dipping/flooding;
- printing.

Besides manual spray applications, spraying installations or spraying machines equipped with two-component dispensing units are in use in the furniture industry. Table 14.5 lists the achievable application efficiency factors.

Table 14.5: Achievable application efficiency factors

Application technique	Efficiency factor (1)	Remarks
Painting, rolling	95-100	Reduced uniformity of surface
Spraying, conventional	30-60	High amount of overspray
Spraying, HVLP	40-75	Application of low-viscosity wood stains, increasing use also for other paint systems
Hot spraying	40-60	Application of paints with a high solids content, also applicable for hot wax spraying
Airless spray application	40-75	Bundling of sprayed material
Air-assisted airless technique	35-50	Bundling of sprayed material
Spraying, electrostatically assisted wet lacquer	50-70	Electrical conductivity has to be considered
Spraying, electrostatically assisted powder	80-95	Electrical conductivity has to be considered. Currently, only applicable for the coating of MDF (only a few applications)
Curtain coating	95	Limited by workpiece's geometry
Rolling	95	Limited by workpiece's geometry
Vacumat technique	95	Only applicable for narrow parts and edges, water-based paints and UV-cured materials with a high solids content; also the workpiece's geometry has to be considered

(1) Depending on the occupancy rate and geometry of the workpieces, etc.
Source: [5, DFIU et al. 2002]

14.2.5 Flash-off and drying/curing

Drying/curing of the paint layer requires an intense flash-off. The flash-off takes place in special installations that are generally located upstream of the dryers. For water-based paints, the humidity of the evaporating air needs to be taken into account to enable sufficient drying.

Some specific drying processes applied (some more commonly applied than others) are:

- through-circulation dryers with dehumidification;

- convection dryers;
- infrared systems:
  - thermal reactors,
  - near infrared drying (NIR drying);
- UV radiation drying;
- microwave;
- high-frequency dryers (HF dryers);
- X-ray curing.

14.2.6 Examples of some coating processes

[5, DFIU et al. 2002] [78, TWG 2005]

Coating of chairs
In most cases, the first layer used for coating of chairs is solvent-based to minimise the raising of the grain. Chairs made of beech wood are generally coated with a colouring wood stain or a glaze first. After pre-sanding, a first layer of a water-based coat (120 g/m^2) is applied. The material dries at ambient temperature or via forced drying. After a second sanding, a second layer of water-based paint (120 g/m^2) is applied and subsequently dried. Electrostatically assisted spray application of water-based paints is usually used for the coating of chairs due to their geometry. Thus the overspray and, therefore, the amount of paint consumed and the VOC emissions are reduced.

Coating of window frames
Compared with other sectors of the wood industry, the coating of wooden windows is often still carried out manually. As the wood surfaces of windows have to resist weather influences and blue stain infestation, up to four coating layers may be necessary to achieve sufficient resistance. Both the grinding and the drying processes are very demanding with respect to time and work. The use of water-based paints (e.g. acrylate paints) for the coating of windows is considered state-of-the-art, although solvent-based coating systems (e.g. alkyd paints) are also used. Water-based paints show a lower wet adhesion compared to conventional solvent-based paints.

Flooding is a widely used application technique for the coating of pressed frameworks for wood preservation and base coating. Here, the topcoat is applied via spray application in one or two layers in the form of a water-based paint system. Due to the workpiece's geometry, a high amount of overspray is generated even if an electrostatically assisted spraying process is used. To reduce costs and environmental impacts, lacquer recovery installations are utilised. Furthermore, the spraying booths are equipped with a dry overspray separation in order to avoid coagulation or disposal of paint sludge.

Coating of high-quality furniture
The following process steps are carried out for the coating of high-quality furniture:
1. sanding and removal of dust;
2. adaptation of colour, e.g. by staining;
3. sanding and removal of dust;
4. base layer;
5. sanding and removal of dust;
6. top layer.

The second step is mostly achieved by (manual) spraying; steps 4 and 6 are also mostly carried out by spraying. UV-cured paints are rarely used in the coating of high-quality furniture. The main reason is because they can only be applied where flat panels can be coated separately and coating is done before the piece of furniture is assembled. However, if the pieces of the furniture are not yet assembled, it is possible to use UV-based coatings, and hence another type of application besides spraying (mostly by rolling).

At least one German company (Rippert GmbH) and one Finnish company (Tikkurila Coatings Oy) have separately developed a UV curing method, which utilises UV curing under inert atmosphere. With this method, it is possible to cure UV lacquers and UV paints on 3D components and on assembled chairs. Equipment and coatings are commercially available.

For furniture made of solid pieces of wood (whose surfaces are oiled or waxed) destined for kitchens, bedrooms, living rooms and children's rooms, the following processes are generally carried out:
1. the pre-sanded furniture parts are treated with smoothing brushes;
2. after dedusting, the oil is applied onto the wood surface with a spraying machine;
3. subsequently the oiled workpieces are brushed;
4. a hot wax is applied via spraying;
5. the waxed surface is brushed;
6. the workpieces are turned over and processes 1 to 5 above are repeated.

Powder coating of MDF panels

Powder application onto MDF panels for the production of television units and office furniture is carried out without previous priming. The entire plant length for preheating, coating, curing and cooling is significantly shorter than for a conventional plant, as coating takes place in a single working cycle.

Due to the very low electrical conductivity of MDF, the plates are preheated up to 60-70 °C before the powder is applied via corona spray guns. At this temperature, the powder particles adhere to the MDF surface, creating a consolidated coating that is subsequently dried by UV radiation. Grinding processes following the respective drying steps are not required.

Due to the recycling and reuse of powder, significant cost savings can be achieved. However, this application technique is only applicable for certain colourings and surface structures.

Coating of wooden kitchen and bathroom furniture

Kitchen and bathroom furniture is made of solid pieces of wood (e.g. oak, beech, maple, stone pine and cherry) and wood materials (e.g. MDF) and coated. For painting, wet paint systems are used exclusively with a significant proportion of water-dilutable UV paint as well as water- or solvent-based wood stains. At present, solvent-based polyester and PUR paint is only applied in small amounts, partly for the painting of spare parts. Wood stains are applied via automated roller coating heads. Conversion to water-dilutable UV-cured paints for base coats and topcoats was undertaken for environmental, labour protection and technological reasons and in order to reduce the fire hazard. The applied materials have a solvent proportion of 1-2.5 wt-%. The coating is mainly carried out in fully automated installations. The material is applied via compressed air spraying. The overspray is collected (via doctor blades) and reused.

Paint particles of the exhaust air are separated dry. In general, the paint system consists of two layers. The base coat surface can be sanded before the topcoat is applied. Due to the use of water-dilutable UV-cured paints, the quantities of emitted solvents are very low and amount, even in big installations, to less than 10 kg/h. Exhaust gas cleaning with regard to VOCs is therefore not in use. The exhaust air is emitted directly via a stack. Cleaning agents are recycled via distillation.

14.2.7 Finishing with solid coating substances

Solid coating substances are materials which are pressed in the solid state onto panel-like or profiled workpieces. They may be veneers, sheets, papers or laminates.

Veneers
Veneers are thin sheets of wood with a thickness of about 0.5 mm to 2 mm and are applied to the base panels by exposing them to heat and pressure in presses. Standard adhesives are urea-formaldehyde (UF) resins and polyvinyl acetate (PVAC) glues.

Sheets, papers or laminates
These are applied to the base panels using various adhesives by exposing them to heat and pressure using surface presses, membrane presses and roller presses. This process is termed lamination. Standard adhesives are glues composed of ethylene vinyl acetate copolymer (EVA) for decorative papers and sheets, and urea-formaldehyde (UF) adhesive resins and polyvinyl acetate (PVAC) glues for laminates.

Adhesives and glues
PVAC glues contain water, the polyvinyl acetate binders and organic solvents (generally up to 3 % by mass of butyl or ethyl acetate) and the amounts applied are approximately 120 g/m^2. During drying, water and no more than 3.6 g of solvent are emitted per m^2.

UF resins contain urea-formaldehyde resin, possible extenders, catalysts and water. The ‘free formaldehyde’ component of the adhesive is between 0.1 % and 0.5 % by mass, most of which is incorporated during curing. The amounts applied are approximately 100 g/m^2. During curing, water and formaldehyde that has not been incorporated are emitted.

EVA glues contain ethylene vinyl acetate copolymer, water and, in some cases, up to 3 % by mass of organic solvents, generally ethanol and toluene. The amounts applied are approximately 90 g/m^2. During drying, water and, if they are present, up to 2.7 g of organic solvents are emitted per m^2.

14.3 Current consumption and emission levels in the coating of wooden surfaces

[5, DFIU et al. 2002] [155, TWG 2016]

Data were submitted for two plants in the data collection exercise for the coating of wooden surfaces:

- One installation dedicated to flooring production using water-based coatings (decorative printing / offset technique) in combination with UV sealing varnish (eight coating layers). The water-based coating system is dried thermally. Organic solvents are only used for subsequent cleaning of machinery parts / rollers after production and in the case of colour changes. The overall solvent concentration in the coating materials was less than 1 % while 80 % of the total solvent usage was for cleaning purposes [Plant #177 in [155, TWG 2016]].
- A second installation producing kitchen fronts operates two coating lines, one airless spraying line with shape air and electric charging (with an efficiency of 20 %) using unsaturated polyester (UP) paints (60 % solids content) and a second roller coating line with an estimated efficiency of 90 % using UV lacquers (99 % solids content) [Plant #141 in [155, TWG 2016]].

14.3.1 Consumption

14.3.1.1 Materials

Table 14.6 below itemises the quantities of paint materials applied for different application techniques.

Table 14.6: Quantities of paint materials applied in different application techniques

Application technique	Quantity (g/m^2)	Remarks
Rolling	25-60	-
Curtain coating	60-250	In exceptional cases up to 500 g/m^2
Dipping	60-200	-
Flooding	60-200	-
Spraying	Up to 250	Material losses due to low efficiency
Printing	1-2	-
Source: [5, DFIU et al. 2002]		

Table 14.7 below gives examples of the amounts of paint and solvent applied on average in each different production sector.

Table 14.7: Applied paints and amounts of organic solvents: examples of different applications in the wood and furniture industry

Product	Coating process	Amount of paint (g/m²)	Amount of solvent (g/m²)
MDF panels	1. Base coat, water-based, roller application 2. Water-based, roller application 3. Printing ink, water-based 4. AC paint via roller application, UV curing* Drying: convection dryers or UV dryers	80	3
Stairs	1. Parquet seal, water-based 2. Grinding 3. Parquet seal, water-based or solvent-based, spray application of one or two layers 4. Hot spraying Drying: at ambient temperature, convection dryers or infrared drying	180	12
Bedroom furniture	1. Spray application of two layers of pigmented water-based or solvent-based paints, with intermediate sanding 2. Lime paste, spray application 3. Grinding 4. Colourless, water-based paints, spray application Drying: at ambient temperature, tray system dryers	150	9
Doors	1. Base coat, water-based, roller application 2. Wood stain, roller application 3. AC base coat via roller application, UV curing* 4. Grinding 5. Two layers of AC paint via roller application, UV curing* Drying: convection dryers or UV dryers	60	10
Tables	1. Combi-stains, spray application 2. AC base coat via roller application, UV curing (3 layers) 3. Grinding 4. AC paint via roller application, UV curing Drying: at ambient temperature	100	30
Living room furniture	1. Natural oil, hot spraying Drying: at ambient temperature 2. grinding 3. Solvent-based products (for assembled products), UV-based for flat pieces natural wax with hot spraying (infrequent) Drying: infrared-curing 4. Polishing	23 55	0 9

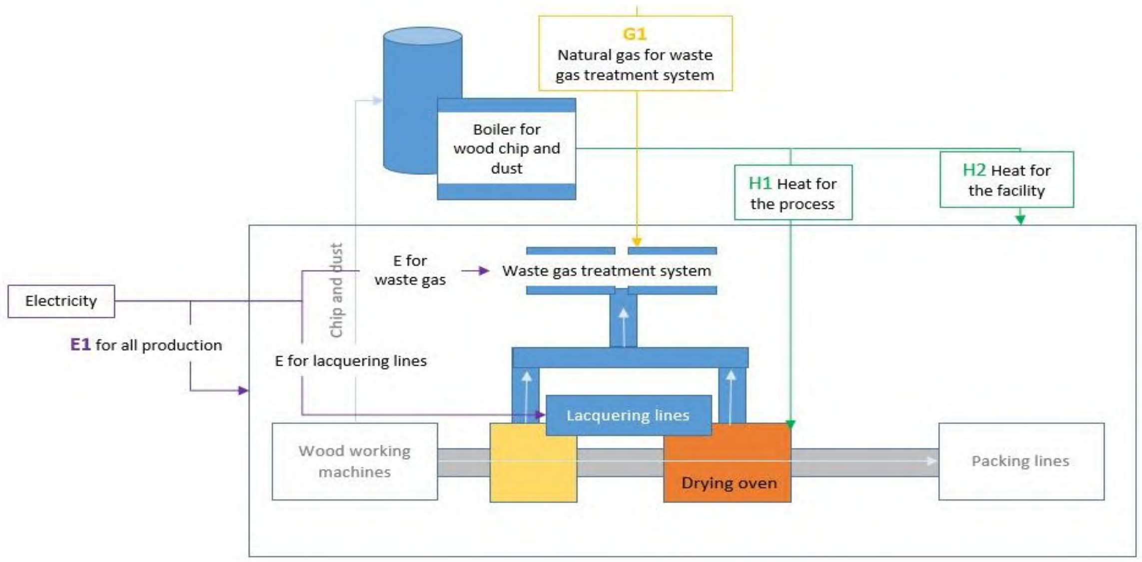
* Solvent-based products are still widely used. In many cases in the furniture industry, UV-cured coatings are used, especially for flat pieces, which are nearly all UV-cured.
Source: [5, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005]

14.3.1.2 Water

No information provided.

14.3.1.3 Energy

The main forms of energy input are electricity for production purposes and natural gas for the needs of the off-gas treatment system. As in the wood machining process there are significant quantities of wood residues remaining (woodchip and sawdust), an interesting option is the use of a dedicated boiler for the exploitation of the energy content of wood residues. The produced heat of the woodchip and dust boiler can be used as heat for the process (drying ovens) or for the facility needs (room heating). A schematic diagram of this system is shown in Figure 14.2 [Plant #141 in [155, TWG 2016]].



Source: Plant #141 in [155, TWG 2016].

Figure 14.2: Schematic diagram of the energy inputs

14.3.2 Emissions

14.3.2.1 Total emissions of VOCs

Total emissions of VOCs were reported in different units for the two plants that participated in the data collection. For the first plant (a polyester lacquering line for the coating of kitchen fronts) (Plant #141), the reported total VOC emissions expressed as a percentage of solvent input was 2.2 % (average for the 3-year reference period 2013-2015). For the second plant (Plant #177), where UV-based coatings are applied, the reported total VOC emissions were 0.04 kg VOCs per kg of solid mass input (average for the 2-year period 2013-2014) [155, TWG 2016].

Table 14.8 summarises specific VOC emission reference values for various painting systems (data from 2005).

Table 14.8: **Specific VOC emissions for various paint systems, some with primary emission reduction measures**

Application technique	Solvent content (wt-%)	Emission reduction measures	VOC emission (g/m^2) (^{1})
Paint system with a high organic solvent proportion and spraying	65	None	80-100
Paint system with a high organic solvent proportion	65	Application techniques with an increased efficiency factor (rolling, flooding, dipping, electrostatically assisted spraying, airless spraying) and good housekeeping	40-60
Paint system with a medium solvent content	20		10-20
Paint system with a low organic solvent content	5		2-5
(^{1}) These figures depend on the amount of material used and the rate of application. The figures given are for usual rates of application and are a guide only. *Source*: [5, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005]			

14.3.2.2 Emissions in waste gases

Data for TVOC emissions in waste gases were reported for both of the installations that participated in the data collection. The first plant (a polyester lacquering line for the coating of kitchen fronts) (Plant #141) reported TOC emission values from the exit of two thermal oxidation abatement systems that vary from 4 mg C/Nm^3 up to 11 mg C/Nm^3 (annual monitoring frequency). At the second plant (Plant #177), continuous TVOC monitoring of waste gases released from dryers, UV lamps (used for the hardening of coatings) and sanding machines was reported with annual average values that vary from 6.5 mg C/Nm^3 to 9 mg C/Nm^3. For the second plant, dust emissions in waste gases were reported in the range of < 0.1 mg/Nm^3 to 0.25 mg/Nm^3 [155, TWG 2016] [221, Germany 2018].

14.3.2.3 Emissions to water

The volume of waste water generated in the coating of wood is generally very small, since the process water circulates in a closed loop. When using water-based coatings, a significant amount of waste water is generated, which, in some cases, exceeds the closed-loop capacity of the spray installation and overflows.

14.3.2.4 Waste generation

[5, DFIU et al. 2002] [78, TWG 2005]

Especially for the coating of profiled, wooden workpieces, the base coat and topcoat are applied by spraying. Thereby, losses via overspray are generated within the spraying booths in one of two waste forms:

- If wet separation is applied, the overspray forms paint sludge. The paint sludge consists of paint particles, small amounts of organic solvents, coagulation agents and water. Paint sludge is generally regarded as a waste that needs monitoring. In general, the material may be used as a fuel in special refuse combustors (combustion system for burning non-hazardous waste).
- If the overspray is separated dry, contaminated glass fibre filter mats have to be disposed of. As soon as a specific minimum velocity of the airflow is reached, the filter mats have to be replaced. The filter mats, now contaminated with dried paint particles, generally do not need monitoring and can be used as a fuel in regular waste incineration plants.

Mixed two-component paints cannot be recycled and are disposed of. The solvents are recovered from non-cured paints. In addition, contaminated solvents are generated by the cleaning of application devices, conveyer systems, paint pipelines, spray booths and others. In general, cleaning agents used in the wood industry are recycled via distillation and can be used as recycled cleaning agents. The distillation generates paint leftovers in solid, liquid or paste-like forms. Contaminated solvent, solids from distillation, dried 2K paint and other residues and leftovers that are not reused are disposed of, usually as hazardous waste.

Hazardous properties of paint sludge from paint overspray have been analysed and, in many cases, there is a lack of overall background data on wastes. Therefore, cooperation between paint or lacquer producers, waste producers, environmental authorities, and waste researchers and laboratories is very important. For example, in one study in Finland, the formaldehyde concentrations were analysed based on information received from the producers of paints and lacquers. This provided the essential information for overall assessment of the chemical and ecotoxicological hazard of the residues studied. The results confirmed the benefit of combining chemical and ecotoxicological assays in assessing the potential environmental hazard of complex organic mixtures found in paint residue wastes. The pretreatment studies showed that the amount of residues could be minimised by reducing the liquid content of water-curtain-booth residues, and the hazard was decreased by changing the raw materials in the spray-painting process to paints and lacquers that contain less harmful solvents. The results also proved that landfilling is not a suitable method of disposal for the paint residues produced in the furniture industry. For these types of organic wastes, a better alternative method of treatment could be incineration. The information on the ecotoxicological and leaching properties of excess paint residues produced in different spray-painting processes helped paint producers to develop their products and makes it possible for furniture producers to choose environmentally safer products. Furthermore, this hazard-screening approach will help furniture producers to improve the surface paint process of furniture-making in order to minimise the amount and hazardousness of the wastes produced.

14.4 Techniques to consider in the determination of BAT for the coating of wooden surfaces

In Chapter 17, techniques are discussed which might also be applicable to the coating of wooden surfaces. In Table 14.9, the general techniques relevant for the coating of wooden surfaces that are described in Chapter 17 are shown. These techniques are not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 17.1.

The EGTEI background document for the coating of wooden surfaces (see Annex 21.3.1) gives some data on the costs and benefits at the European level of some techniques to reduce VOC emissions. However, the EGTEI approach necessarily has to limit its complexity, and only key techniques are given without consideration of the other BAT factors, such as cross-media effects, or of the technical characteristics of individual installations or products [89, EGTEI 2005].

Table 14.9: Reference to techniques generally applicable to the sector

Technique	Section number
Environmental management techniques	17.1
Storage and handling of raw materials	17.2
Monitoring	17.3
Water use and waste water generation	17.4
Energy management and energy efficiency	17.5
Raw material management (including substitution)	17.6
Coating processes and equipment	17.7
Drying and/or curing techniques	17.8
Cleaning techniques	17.9
Off-gas extraction and treatment	17.10
Waste water treatment techniques	17.11
Waste management techniques	17.12
Odour emissions	17.13

14.4.1 Minimisation of raw material consumption

14.4.1.1 Batch painting/colour grouping

A general description of the technique is given in Section 17.6.2.1.

Example plants
Plant #141 in [155, TWG 2016].

14.4.1.2 Pig cleaning systems

For a general description, see Section 17.2.4.2. In the furniture industry, there is an increasing demand for furniture to be painted in individual and special colours and, consequently, the use of pig cleaning systems.

Reference literature
[5, DFIU et al. 2002]

14.4.1.3 Online mixing system for two-component products

For a general description, see Section 17.2.4.1. This technique is commonly applied.

Reference literature

[5, DFIU et al. 2002] [27, VITO 2003]

14.4.2 Material-based techniques (substitution)

14.4.2.1 Water-based coatings, paints, varnishes and adhesives

Description

For a general description, see Section 17.7.2.2. The following water-based coating systems are applied:

- wood stain: 0 % organic solvent;
- wood stain: 25-30 % organic solvent;
- base coat and topcoat: 5-7 % organic solvent; conventional drying system.

Water-based UV-cured paints (about 2 % organic solvent) and two-component paints based on polyurethane (about 9 % organic solvent) are also applied.

Achieved environmental benefits

Significant VOC reductions.

Cross-media effects

Extra sanding and polishing is often necessary to get a smooth surface after each painting step. This produces more waste and more raw materials are consumed.

Technical considerations relevant to applicability

The application of water-based paints depend on the product used, the surface, the base coat layer (primer), the application method, the desired end quality, the availability of high-quality products and the product segment the company is aiming at. Currently, the availability of high-quality coatings is not sufficient.

Two-component paints are widely applied in painting, e.g. for durable surfaces such as floor coverings and kitchen fronts.

Economics

The following investments may be necessary:

- forced drying (usually the largest investment);
- additional area needed for the dryer as well as the larger intermediate storage for painted workpieces, in between repeated operation cycles;
- stainless steel equipment for paint storage, tool manipulation equipment, etc. whereas standard steel grades can be used for solvent-based paints.

Reference literature

[5, DFIU et al. 2002] [27, VITO 2003] [96, Presti 2005]

14.4.2.2 Powder coating – conventionally dried

Description
For a general description, see Section 17.7.2.6. Powder coatings with conventional convection drying are applied to MDF and HDF (medium- and high-density fibreboard). They are currently not suitable for the painting of wood, because of the high temperatures needed for drying and the low surface quality achieved.

Achieved environmental benefits
See Section 17.7.2.6.

Cross-media effect
See Section 17.7.2.6.

Environmental performance and operational data
The powder application onto MDF panels for the production of television and office furniture is carried out without previous priming. The entire length of plant needed for preheating, coating, curing and cooling is significantly shorter than that needed for a conventional plant: coating takes place in a single working cycle. Sanding processes after drying steps do not apply.

Due to the very low electrical conductivity of MDF, the plates are preheated up to 60-70 °C before the powder is applied via electrostatically assisted spray guns. At this temperature, the powder particles adhere to the MDF surface, creating a paint layer which is consolidated and subsequently dried by UV radiation.

Low-temperature powder coatings, suitable for wooden substrates in general, are applied in Sweden and the UK for example.

The reuse of overspray is not possible in short production runs and for frequent colour changes, which often occur in furniture manufacturing.

Technical considerations relevant to applicability
Only used for MDF and for low-quality parts. Not suitable for coating of solid wood or coating with veneers.

Economics
Due to the recycling and reuse of powder, significant cost savings can be achieved.

Example plants
Stilexo Industrial, UK.

Reference literature
[5, DFIU et al. 2002] [27, VITO 2003] [78, TWG 2005]

14.4.2.3 UV-radiation-cured coatings, paints, varnishes and adhesives

Description
For a general description, see Section 17.7.2.3.

Achieved environmental benefits
Water-based and solvent-free radiation-cured paints do not generate VOC emissions.

Cross-media effects
None.

Environmental performance and operational data
UV-cured paints can be applied by several different techniques, such as brushing, rolling, casting, spraying and vacuum coating.

Technical considerations relevant to applicability
UV-cured water-based coatings are increasingly applied in furniture and wood painting. UV-cured water-based paints are commonly applied in the coating of chairs, box-like furniture, office and kitchen furniture, room doors, panels, chipboard for living and bedroom furniture, etc. These paints can be applied for all paint layers. UV-cured products are possible where flat panels can be coated separately and coating is done before assembling the piece of furniture. There can be some application of UV-cured coatings in the section of joinery and finishing panels. The use of infrared curing products is less known.

At least one German company and one Finnish company have separately developed a UV curing method, which utilises UV curing under inert atmosphere. With this method, it is possible to cure UV lacquers and UV paints on 3D components such as assembled chairs. Equipment and coatings are commercially available.

Example plants
Plant #144 in [155, TWG 2016].
For 3D coatings: Rippert GmbH, Germany, and Tikkurila Coatings Oy, Finland.

Reference literature
[5, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005] [155, TWG 2016]
For coating in 3D: RadTech 2005 conference proceedings, www.tikkurila.fi.

14.4.3 Paint application techniques and equipment

14.4.3.1 Roller coating

Description
For a general description, see Section 17.7.3.1.

Achieved environmental benefits
Depending on the workpiece and the processing conditions, application efficiencies of about 90-100 % can be achieved. Material savings of up to 40 % can also be achieved.

Environmental performance and operational data
In most cases, normal roller coating is used, with good results, including on closed-cell surfaces.

In 2002, an increasing demand was seen for coatings for closed-cell substrates such as beech, maple, pear, birch and cherry woods. For the best-quality veneer, this had previously only been possible with conventional rolling or spray applications. However, the use of heated smoothing rollers for the application of base coat shows significant advantages. It enables the filling and smoothing of porous surfaces without the application of excess material. Furthermore, cracks in the surface of the veneer and joint connections, raw chipboards, MDF panels and other wood material panels can be filled. Thus, a smoother surface is created and the wood obtains a filled and smooth appearance.

These advantages are caused by the opposite rotating heated smoothing rollers that process the UV paint applied onto the workpiece surfaces via the application roller. In this way, the paint is worked into the workpiece's surface. Pores, veneer cracks and splices are also filled this way. The heating of the smoothing roller ensures that the cohesion within the paint layer is reduced, so that the material remains in the filled pores. Additionally, the paint material shows better running properties and forms a plain, even surface.

Technical considerations relevant to applicability
In general, rolling techniques are in use for the application of water-dilutable paints and UV radiation curing paints. They are mainly applicable to flat workpieces, but slightly curved products such as wooden panels can also be processed. Application weights from 25 g/m^2 to

60 g/m^2 can be processed, depending on the machine type. Reverse coaters are only applicable for flat workpieces and, therefore, mainly used for plates derived from wood products. For more curved surfaces, stoppers are applied by hand-operated equipment such as palette knives.

Economics

A lightweight filling machine used in wood and furniture coating, with a working width of 1.3 metres and an installed electrical load of 5.5 kW cost EUR 55 000 in 2000. A machine used in wood and furniture coating with, for example, a foam roller, a working width of 1.3 metres and an electrical load of 3 kW cost about EUR 30 000 in 2005. And, also in 2005, a machine applying two rollers (double system) with the same working width and an electrical load of 6 kW cost EUR 60 000.

Example plants

Plant #141 in [155, TWG 2016].

Reference literature

[5, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005] [155, TWG 2016]

14.4.3.2 Curtain coating (casting)

Description

For a general description, see Section 17.7.3.4. Curtain coating (casting) is commonly applied for coating doors, wall units and other plates. Mostly solvent-free lacquers based on polyester are applied, but other types of coating materials can also be processed. Curtain coating can achieve a high uniformity in the layer thickness.

Achieved environmental benefits

Depending on the workpiece and the processing conditions, material efficiencies of about 90-98 % can be achieved.

Environmental performance and operational data

In comparison to rolling, the wooden workpieces do not have to be absolutely plain. Within a curtain coater, the paint material used is pumped into a header tank from where the coating is discharged in the form of a fine lamina film. The workpieces that need to be coated are sent through this film. Excess paint material is collected in a reservoir and pumped back into the header tank. An efficiency of approximately 95 % is achieved. All types of paint materials can be applied by this technique.

Technical considerations relevant to applicability

In the casting process, plain or almost plain workpieces are coated. According to the machine type, application weights from 60 g/m^2 to 250 g/m^2 can be processed.

Economics

A casting installation applied in wood and furniture coating with a working width of 1.3 metres and an installed electrical load of 3 kW cost EUR 35 000 in 2000.

Reference literature

[5, DFIU et al. 2002] [27, VITO 2003] [78, TWG 2005]

14.4.3.3 Flooding

Description
For a general description, see Section 0.

Achieved environmental benefits
Depending on the workpiece and the processing conditions, efficiencies of 95-99 % can be achieved. In comparison to the dipping application, the evaporation losses are higher.

Environmental performance and operational data
In flood-coating installations, the workpieces are transported via conveyor systems into closed channels. There, the workpieces are flooded with the paint material via injection tubes. The surplus paint material is absorbed at the bottom of the channel and reused.

Application weights from 60 g/m^2 to 200 g/m^2 can be processed.

Technical considerations relevant to applicability
The process is especially suitable for wooden workpieces that tend to float. It is applicable for serial production and large workpieces with a large surface area, without a lot of colour changes.

Reference literature
[5, DFIU et al. 2002]

14.4.3.4 High-volume low-pressure (HVLP) atomisation

See Section 17.7.3.10. This is commonly applied for low-viscosity wood stains and increasingly for other paint systems [5, DFIU et al. 2002].

14.4.3.5 Electrostatically assisted air or airless spraying

Description
In this technique, the paint is atomised in an electric field, see Section 17.7.3.12. Electrostatically assisted spray applications can be utilised if more electrically conductive materials, such as solid wood for the production of windows, chairs and pad racks are processed. This technique is also suitable for the application of powder coatings.

Environmental performance and operational data
When powder coatings are applied, due to the very low electrical conductivity of MDF, the plates are preheated up to 60-70 °C before the powder is applied by electrostatically assisted spraying. At this temperature, the powder particles adhere to the MDF surface, creating a paint layer which is consolidated and subsequently dried by UV radiation.

Technical considerations relevant to applicability
The Faraday cage effect makes it impossible for the paint particles to reach cavities. The moisture content of the wood needs to be at least 10 % to achieve sufficient conductivity of the workpiece.

Example plants
Plant #141 (airless spraying with shaping air and electric charging) in [155, TWG 2016].

Reference literature
[5, DFIU et al. 2002] [96, Presti 2005] [155, TWG 2016] [212, TWG 2018]

14.4.4 Spray booths

14.4.4.1 Wet separation spray booth

Description
See Section 17.10.4.1. This is a spray booth of stainless steel equipped with a water spray at the back and possibly sides, to abate the overspray. These are commonly applied and equipped with cascades, or the water is circulated with air flotation and with paint recycling.

Economics
Purchasing costs for a wet separation spray booth with a capacity of 13 kW and 7 000 m^3/h air output were reportedly EUR 150 000 in 2002.

Reference literature
[5, DFIU et al. 2002] [27, VITO 2003]

14.4.5 Drying/curing

14.4.5.1 Convection drying/curing

For a general description, see Section 17.8.6.

Example plants
Plant #141 in [155, TWG 2016].

14.4.5.2 Microwave drying/curing

Description
For a general description, see Section 17.8.3.

Technical considerations relevant to applicability
A microwave dryer is not suitable for thick workpieces (> 20 cm). This technique is not commonly used in Europe.

Economics
The costs for an installation (without the connection, etc.) are between EUR 55 000 and EUR 100 000 (12 kW) (2006 data).

Example plants
One experimental installation in Norway. The energy consumption is estimated to be 10-30 % higher than traditional techniques (IR, hot air).

Reference literature
[5, DFIU et al. 2002] [38, TWG 2004] [95, CEI-BOIS 2006] [96, Presti 2005]

14.4.5.3 High-frequency (HF) drying/curing

For a general description, see Section 17.8.3. Due to the fast evaporation of water, the napping of wood fibres and the amount of dust arising are significantly reduced. Finishing panels is done with UV-cured products, which requires other types of dryers.

Reference literature
[5, DFIU et al. 2002] [38, TWG 2004]

14.4.5.4 Infrared radiation drying/curing

For a general description, see Section 17.8.5.1. This technique is applied in combination with circulating air dryers. Infrared radiation may alter the wood.

Example plants
Plant #141 (for polyester paint) in [155, TWG 2016].

Reference literature
[5, DFIU et al. 2002] [38, TWG 2004] [155, TWG 2016]

14.4.5.5 Near-infrared radiation (NIR) curing

For a general description, see Section 17.8.5.1. This technique is commonly applied because it is very suitable for heat-sensitive materials such as wood due to very short (1-5 seconds) curing times. Powder coatings are usually cured by applying NIR curing and also water-based paints on wood. Regarding the coating of wood, the NIR technique achieves the shortest drying and cycle times [5, DFIU et al. 2002].

14.4.5.6 Ultraviolet (UV) curing

For a general description, see Section 17.8.5.4. This technique is widely applied for the drying of painted furniture, especially of flat parts. Wooden or plastic substrates can show a yellowing and may become brittle. A technique also exists commercially to cure UV coatings in 3D, see Section 14.4.2.3 [5, DFIU et al. 2002] [27, VITO 2003].

Example plants
Plants #177 (for UV coatings) and #141 (for UV lacquers) in [155, TWG 2016].

14.4.5.7 Electron beam curing (EB)

For a general description, see Section 17.8.5.5. This technique requires a special, solvent-free coating substance. Due to high investment costs, this technique is currently only applied for large surface throughputs.

Reference literature
[5, DFIU et al. 2002] [57, VDI 2005]

14.4.5.8 Combined convection and IR radiation drying/curing

For a general description, see Section 17.8.4. The technique is applied in the coating of wooden surfaces. The coated substrate should be heat-resistant.

Reference literature
[5, DFIU et al. 2002] [38, TWG 2004]

14.4.6 Off-gas treatment

14.4.6.1 Dry overspray separation

For a general description, see Section 17.10.4.4. Paint stop filters and paper filters are commonly used in the wood and furniture industry. Dust emission values of 3 mg/m^3 or less are generally achieved using this technique. Reported dust emission levels for one plant in Germany are lower than 0.25 mg/Nm^3 (see also Section 14.3.2.2).

Reference literature
[27, VITO 2003] [137, CEI-BOIS 2006] [155, TWG 2016]

14.4.6.2 Electrostatic filter (precipitator)

For a general description, see Section 17.10.4.5. The technique is applied for spray booths. However, no information was made available on how the waste water and waste gas are treated. This technique is sometimes considered not economical for the sector.

Reference literature
[5, DFIU et al. 2002] [38, TWG 2004]

14.4.6.3 Wet scrubbing

For a general description, see Section 17.10.4.2. The technique is applied for spray booths. However, no information was made available on how the waste water and off-gas are treated. No relevant data on achieved emission levels were reported.

Reference literature
[5, DFIU et al. 2002] [27, VITO 2003] [38, TWG 2004] [137, CEI-BOIS 2006]

14.4.6.4 Biological treatment

For a general description, see Section 17.10.7. In Germany, only one plant is equipped with a biofiltration system for the reduction of odour [5, DFIU et al. 2002].

14.4.6.5 Thermal oxidation

For a general description, see Section 17.10.5.2.

This technique may be considered not economically viable when VOC concentrations are low and/or the gas flows are high, because of the high investment and operational costs (additional heat input, electricity consumption of fans). Many wood-based companies work discontinuously and in single- or double-shift operations. This makes steady conditions hard to achieve, as the thermal inertia after cooling down reduces thermal efficiency, and some installations have complex process control equipment that needs time to stabilise after start-up or adjustment. Moreover, VOC loads in exhaust gas flows might be irregular during a shift.

However, it may be considered when there is no alternative to using high-solvent coatings. Simple thermal oxidation is well-suited to intermittent use and flows < 2 000 m^3/h, although varying VOC loads may be a problem (see Annex 21.6) [5, DFIU et al. 2002] [96, Presti 2005].

The technique was reported by one plant in the data collection for the treatment of off-gases from spray booths and drying ovens [155, TWG 2016].

Reference literature
[5, DFIU et al. 2002] [96, Presti 2005] [155, TWG 2016]

14.4.7 Waste water treatment

14.4.7.1 Waste water treatment for wet separation spray booths

See Section 17.10.4.1 for the description of the wet separation spray booth.
Section 17.11 describes waste water treatment options.

14.4.7.2 Ultra and nanofiltration

For a general description, see Section 17.11.4.3. Wet separation spray booths are applied and are equipped with an ultrafiltration unit to separate and recover the paint material. This technique is sometimes considered not economical for the sector.

Reference literature
[5, DFIU et al. 2002] [38, TWG 2004]

14.4.8 Waste treatment

14.4.8.1 Recovery of used solvents by applying distillation

For a general description, see Section 17.12.3.1.2. Recovery of cleaning agents is commonly applied, e.g. in the coating of wooden kitchen and bathroom furniture.

Reference literature
[1, INTERGRAF and EGF 1999] [5, DFIU et al. 2002] [26, CITEPA 2003]
[6, DFIU et al. 2002]

15 PRESERVATION OF WOOD AND WOOD PRODUCTS WITH CHEMICALS

15.1 General information on preservation of wood and wood products with chemicals

Many wood species have heartwood with insufficient or no natural resistance to wood-destroying organisms. Heartwood with insufficient or no natural resistance will decay (attacked by wood-destroying fungi) when it becomes and remains wet. It will be attacked by wood-destroying beetles and termites in many end uses. Wood in the sea is susceptible to damage by marine animals and fungi. The sapwood of all species is susceptible to attack by all wood-destroying organisms and by staining fungi. Where the natural protective constituents are insufficient or totally absent, wood and wood products are treated with preservatives to protect them from the damaging effects of fungi, bacteria, insects, water, weather or fire; providing long-term conservation of structural integrity and improving the resistance.

Wood or wood products treated with wood preservatives can be found, for example, in the building and construction sector (wood lattices, bridges, alpine cabins or chalets, etc.), in gardening and landscaping (fences, arches, etc.), as well as in agriculture (poles for fruit and wine growing), toys and playground equipment, avalanche and noise barriers, railway sleepers and telegraph poles. Depending on where the wood is used, use classes in a range of 0 to 5 are defined. For use classes 1 to 4, there is an increasing risk of wood becoming and remaining wet and a concomitant increase in risk of fungal decay.

Wood preservation can take place in specialised companies, as a part of the production in sawmills (where sawmills offer not only sawn timber, but also treated timber) or in other wood-processing industries, e.g. window and door production.

In Europe, it is claimed that there are approximately 250 installations with a production capacity of more than 75 m^3 per day [148, COM 2009]. However, accurate figures on the size distribution, production, employment or trade balance of the sector in the EU are lacking. The results of a data gathering exercise conducted in preparation for a potential review of the IPPC Directive (‘*Data gathering and impact assessment for a possible technical review of the IPPC Directive – Part 2*’, *Fact sheet B5 Wood preservation, September 2007)* are given in Table 15.1 below.

Table 15.1: Results from a questionnaire concerning the number and size of installations for the preservation of wood

Country	Total number	< 50 m^3/day	50-100 m^3/day	> 100 m^3/day
Austria	3 (1)	NI	NI	NI
Czech Republic	55	53	1	1
Hungary	7	NI	NI	NI
Latvia	17	12	2	3
Total	82	65	3	4

(1) Installations for wood preservation exceeding a consumption of 25 tonnes organic solvent per year.
NB:
NI: No information provided.
Source: [228, IEEP et al. 2007]

From a questionnaire that was sent to 10 international suppliers of wood preservation agents, only one response (supplier of creosote) was returned. The results are given in Table 15.2. However, this provides only a very incomplete picture. The information only refers to installations using creosote in some western European Member States. Of these installations, 60 % treat less than 50 m^3 of wood per day. No additional information was obtained from the installations using water-based preservatives or light organic solvent preservatives or on the situation in other parts of Europe.

Table 15.2: Estimation of number and size of installations for wood preservation in the EU from one supplier of creosote

Country	Total number	< 50 m^3/day	50-100 m^3/day	> 100 m^3/day
Austria	1	0	0	1
Belgium	2	1	1	0
France	1	0	1	0
Germany	7	6	1	0
Ireland	1	0	0	1
Netherlands	1	1	0	0
UK	4	3	0	1
Total	17	11	3	3

NB:
NI: No information provided.
Source: [228, IEEP et al. 2007]

From analysis of reports on the implementation of the Solvent Emissions Directive (SED) submitted by the Member States, Table 15.3 was derived. This table is incomplete in that it represents only those installations that impregnate wood with an annual solvent consumption equal to or greater than 25 t.

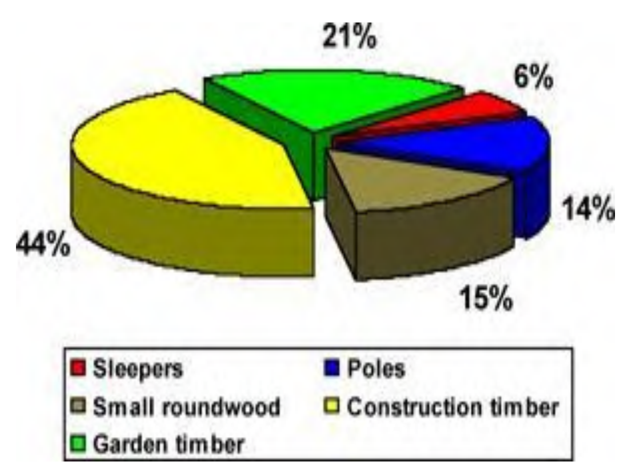
Table 15.3: Existing installations for wood impregnation encompassed by Article 2(2) of the SED, 2003-2004

Country	**Number of installations**
Austria	3
Belgium	1
Denmark	3
Finland	0
France	648
Germany	10
Greece	4
Ireland	72
Italy	NI
Luxembourg	0
Netherlands	0
Portugal	0
Spain	4
Sweden	NI
UK	17
Total	**762**

NB:
NI: No information provided.
Source: [228, IEEP et al. 2007]

Pressure-treated wood

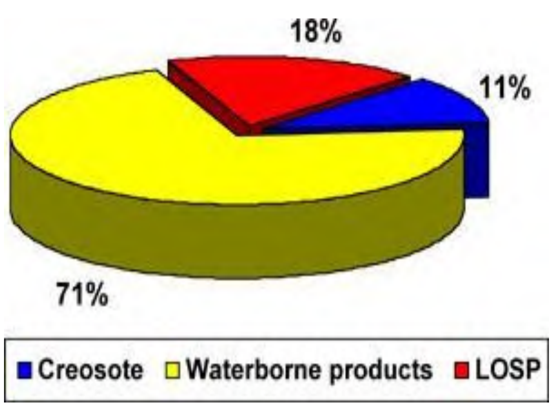
Europe's wood preservation industry supplies around 6.5 million m^3 of pressure-treated wood per year for woodworking, construction, landscaping, leisure wood, agriculture, marine, railway, telecommunications, electricity generation and distribution applications. As shown in Figure 15.1, 44 % of the production (of pressure-treated wood) is used as construction timber, 21 % as garden timber, 15 % as small roundwood, 14 % as poles and 6 % as sleepers [229, WEI 2017].



Source: [229, WEI 2017]

Figure 15.1: European wood preservation industry production categorised by types of product

In total, 71 % of the wood is treated with water-based preservatives, 11 % with creosote, mainly poles and sleepers, and 18 % with solvent-based preservatives, mainly construction timber such as window and door joinery (see Figure 15.2). Creosote impregnation is generally declining due to regulations on creosote use and because of new non-wooden products, e.g. the use of concrete sleepers for new railway lines. In the case of poles, however, an increased use of creosote in impregnation has been reported in Europe. A significant share of this is exported to countries outside the EU [229, WEI 2017].



NB:
LOSP: Light organic solvent preservatives.
Source: [229, WEI 2017]

Figure 15.2: European wood preservation industry production categorised by preservative type

Only limited information was submitted on the total number of plants and the number of IED plants in the EU. The data submitted often lack information on the preservative type used (water-based, solvent-based or creosote) and/or refer to estimates. Only a few Member States submitted information (statistics) on their wood preservation industry [229, WEI 2017].

Table 15.4 provides an overview of the information available on the wood preservation industry in the EU Member States.

Table 15.4: Number of WPC plants (total) and of WPC plants with a production capacity > 75 m^3 per preservative type reported by EU Member States (status 5/2017)

Member State	No of WPC plants / IED plants (1)	Water-based preservatives (WB)	Solvent-based preservatives (SB)	Creosote (C)	Mixed WB-C	Mixed SB-C	Mixed WB-SB
		No of WB plants / IED plants	No of SB plants / IED plants	No of C plants / IED plants	No of WB-C plants / IED plants	No of SB-C plants / IED plants	No of WB–SB plants / IED plants
Austria	NI / 0	NI / 0	NI / 0	NI / 0	NI	NI	NI
Belgium (2)	9 / 8	4 / 3	1 / 1	1 / 1	1 / 1	2 / 1	NI
Bulgaria	NI	NI	NI	NI	NI	NI	NI
Croatia	NI	NI	NI	NI	NI	NI	NI
Cyprus	NI	NI	NI	NI	NI	NI	NI
Czech Republic	NI	NI	NI	NI	NI	NI	NI
Denmark	NI / 2	NI / 2	0	0	NI	NI	NI
Estonia	NI	NI	NI	NI	NI	NI	NI
Finland	21 / 7-11*	18 / 4-8	NI	1 / 1	2 / 2	NI	NI
France	NI / identified 36 (60-100*)	NI / 30* (others)	NI / 30* (others)	NI / 6*	NI	NI	NI
Germany	NI / 0-25*	60-120 / 0-25	0	2 / 0	3/0	0/0	0/0
Greece	NI	NI	NI	NI / 1	NI	NI	NI
Hungary	NI	NI	NI	NI	NI	NI	NI
Ireland	20 / 8	NI	1 / 1	NI	NI	1 / 1	NI
Italy	NI / 2	NI / 2	NI	NI	NI	NI	NI
Latvia	NI	NI	NI	NI	NI	NI	NI
Lithuania	NI	NI	NI	NI	NI	NI	NI
Luxembourg	NI	NI	NI	NI	NI	NI	NI
Malta	NI	NI	NI	NI	NI	NI	NI
Netherlands	2 / NI	NI	0	2 / NI	NI	NI	NI
Poland	NI	NI	NI	/	NI	NI	NI
Portugal	NI	NI	NI	NI	NI	NI	NI
Romania	NI	NI	NI	NI	NI	NI	NI
Slovakia	NI	NI	NI	NI	NI	NI	NI
Slovenia	NI	NI	NI	NI	NI	NI	NI
Spain	NI	68 / 0	78 / 0	3 / 0	NI	NI	NI
Sweden	70* / 29*	NI / 25*	NI / 1*	0* / 0*	0* / 2*	0* / 0*	NI / 1*
United Kingdom	NI	NI / 160*	NI / 35*	NI / 5*	NI	NI	NI

(1) IED plants refers to plants exceeding the threshold of IED Annex I, 6.10, i.e. plants with a production capacity of > 75 m^3 wood per day. (No information was submitted on WPC plants being IED plants due to exceeding the relevant thresholds of IED Annex I, 6.7 (solvent consumption capacity of > 150 kg/h or 200 t/yr).)

(2) One IED plant (> 75 m^3) reported with an unknown preservative type.

* Estimate.

NB:

NI: No information provided.

Source: [161, TWG 2015] [212, TWG 2018]

Environmental impacts

The environmental issues related to the preservation of wood with chemicals are strongly linked to the chemicals that are used to impregnate the wood. The preservatives used are water-based, tar-oil-based (creosote) or solvent-based preservatives. Impregnation of wood potentially causes emissions to air, releases of hazardous substances to water, and risks of soil/groundwater contamination. In addition, energy aspects and waste generation are issues to consider.

Emissions in waste gases

The main emission in waste gases is caused by the solvent content of the solvent-based and creosote preservatives (volatile organic compounds (VOCs)). Aerosols and vapours may be emitted during loading, storage, handling, and mixing processes involving organic solvents and organic-solvent-containing materials, as well as during preservative solution handling.

Emissions in waste gases are generally discontinuous which is a result of the batch processes carried out at WPC plants. A major source of aerosol emissions from the (pressure) preservation process may be when the vessel door is opened after the treatment cycle. During treatment, additional vapour emissions may occur from the treatment tank during the initial vacuum stage, the flooding under vacuum, pressure relief and blowback, and the final vacuum. The majority of the diffuse emissions occur during the drying stages, as the wood treated with solvent-based agents or creosote still emits VOCs to air for some time.

Cleaning operations using organic-solvent-based cleaning fluids and handling and storage of waste organic solvents and organic-solvent-contaminated wastes can also give rise to VOC emissions.

Due to the composition of the preservative, PAH (including benzo(a)pyrene) emissions to air and odour are issues for creosote plants. The use of water-based preservatives may cause emissions to air, such as ammonia (if present in the preservative used).

Traffic on site and combustion processes used to produce heat or steam may result in emissions to air (CO, CO_2, NO_X, SO_2 and dust). In cases where thermal oxidation of VOC-containing off-gases is applied as the end-of-pipe treatment, this contributes to the emissions to air.

Emissions to water

The use of hazardous chemicals as wood preservatives implies the risk of emitting these substances to water. Drips and spills from any area where wood preservatives are being delivered, stored, mixed, handled or applied and from freshly treated wood might get mixed with precipitation water and lead to contaminated surface run-off water. The contamination depends on the chemicals used and their composition. Substances that might be emitted from wood preservation include: copper salts, ammonia, organic biocides, creosote (which consists of substances such as toluene, xylene and polycyclic aromatic compounds) [WEI/EWPM comment #64 in [212, TWG 2018]].

Impregnation processes using water-based salt or emulsion concentrates are basically waste-water-free processes. Secondary containment and recirculation systems are used to prevent condensates and cooling water from the impregnation plant or surface water contaminated with aqueous preservatives from entering the soil, the groundwater or adjacent watercourses. The water collected or retained can be returned to the production process (closed circuit).

In pressure treatment plants using impregnating oils (creosote), waste water streams are generated in the form of condensates during depressurisation of the treatment vessel and during the vacuum periods. The condensates are collected, allowed to settle and treated in an activated carbon filter. The treated water is either reused (closed circuit) or discharged into the public sewer system [230, VDI 2014] [231, Germany 2013].

Condensates from steaming and drying processes, unless they are recirculated to the process, may lead to waste water emissions.

Odour

Odour emissions are mainly associated with creosote plants due to the naphthalene content of creosote. In water-based impregnation, sometimes the use of ammonia agents can cause some odour impacts on the environment.

Pollution of soil and groundwater

As for the potential emissions to water, areas for chemical delivery, storage, mixing, handling, application and storage of freshly treated wood run the risk of soil and groundwater pollution if spills and drips occur and are not properly collected. Prevention of leaks and accidental spills is considered a major issue for the WPC sector.

Waste

Wood impregnation plants may produce relatively small amounts of various non-hazardous and hazardous wastes. Non-hazardous wastes include untreated wood waste and uncontaminated packaging. Hazardous wastes may include out-of-date and contaminated chemicals, redundant preservative solution, chemical packaging, contaminated wiping materials, sawdust or other materials used to soak up spills, absorbent, sludge and debris from tanks and process equipment, etc.

Energy

The most energy-consuming process is the impregnation under pressure (pressure/vacuum pumps) and the heating of creosote.

Noise

Some noise may arise from wood preservation activities, mainly related to traffic and loading/unloading activities or the mechanical processing of wood. Blowing into silos from road tankers can create disturbances such as pump noise, and resonation in pipework.

15.2 Applied processes and techniques in preservation of wood and wood products with chemicals

15.2.1 Overview

The treatment processes for wood and wood products can be categorised by the type of preservative application process (non-pressure or pressure process) and/or by the type of preservative used (water-based or solvent-based preservatives or creosote).

Non-pressure processes comprise immersion processes (trough impregnation (dipping) and hot-cold baths) and superficial treatments (such as brushing, spraying, deluging and brief dipping (timed immersion)).

Pressure processes comprise a variety of processes based on autoclave treatment, differing mainly in the sequence and number of high-pressure and low-pressure / vacuum steps applied during the impregnation process. The processes currently employed in commercial practice are as follows:

- High-pressure:
  - full-cell impregnation process/vacuum-pressure process (Bethell process);
  - alternating pressure process (Henriksson process);
  - modified alternating pressure process ('Hamburger process');
  - Rueping process;
  - double Rueping process.

- Low-pressure:
  - double vacuum process;
  - modified Lowry process.

Wood preservation with water-based preservatives (WB)
The water-based wood preservatives include boron salts (inorganic boron), quat salts (quaternary ammonium compounds), quat-boron formulations (with boron, and quaternary ammonium compounds), chromium-free copper formulations (Cu-boron, and Cu-HDO formulations, Cu, boron and triazole compounds, Cu-quat) and formulations containing combinations of organic substances (for example, triazoles, pyrethroids carbamate) [231, Germany 2013].

Copper-organic preservatives are generally suitable for use classes 1 to 4 and are applied by high-pressure processes. They are suitable for situations where timber is exposed to a high risk of biological attack, e.g. fencing, path edge boards, timber embedded in masonry. The treatment will cause timber to swell, raise the grain and may cause some distortion [232, WPA 2012].

Organic preservatives are suitable for use class 3 (uncoated and coated), ideally for external landscape and cladding timbers, but can also be used in use classes 1 and 2. They are applied by high-pressure processes. The treatment will cause timber to swell, raise the grain and may cause some distortion [232, WPA 2012].

Microemulsions (water-based) are generally restricted to use classes 1, 2 and 3 (coated), and ideally suited for internal construction timbers. They are normally applied by low-pressure (double vacuum) processes. Although water-based, the treatment has little effect on the dimensions of timber but may raise the grain. They can be used on joinery items where surface appearance is not of prime importance. Where applied by high pressure, the treatment will cause the timber to swell, will raise the grain and may cause some distortion [232, WPA 2012].

Water-based copper chromium arsenic (CCA) products were used as preservatives in the past. Since 2006 CCA is no longer authorised for use in the EU as a biocide (according to Directive

98/8/EC) [148, COM 2009]. Also, pentachlorophenol (PCP) - which was used as a preservative – was banned under the Stockholm Convention on Persistent Organic Pollutants (2015 amendment).

Wood preservation with solvent-based preservatives (SB)
Solvent-based preservatives refer to preservative solutions where the active ingredients are carried by organic solvents (also commonly known as light organic solvent preservatives (LOSP)). They are generally restricted to use classes 1, 2 and 3 (coated) and applied by low-pressure processes. Their main advantage is that they do not change the dimensions of timber or raise its grain, thus making them particularly suitable for joinery components [232, WPA 2012].

Wood preservation with creosote (oil-based) preservatives (C)
Creosote is a complex mixture of coal tar derivatives. It is a mixture of hundreds of distinct chemicals rather than one specific chemical. Owing to its classification as carcinogen, the use of creosote in wood preservation is restricted to professional use only and to specific outdoor uses. Creosote is suitable for timbers to be used externally, above and below ground and in contact with water (use classes 3 (uncoated), 4 and 5). It is applied by high-pressure processes. Treatment with creosote reduces moisture movement in timber [232, WPA 2012].

The **supercritical carbon dioxide process** constitutes a special case, with the carrier medium for the preservatives (active ingredients) being CO_2 gas in a supercritical state. In 2017, only one plant in Europe was reported to apply this preservation process.

Other chemicals used in wood preservation include chemicals for waterproofing (e.g. oils, emulsions, wax), fire-retardants and chemicals used in chemical wood modification or hydrophobisation (like acetic anhydride, furfuryl alcohol, silicones and others).

The wood preservation process consists in principle of the following basic process steps/areas.

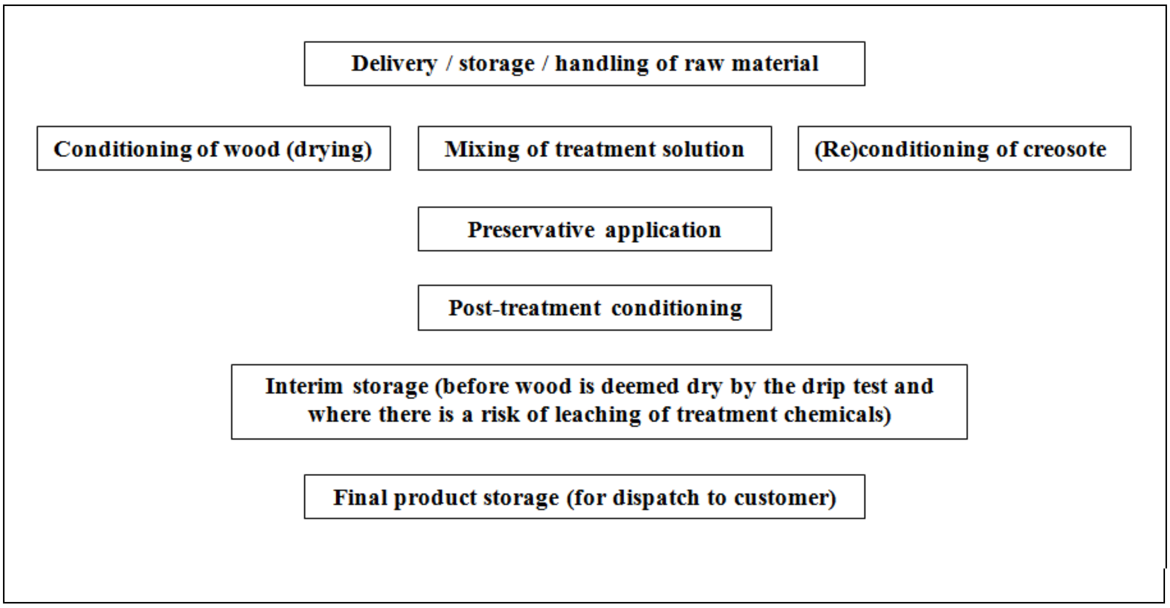


Figure 15.3: Overview of process steps for wood preservation

15.2.2 Delivery, storage and handling of raw materials

Wood and wood products to be treated are stored in the open or in roofed areas. The transportation of wood within the WPC plant is usually done by industrial forklift or by a crane. Wood preservatives/treatment chemicals are stored in original containers or in an approved container in order to minimise the risks of accidental leakages [231, Germany 2013].

Wood preservatives are delivered to the site as a concentrate for dilution in water or an organic solvent or in ready-to-use form not requiring further dilution (e.g. creosote).

Preparation of preservative mixtures
Preservatives supplied as concentrates are diluted with a carrier solvent (typically water) in accordance with manufacturer's instructions. Typically, this process is computer-controlled [WEI/EWPM comment #75 in [212, TWG 2018]].

(Re)conditioning of creosote
During the treatment process, the creosote may accumulate water which has to be driven out before the creosote can be recirculated in the treatment process. The limit for water content is usually around 3 % and it is generally controlled to below 1 %.

Some plants include creosote reconditioning systems where the water is boiled off at temperatures above 100 °C (in some cases at 120 °C [Plant DE-5 in [236, TWG 2017]]).

Others reported that creosote reconditioning may not be necessary because, due to the thermal oxidiser, the off-gas is not cooled down and the water stays as vapour in the off-gas and passes through the thermal oxidiser [Plant DE-9 in [236, TWG 2017]].

15.2.3 Preparation/Conditioning of Wood

Mechanical processing
The wood or wood product normally arrives at the wood preservation plant in a ready-to-treat form. Any mechanical processing is preferably done before the preservative treatment as – if done afterwards – it might expose untreated wood. Debarking, peeling, cutting, planning, drilling, etc. are mostly done in upstream wood processing plants, such as sawmills. However, in some WPC plants, mechanical processing might take place to some degree. As the processes, the impacts and the techniques are not specific to WPC, and as sawmills are not covered by the IED, the TWG concluded not to cover these processes in this document.

Incising is a mechanical pretreatment process applied in WPC plants to enhance the preservative penetration and retention. In incising, rotating blades are run over the surface of the wood to create a pattern of incisions; pattern, density and depth vary depending on the product specifications.

The wood/wood product may be loaded into the treatment vessels manually or automatically. Depending on the type of treatment vessel, forklifts, push/pull trolleys, etc. are used. The wood/wood products may be loaded in packs, in cages or, when large-dimension wood components (e.g. poles) are being treated, as individual pieces.

Conditioning (adjustment of moisture content)
For obtaining optimum wood preservation results, the wood has to have a certain moisture content/dryness before several impregnation processes (e.g. vacuum-pressure process). This can be achieved by seasoning (air drying), kiln drying, steam conditioning (vapour drying) or the Boulton process (heating in solvent / boiling under vacuum).

The most commonly applied process in WPC plants is seasoning, where the wood is stored in well-vented open storage yards for a certain length of time. In some plants, wood may also be dried in drying kilns. Only 4 of the 23 plants that took part in the WPC data collection (2017) reported kiln drying, mainly indirect drying (i.e. without direct contact between the combustion gases and the wood). One plant reported direct drying and steam drying, but no further information was submitted. Two plants apply the Boulton process but, again, no technical information was provided [236, TWG 2017].

15.2.4 Preservative application processes

The preservative application processes are generally divided into non-pressure and pressure processes. Table 15.5 provides an overview of the different types of preservative application processes used for wood preservation with chemicals.

Table 15.5: Preservative application processes used in wood preservation

Non-pressure processes	
Brushing	Superficial
Spraying / Spray tunnel	
Deluging	
Dipping / Immersion • Brief dipping (timed immersion) • Trough impregnation • Hot-cold bath treatment	Impregnation
(High/Low-) Pressure processes	
High-pressure: • Full cell process (‘Bethell’)/Vacuum-pressure process (plus variations) • Empty cell process (variations: Lowry, Rueping process)	Impregnation
• Alternating pressure / modified alternating pressure	
Low-pressure:	
• Double vacuum process	

15.2.4.1 Non-pressure processes

15.2.4.1.1 Brushing

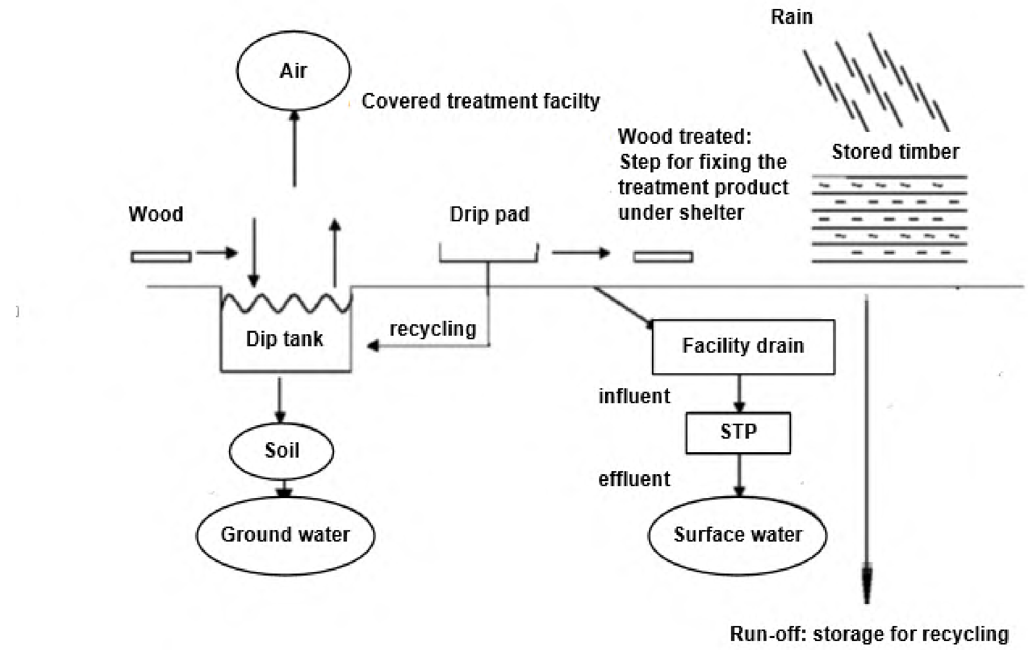
No information provided.

15.2.4.1.2 Brief dipping (short-term dipping / timed immersion)

In brief dipping (short-term dipping / timed immersion), the wood (either wood packages or single wood items) is immersed in the preservative solution in a soaking tank for a period of several seconds to several minutes. Then, the wood is raised from the bath and held over the treatment solution tank for a certain time to drain excess preservative solution. A fixing time of the treatment solution in the wood is mandatory (fixing time under cover: minimum 4 hours). After that, the wood can be moved to storage.

Artificial/forced drying is not recommended. Natural drying takes a few days for light-solvent- and water-based preservatives up to a few weeks for heavy solvents. The drying time also varies depending on the wood’s impregnability, the storage mode and the climatic conditions [230, VDI 2014] [233, France 2017].

Brief dipping (short-term dipping / timed immersion) is predominantly used in the manufacture of wood for use classes 1, 2 and 3.1 (e.g. internal structure wood). Figure 15.4 and Figure 15.5 depict the process.



Source: [233, France 2017]

Figure 15.4: Flow diagram for the brief dipping (short-term dipping / timed immersion) process

Source: [233, France 2017]

Figure 15.5: Example for brief dipping (short-term dipping / timed immersion) - tank allowing the simultaneous treatment of several batteries with the fixing done on racks next to the dipping tank

15.2.4.1.3 Deluging

In deluging, the wood is placed above a suitable, liquid-impervious containment pad and the deluging lance is run over the wood by hand. The outlet opening of the deluging lance is designed so that the wood preservative exits in the form of a liquid plume, flooding the surface to be treated. Drippage and excess fluid run-off are collected and recirculated; woodchips and other coarse debris are retained in a basket-type strainer. The strainer is checked and cleaned at regular intervals. Compared to spraying, this method largely avoids the risk of mist formation [230, VDI 2014].

15.2.4.1.4 Spraying / spray tunnels

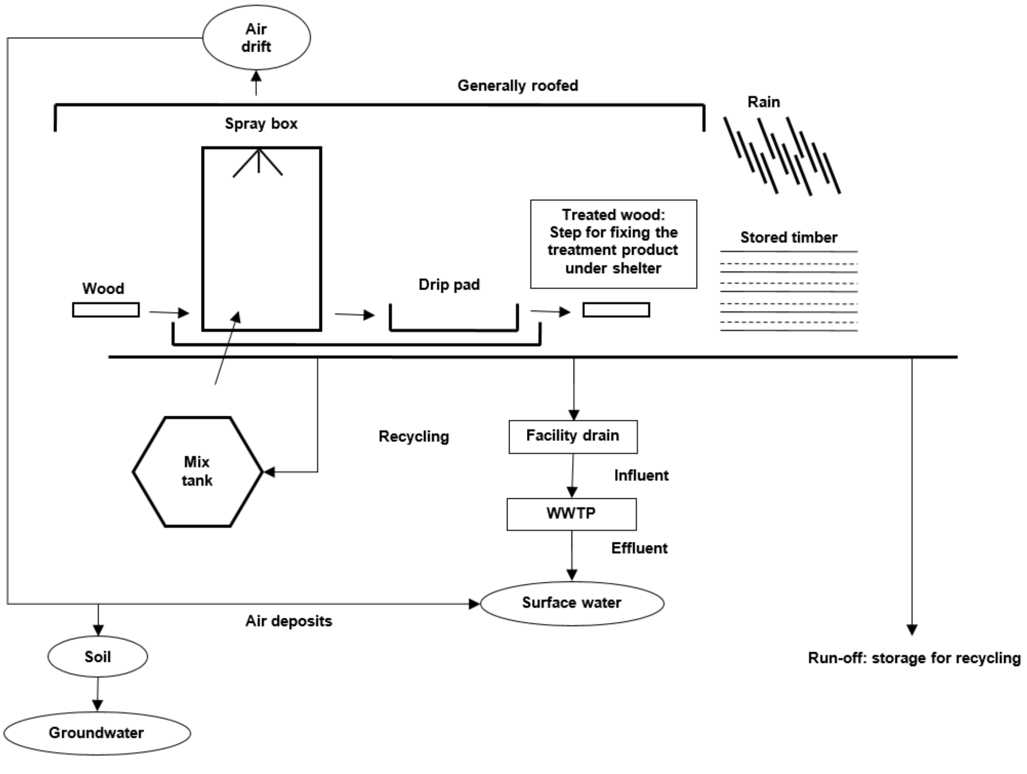
Spray tunnel systems are available as mobile and permanently installed systems. The wood (debarked logs or fully or partly machined timber) is moved through one or more longitudinal or transversal chambers on a continuously moving conveyor system. In these spray chambers, spray nozzles are arranged in such a way as to ensure that the preservative is applied to all sides of the wood as it is continuously moved through. The spray is usually coarse, i.e. in particle size, to ensure the wetting of the wood with the correct amount of wood preservative. The spraying units are sealed against the ambient air. The overspray and the drippage are collected and led back to the storage tank for reuse. To ensure uniform preservative application while at the same time minimising dripping losses on the drying side, the spray chamber is usually followed by a squeegeeing device [230, VDI 2014] [233, France 2017].

Splashguards surrounding the spray chambers prevent any droplets of spray from entering the rest of the plant area and may have local exhaust ventilation.

After the wood has been treated, it is stacked or sorted, either mechanically or manually, and dries on the conveyor belt or in the post-treatment drip-dry conditioning area before being moved off site to manufacturers or used on site.

The treatment apparatus is typically established in a contained or bunded area fabricated from materials resistant to the wood preservative used. Provision is made for the collection, recycling and reuse of wood preservative collected from the conveyor or drip-dry area. The releases of wood preservatives from the treating installation or where the treated wood is stored are collected in a surface water drain or drain connected to a waste water treatment plant (WWTP) [233, France 2017].

Spraying is typically used in sawmills and carpentry/joinery shops. Figure 15.6 and Figure 15.7 depict the process.



Source: [233, France 2017]

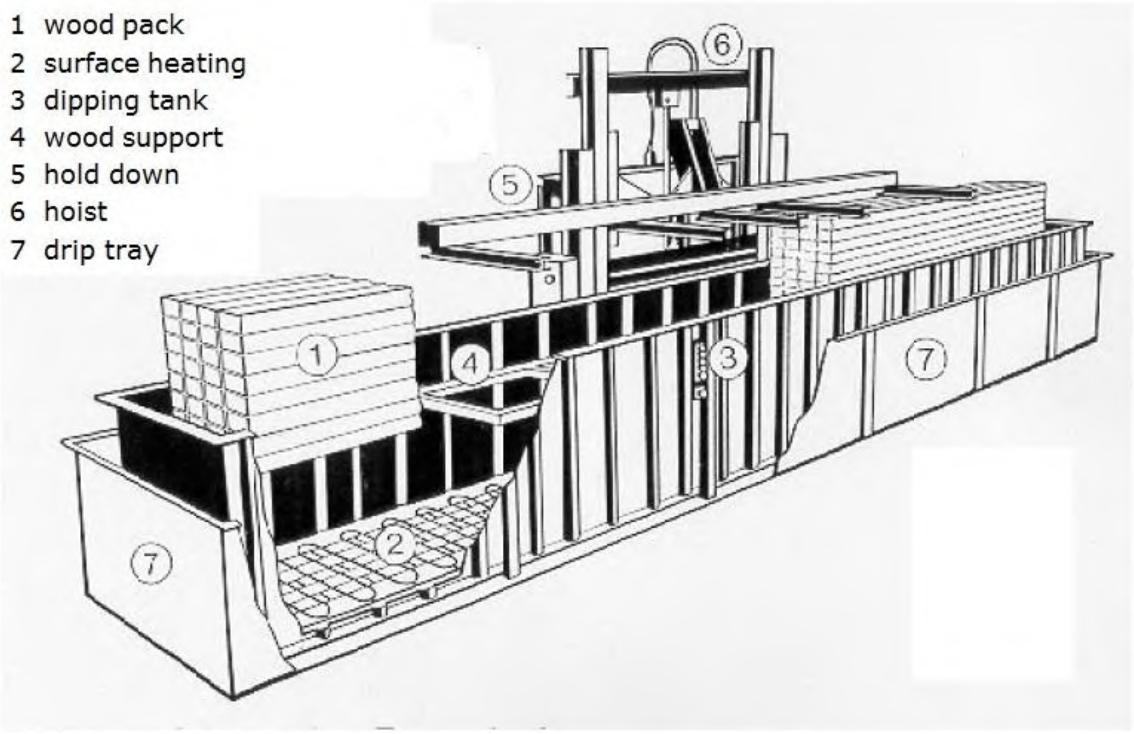
Figure 15.6: Flow diagram for spraying / spray tunnel process

Source: [233, France 2017]

Figure 15.7: Wood in closed spraying tunnel

15.2.4.1.5 Trough impregnation / dipping process

In trough impregnation, the wood is completely immersed in a tank filled with the wood preservative over a period of one to several days. In the dipping process - these days the prevalent method for treating structural timber - the wood is immersed over a period of several minutes up to several hours. Modern impregnation troughs are typically designed as double-walled tanks and provided with corrosion protection. For older single-walled impregnation tanks, a separate secondary containment system is used to ensure reliable retention of the impregnating solution in case of leakage. The trough impregnation system is installed under cover to ensure protection against precipitation [230, VDI 2014].



Source: [234, Austrian Umweltbundesamt 2015]

Figure 15.8: Schematic of trough impregnation

15.2.4.1.6 Hot-cold bath process

The hot-cold bath process is used for the treatment of wooden posts (supports for vineyards and orchards as well as horticulture and landscaping applications: e.g. vineyard posts, fruit tree and tree support posts). If stakes/posts have a moisture content between 20 % and maximum 30 %, they are placed in a treatment tank filled with impregnating oil (creosote) with a contact depth depending on the length of the post to be protected (70 cm to 90 cm from the end of the stake/post). The impregnation takes place in enclosed equipment. The impregnating oil is heated up to 110 °C ± 5 °C and maintained at this temperature for 120 minutes to allow the escape of the air out of the wood. After that, the heating is stopped to allow cooling to a temperature of 40 °C to 50 °C (temperature difference depending on the site-specific conditions and the required level of preservative retention). A lower cooling temperature (< 40 °C) leads to undesirable adhesion of creosote on the wood surface, which later (when in service) can leach out and may have negative effects on the environment. A higher temperature (> 50 °C) may cause steam emissions from water, which is still contained in the wood (wood moisture). When this temperature is attained (duration ~ 12 to 16 hours), the stakes/posts are lifted out of the impregnating fluid by a lifting cage.

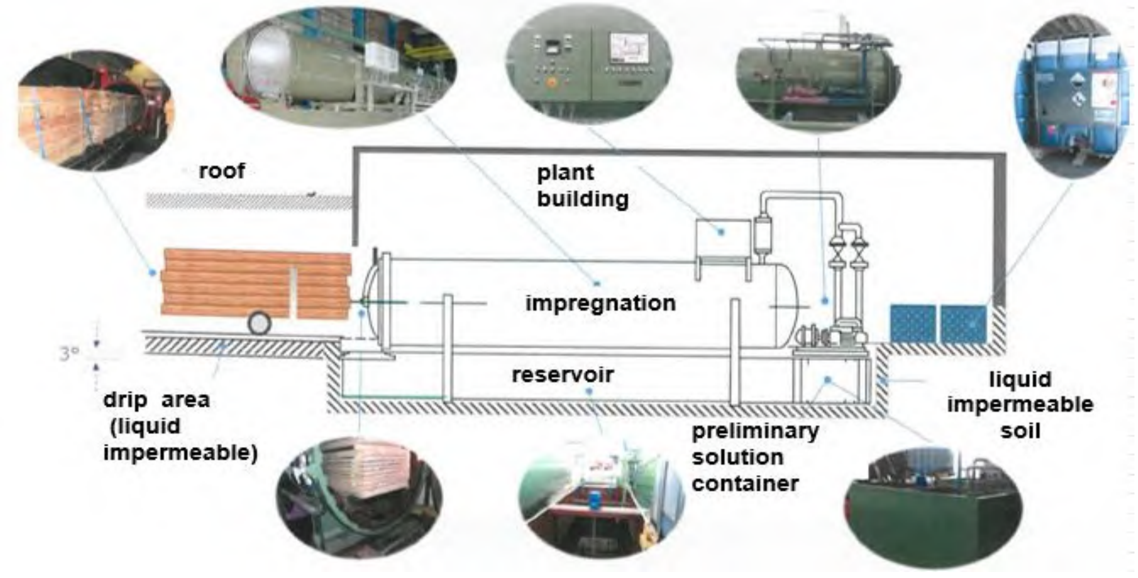
Creosote temperature should be adjusted accordingly before the wood timber can be taken out of the treatment tank. This leads to easier dripping of excess creosote from the stake/post surface and avoids environmental risks during service life. The lifting cage is held over the treatment tank in the area of the exhaust gas extraction system for a minimum period of 60 minutes (during the dripping and condensing phase) before the system is opened to remove treated stakes/posts [230, VDI 2014] [231, Germany 2013] [DE comment #377 in [212, TWG 2018]].

When the system is opened for removing the treated wood, emissions of organic and odour compounds to air may occur. Fugitive emissions of the same compounds, although at lower concentrations, may occur during subsequent storage [230, VDI 2014] [231, Germany 2013].

15.2.4.2 Pressure processes

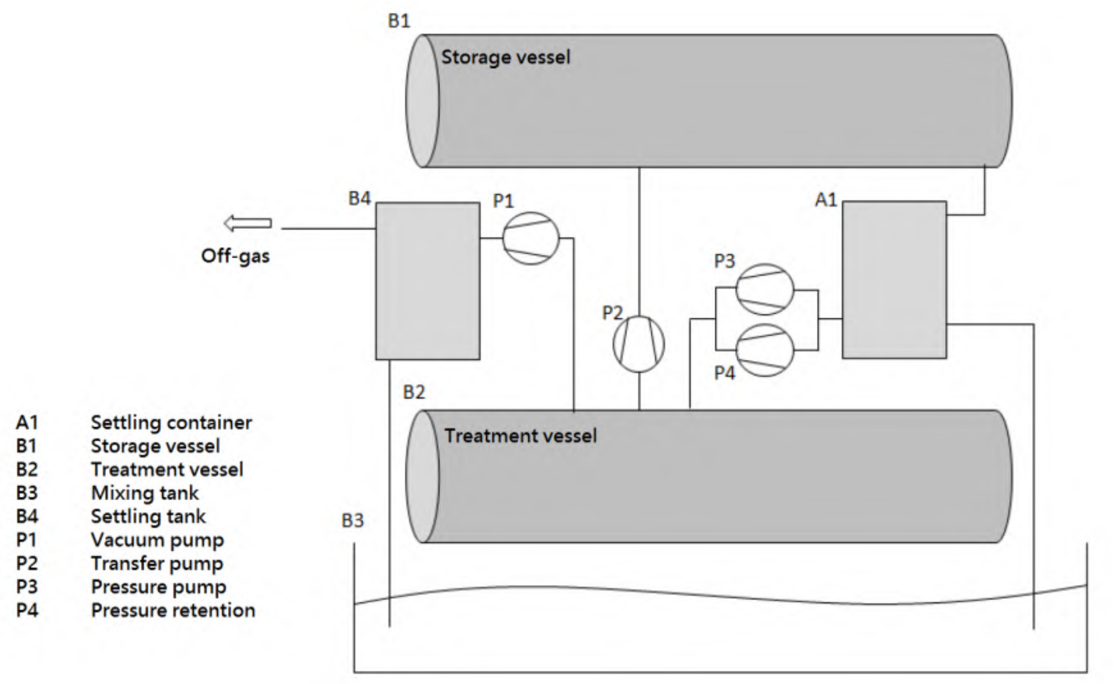
The treatment equipment for pressure processes consists of the treatment vessel, which may be a cylindrical or rectangular pressure vessel (autoclave), and one or more storage vessels. In the case of two storage vessels, one is the working vessel which holds the preservative to flood the treatment vessel and the other is the bulk tank which is used to accept delivery of new preservative and to replenish the working/treatment vessel. The treatment vessel incorporates a loading system to enable packs of wood to be moved in and out, either manually or automatically. Loading/unloading from one end of the treatment vessel or from both ends ('roll-in roll-out') is available.

The treatment vessel door incorporates safety devices to prevent the process starting until the door is fully closed and locked and to prevent it being opened until all preservative is removed at the end of the treatment cycle.



Source: [DE comment #376 in [212, TWG 2018]]

Figure 15.9: Example of a water-based pressure treatment plant with an open mixing/storage tank



Source: [231, Germany 2013]

Figure 15.10: Example schematic of a pressure treatment plant for water-based preservatives

Once the wood is loaded into the treatment vessel, the door is closed and safely locked. The treatment cycles for all pressure processes are basically variations of the following main stages, (stage 1 may be omitted or replaced with an air pressure phase, and the sequence or number of pressure phases may differ):

1) Initial vacuum: an initial vacuum is used to take air out of the wood. The length of this vacuum period and the level used vary according to the specification being followed. The amount of air removed will affect the final uptake and penetration of preservative. To control retention, some processes run without applying an initial vacuum.

2) Flooding: the preservative solution is transferred from the working vessel to the treatment vessel. If applied, the vacuum is maintained during transfer.

3) Pressure period: once the treatment vessel is full, the vacuum is released and, unless atmospheric pressure only is to be used, hydraulic pressure is applied using a pump. The wood is held in the preservative for a period of time. Pressure is then released in a controlled manner.

4) Initial drain: at the end of the pressure period, the preservative is transferred back to the working vessel.

5) Final vacuum: a final vacuum is applied to the wood, both to remove any excess preservative from the surface layer of the wood and to reduce dripping of the treated wood at the end of the process. As this vacuum is released, air moves back into the vessel and into the surface cells of the wood, carrying with it some of the residual preservative solution on the wood surface. This stage may be replaced or augmented when using steam conditioning to initiate drying of the treated wood.

6) Final drain: during the final vacuum, the preservative collected in the treatment vessel is pumped back into the working vessel. Fresh air is often drawn through the vessel before the

wood is removed, to remove vapour from the working area around the door and to minimise operator exposure.

Creosote treatment process
When treating wood with creosote in pressure processes (commonly in the ‘Rueping process’ or ‘double Rueping process’), the treatment vessel is flooded with hot impregnating oil at a temperature of 110 °C (some reported minimum temperatures of 90 °C) to maximum 120 °C while maintaining the air pressure. Heat losses of the impregnating oil in the treatment vessel are made up by reheating to 110 °C ± 10 °C (exchanging parts of the creosote with hot creosote). The temperature must be maintained throughout the pressure period.

In the simple Rueping process cycle, a thermal conditioning step can be carried out before proceeding to the pressure phase. Once the preliminary air pressure has been established, the wood is thermally conditioned under preliminary air pressure conditions in an impregnating oil bath for varying periods of time. Thermal conditioning raises the temperature of the impregnating oil (lower viscosity) and hence improves oil penetration into the wood. In a next step, the pressure (absolute) is increased to 9 bar at a minimum. The oil pressure level and the duration of the oil pressure period are determined by the required depth of penetration of the sapwood through to the heartwood boundary and the required preservative retention as well as by the wood species, wood condition and wood dimensions. The process ends with the depressurisation of the treatment vessel to atmospheric pressure, the return of the impregnating oil to the storage tank and the application of as high a final vacuum as possible which has to be maintained for a defined period [231, Germany 2013].

15.2.5 Post-treatment conditioning and interim storage

15.2.5.1 Interim storage of freshly treated wood

After treatment, dripping or leaching of preservative solution may occur during a variable time depending on the application process or the preservative used. Wood removed from the treatment vessel is therefore held in special areas with protective measures in place to capture drips of preservatives and/or to protect the wood from rain. Wood is only removed from these areas once it is deemed dry (drip-free) or the preservative is fixed in the wood.

15.2.5.2 Drying of treated wood

Water-based preservatives
High-pressure impregnation with water-containing preservatives increases the moisture content of wood. After treatment, this needs to be reduced to a level suitable for the end use of the wood. Drying may be accelerated by open stacking with good ventilation, by an increase in temperature, or by use of other means such as kiln drying. Low-pressure impregnation with water-containing preservatives will raise moisture levels only in a superficial outer zone and this is normally fully reversible within a short time by air drying [232, WPA 2012].

Organic-solvent-based preservatives
The moisture content is not increased with treatments using organic solvent-based preservatives. The solvents evaporate relatively quickly providing there is adequate ventilation and good airflow. Most timbers can be used within 2 to 7 days of treatment depending on the uptake of preservative and the prevailing conditions. Occasionally a pack of treated wood will contain some pieces which have pockets of abnormally permeable sapwood. Although undetectable before treatment, after treatment these can be seen as dark-coloured streaks. Such pieces, when identified, are removed from the pack for prolonged drying before gluing, painting or installation [232, WPA 2012].

Creosote
Creosote is used undiluted and as such has no carrier solvent to evaporate and so does not ‘dry’ in the conventional sense, but as it continues to contain liquid preservative for many years it is in the nature of creosoted wood that creosote may resurface, especially when the wood is exposed to sunlight [232, WPA 2012].

15.2.5.3 Steam fixation

For wood treated with non-fixating preservatives, steam fixation may be applied. The wood is put in a closed treatment vessel (without pressurisation) and ‘rinsed’ with steam. Fans are used to circulate the steam in the treatment vessel until the desired fixation is achieved [231, Germany 2013].

15.2.5.4 Storage of treated timber (before dispatch to customer)

After fixation and/or when treated wood is dry, it is usually removed from the treatment area and stored until dispatch to the customers. Some plants deliver their products directly to the customers (‘just-in-time production’). If stored, final storage options for treated wood/wood products vary from plant to plant; some apply outside storage without any special provisions, others store their products outside on hard-surfaced ground/impermeable ground (with or without surface run-off collection). While some store under a roof, others use plastic protection or tarpaulins to shield the wood/wood products from rainwater.

15.2.6 Impregnating with hydrophobing agents

An option for wood enhancement is impregnation with hydrophobisation agents such as oils, waxes or silicon compounds. Impregnation of wood with a melt of natural waxes and resins or paraffin resins significantly increases its durability and (compressive) strength. Plants of this type are operated *inter alia* in Germany, Austria, Sweden and Italy [230, VDI 2014] [231, Germany 2013] [Plants SE-2 and IT-2 in [236, TWG 2017]].

Linseed oil treatment is done in an additional process step after the conventional impregnation, which is known as the Royal process. After the conventional impregnation, the autoclave is filled with hot (~ 80 °C) pigmented (or unpigmented) linseed oil and a vacuum is applied. During this step, the water evaporating from the wood is led to a condenser. The process continues until the moisture content of the wood is around 18 %. A thin layer of the oil remains on the wood surface [Plant SE-2 in [236, TWG 2017]] [SE comment #6 and WEI/EWPM comment #81 in [212, TWG 2018]].

15.2.7 Cleaning of treatment equipment

Process vessel cleaning may be a necessary stage in the treatment process. Process vessels and associated connecting pipes, pumps and filters can only be cleaned *in situ*. The range of cleaning equipment and the method used vary according to the shape of the tanks, the treatment systems concerned, the degree of cleanliness to be achieved and the quality requirements. Fixed vessels are often cleaned using static spray heads that can be fixed into position over the top of the vessel or through a cleaning port.

Usually, organic solvent is used in such systems as the cleaning medium and is sprayed at low pressure into the top of the vessel. Other cleaning methods may involve physical techniques using brushes instead of spray heads, and manual cleaning performed from outside or directly inside the tank. Cleaning media other than solvent may include caustic solutions, water-based cleaners and abrasive impact techniques using inert particles [235, UK DEFRA 2013].

Pipelines connecting tanks are normally cleaned by flushing.

Often, it is difficult to find one machine that can clean all shapes and sizes of portable tanks and, invariably, some manual cleaning will need to be carried out, normally the external shell of the tank and valves.

Filters are cleaned either *in situ* as part of the pipe flushing/pigging process or as an open manual process under local or general exhaust ventilation. The method of cleaning will depend on the type of filter. Filter cleaning can be avoided by using disposable filters, which are available for certain pieces of equipment and are suitable for certain products [235, UK DEFRA 2013].

15.2.8 Other activities on site

Other activities or facilities that might be present on WPC sites, but that are not covered in detail in this BREF, comprise the following:

- **Combustion plants**: for heating purposes/steam generation (heating of creosote, steam fixation, etc.)
- **Compressor stations**: to produce compressed air for operation of the treatment facilities, valves and to seal the door of pressure treatment vessel. The plant is designed in such a way as to ensure safe operation during power cuts (ensure tightness of treatment vessel).
- **Electricity production**: pumps and compressors may be major consumers of energy/electricity, some plants generate electricity on site; examples were reported of solar-powered electricity generation (Plant DE 1: 60 000 kWh of the yearly consumption of 198 900 kWh is produced by solar panels).

15.2.9 Waste management

Waste management comprises all activities on site regarding waste minimisation, waste handling and on-site waste treatment. The main principles for WPC plants are reduction of the amounts of waste, especially hazardous wastes, generated; separation of hazardous and non-hazardous wastes; and reuse where feasible (e.g. preservative spills).

Table 15.6 provides some examples of management options.

Table 15.6: Examples of management options for waste generated by WPC plants

Waste (type)	**Management option**
	Reduction (of amount generated)
Contaminated wrappings from packs of wood	• Remove before treatment
Sludge/dirt and contaminated sawdust	• Locate plant in building • Stabilise yard surfaces • Clean wood before treatment
Contaminated rainwater	• Cover plant and post-treatment conditioning area
Post-treatment drippings	• Slope packs in vessel • Optimise treatment cycle • Leave in vessel
Offcuts (potentially hazardous waste)	• Cut timber to size before treatment
Treatment chemicals lost from the plant	• Repair leaking valves, door seals, pumps
Redundant treatment solution	• Check option of another plant using up the product
	Reuse
Collected post-treatment drippings	• Return to plant storage tanks
Unused treatment solution	• Recover at the end of the treatment cycle and reuse
Wood bearers used on bogies	• Reuse/fit metal bearers
	Recycling/recovery
Contaminated packaging/containers	• Have chemicals delivered in recyclable packaging/ containers and recirculate to chemical providers
Non-hazardous waste (e.g. untreated wood, paper, metal)	• Separate components, e.g. wood, paper from metal or from inert waste • Sort out and collect in designated containers
Untreated wood waste	• Send off for: wood fibre recovery, energy generation or composting
	Disposal
Treated wood waste	• Dispose of safely (by authorised companies)

Source: [236, TWG 2017]

15.2.10 Water/Waste water management

Water/waste water management comprises all activities on site regarding the prevention of waste water, handling of water streams (including surface run-off water) and waste water treatment.

Waste water can derive from process water, surface run-off water, but also from firefighting water (OTNOC). A summary of the information provided on the collection of uncontaminated rainwater / surface run-off water is given in Table 15.7 and in Table 15.8 for potentially contaminated rainwater / surface run-off water.

Table 15.7: Collection of uncontaminated rainwater / surface run-off water

Example plant	Plant type	Areas from which water is collected	Description	Water reuse	Type of discharge	Monitoring
DK-2	WB	Roof area and paved surfaces	Rainwater from the roof area and paved surfaces is led to the municipal sewage treatment plant via a sewer collection system	No, as no water is used in CO_2 process	Indirect discharge - sewer system, WWTP	No
DK-1	WB	Drying area, roof of impregnation plant and of storage facility	Via a sewer collection system	Preparation of treatment solution	NI	NI
UK-1	WB+C	Entire site	Drains	No, collected water is treated in a WWTP and discharged	NI	Yes, periodical samples
UK-4	WB	Roof of treatment shed and sawmill	Rainwater is collected in two storage tanks	Preparation of treatment solution	NI	NI
IT-1	WB	All uncovered site areas (including roofs of treatment line)	Internal drain network, with two main drainpipes, collected to the municipal drain system and waste water treatment plant	No	Indirect discharge - sewer system, WWTP	No
SE-2	WB	Roofs	Through pipes and collected in a pond	Preparation of treatment solution	NI	NI
FR-4	WB	Output treatment area / fixation area	Pipeline to plant retention	Preparation of treatment solution	NI	NI
FR-1	C	Covered areas	Rainwater is collected from complete new tubes network	Partially, only 'process water' (steam for heating creosote) is reused	Direct discharge - surface water body	No
DE-9	WB+C	Roofs	Sedimentation basin (sludge trap) to remove dust (from the roofs), then direct discharge in a canal for irrigation of fields	Not in impregnation plant, but in field irrigation	Direct discharge	NI
DE-5	C	Roofs, roads	Led to inlet area	No	NI	No
DE-8	WB+C	Roofs and surface run-off from open storage area	Storage of run-off from roofs in double-walled steel tank underground (approx. 30 m^3). Surface run-off from open storage of treated wood is treated in a sedimentation basin, prior to discharge	Surface run-off from roofs is completely used for preparation of treatment solution	Direct discharge (water from open storage only) - surface water body	No
DE-6	WB	Roofs and areas without dripping from freshly treated wood	Pipe system leads to a concrete basin	No	Indirect discharge - sewer system, WWTP	Yes
DE-7	WB	Roofs, storage of fresh wood	Sedimentation basin, afterwards seepage	No	NI	NI

FR-2	WB+C	Separate network for sewer water recuperation. All surface water is collected by a rainwater network	Separate network for sewer water recuperation	Partially, recycling of water from the fixing areas to the outlet of autoclaves and storage areas under the poles (both WB and C post-treatment). Collection in two ponds. Collected water is reused for WB treatment.	Direct discharge - surface water body	Yes
NB: NI: No information provided. *Source*: [236, TWG 2017]						

Table 15.8: Collection of potentially contaminated rainwater / surface run-off water

Example plant	Plant type	Areas from which water is collected	Description	Analysis of collected water	Water reuse	Treatment	Monitoring before discharge
DK-1	WB	Drying area, the facility	Via a sewer collection system	No	Preparation of treatment solution	NI	NI
PL-1	WB+C	NI	Concrete tanks 3x10 m^3	Yes, by waste water company	No, disposed of as liquid waste	NI	No
UK-1	WB+C	Entire site / all surface water	Drains	Yes, release from on-site WWTP is measured for: flow, Cu, Cr, PAHs, benzo[a]pyrene	No, discharged after WWTP	NI	Yes
UK-2	WB	Whole timber handling area	Water is collected from the sump area of the plant and reused directly in the mixing process	No	NI	NI	NI
IT-1	WB	(Only) uncovered areas on site: dedicated to washing/and cleaning of handling machines, which are the only sources of industrial waste water discharge. Monitoring prescribed at the discharge point, before mixing with domestic water/rainwater.	NI	NI	NI	NI	Yes
SE-2	WB	Asphalt hard surfaces	Through pipes and ditches to a pond	Yes, twice a year water samples are sent for analysis	Preparation of treatment solution	NI	NI
SE-1	WB+C	Storage areas for creosoted woodchips	An area with asphalt that has collection points that lead to a sediment and oil separator	Yes, twice a year water from the separator is collected and analysed	NI	On-site treatment	Yes
FR-3	WB	Inside the treatment building	Watertight sloping floor which brings any treatment water back into a sump at the bottom of the building. The sump is then emptied via a lifting pump into one of the treatment tanks.	No	Preparation of treatment solution	NI	No
FR-4	WB	Output treatment area / fixation area	Pipeline to plant retention	No	Preparation of treatment solution	NI	NI
FR-1	C	Areas with creosote tubes, impregnation area and covered	Water is collected from sealed soil area and led to a treatment station	No	NI	On-site treatment: active charcoal filter	No

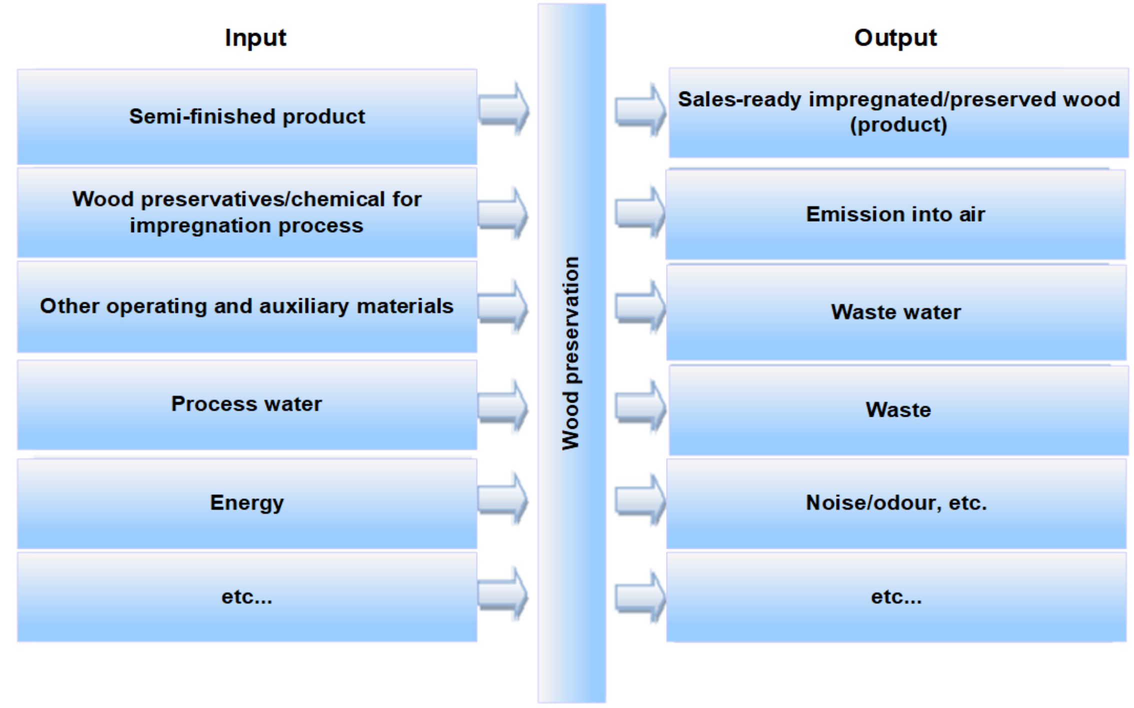
		areas for treated wood storage	by tube system			and reverse osmosis	
DE-9	WB+C	Streets, open storage of impregnated wood (WB, C), turnout tracks of WB	Collected water is led to a sedimentation basin (sludge trap) and then stored in a cistern for further recycling in the WB process	No	Preparation of treatment solution	NI	NI
DE-5	C	Transportation area between cooling-down building and building for putting base plates on sleepers	Collected with waterproof foil and led to a waste water treatment plant	Yes, monitoring of waste water treatment plant	NI	NI	Yes
DE-6	WB	Areas where treated timber is pulled directly after unloading the treatment vessel	The impermeable hardstanding between and beside the rails for unloading the treatment vessel has a slope toward the contained area beyond the treatment vessel (collecting tray)	No	Preparation of treatment solution	NI	NI
IT-2	WB	Uncovered paved surfaces and stabilised ground surfaces, buildings, surfaces, uncovered concrete surface	By pipes carrying water to a collecting tank	Yes, periodic water analysis	NI	On-site treatment	Yes
DE-7	WB	Storage of impregnated wood products	Sedimentation basin, afterwards seepage. Collection together with uncontaminated rainwater.	No	NI	On-site treatment sedimentation	No
FR-5	WB	NI	Collection of treatment solution from sealed surfaces and treatment area, treatment solution then pumped back to the process.	No	Preparation of treatment solution	NI	No
FR-2	WB+C	Injection and storage	Pond	No	Preparation of treatment solution	NI	NI

NB:
NI: No information provided.
Source: [236, TWG 2017]

15.3 Current consumption and emission levels on preservation of wood and wood products with chemicals

15.3.1 General overview of inputs and outputs of WPC plants

Figure 15.11 gives an overview of the main inputs/consumption and outputs/emissions for the preservation of wood and wood products with chemicals.



Source: [231, Germany 2013]

Figure 15.11: Typical input and output for wood preservation plants

Chemicals used in wood preservation comprise biocides and the corresponding ‘carrier chemicals’: water, solvents, CO_2, but also chemicals used for waterproofing (e.g. oils, emulsions), fire-retardants and chemicals used in chemical wood modification or hydrophobisation (like acetic anhydride, furfuryl alcohol, silicones). As chemical wood modification (CWM) and hydrophobisation are excluded from the scope of this BREF, these chemicals are not covered in the following sections. However, some information and data on these chemicals may be given in the section on emerging techniques dealing with CWM (see Section 19.6.1) and in the section on hydrophobisation (see Section 15.2.6).

An overview of types of wood preservatives and the wood preservation process they are used in is presented in Table 15.9.

Table 15.9: Overview of wood preservative types and preservation processes applied

Wood preservation process			Wood preservative type employed
Pressure processes	Retort pressure treatment processes	Vacuum-pressure process	Water-soluble salt concentrates
		Alternating pressure process	Water-soluble salt concentrates
		Rueping process	Impregnating oil (creosote) or emulsion concentrates based on impregnating oil (creosote)
		Double Rueping process	Impregnating oil (creosote) or emulsion concentrates based on impregnating oil (creosote)
	Low-pressure processes	Double vacuum process	Solvent-based preservatives
Non-pressure processes	Immersion processes	Trough impregnation	Water-dilutable salt concentrates and water-dilutable emulsion concentrates
		Dipping	Water-dilutable salt concentrates and water-dilutable emulsion concentrates
		Hot-cold bath treatment	Impregnating oil (creosote)
	Superficial processes	Brief dipping (short-term dipping / timed immersion)	Ready-to-use aqueous products or water-dilutable products
		Deluging	Ready-to-use aqueous or water-dilutable products, solvent-based products in exceptional cases
		Spray tunnel	Water-dilutable salt concentrates or ready-to-use aqueous salt solutions, predominantly boron salt formulations
		Spraying	Water-based formulations for preventive treatment at manufacturing plants; for use in closed systems only
		Brush application	Ready-to-use water-based products

Source: [231, Germany 2013]

15.3.2 Inputs and consumption

15.3.2.1 Wood input

Different wood types with insufficient or no natural resistance to wood-destroying or wood-staining organisms for the specific end uses are impregnated. In terms of quantitative relevance, species such as pine and spruce are important. In addition, beech, oak and other wood species are used.

The type of wood species to be treated has an impact on the impregnability, biocide consumption and/or treatment class/use class achievable by certain biocide amounts or preservation techniques. However, the information provided during the data collection does not allow for any reliable statements on consumption in relation to the wood species or the amounts treated.

15.3.2.2 Biocides consumption

Wood preservatives consist of preparations which contain one or more biocides (active substances). Biocides/biocidal products are regulated by Regulation (EU) 528/2012, the BPR (repealing the Biocidal Products Directive 98/8/EC). According to the BPR, all biocidal products require an authorisation before they can be placed on the market, and the active substances contained in that biocidal product must be previously approved. There are, however, certain exceptions to this principle. For example, biocidal products containing active substances in the Review Programme can be made available on the market and used (subject to national laws) pending the final decision on the approval of the active substance (and up to 3 years after).

Products containing new active substances that are still under assessment may also be allowed on the market where a provisional authorisation is granted [237, ECHA 2018].

As the products and/or active substances which are authorised may change over time, no list of currently authorised biocidal products or active substances is given in this document. Instead the reader is referred to the relevant and up-to-date website of the European Chemicals Agency – ECHA (https://echa.europa.eu/regulations/biocidal-products-regulation).

The specific biocide consumption per m^3 of wood treated reported during the data collection for this BREF (2017) for water-based preservative treatment and one CO_2 process is summarised in Table 15.11. No data were reported for solvent-based wood preservation.

The data submitted do not allow for detailed figures for certain active substances or chemical components in the biocidal products, but a non-exhaustive overview of the ingredients of the biocidal product types - that are used in the plants that took part in the data collection - is given in Table 15.10.

Table 15.10: Non-exhaustive overview of ingredients of biocidal product types used in plants that took part in the WPC 2017 data collection

Biocidal product type	Exemplary ingredients
a	- Basic copper carbonate, - 2-Aminoethanol, - Quaternary ammonium compounds, - Benzalkonium chloride, cyproconazole
b	- Copper, - Quaternary ammonium compounds, - Boric acid
c	- Copper hydroxide carbonate - N, N-Didecyl-N methylpoly (oxyethyl) ammonium propionate
d	- Copper carbonate, - 2-Aminoethanol, - Boric acid, - Tebuconazole, propiconazole, - Polyethyleneamine - Organic acids and surfactants
e	- Propiconazole, tebuconazole, permethrin
f	- Propiconazole, tebuconazole
g	- Bis-(N-cyclohexyldiazeniumdioxy)-copper, - Copper hydroxide carbonate - Boric acid, - 2-Aminoethanol
h	- Permethrin, propiconazole

Source: [236, TWG 2017]

Table 15.11: Reported specific biocide consumption for water-based preservative treatment (reporting period 2014-2016)

Example plant	Process	Commodities	Penetration class (EN 351)	Use class	Specific biocidal product consumption (kg/m^3)	Biocidal product type
DK-2	Pressure process (autoclave)	Exterior walls and joinery, posts	NI	UC 2 UC 3	1	f
DK-1	Pressure process (autoclave)	Exterior walls and joinery, posts	NI	UC 1 UC 3 UC 3 UC 4	8 (for UC 3) 16 (for UC 4)	d
PL-1	Pressure process (autoclave)	Poles	NP 5	UC 4	8.94–13.69	g
UK-1	Pressure process (autoclave)	Poles, sleepers, posts, fence rails / decking boards	NP 3 NP 5 NP 6	UC 3 UC 4	18.31-28.38*	NI
UK-4	Pressure process (autoclave)	Fence rails / decking boards, posts, sleepers, exterior walls and joinery, purlins	NI	UC 1 UC 2 UC 3 UC 4	3.52	a
SE-2	Pressure process (autoclave)	Fence rails / decking boards	NP 5 NP 2	UC 3 UC 4 UC 2	2.28-3.08	a, d, g
SE-3	Pressure process (autoclave)	NI	NP 1 NP 5	UC 1 UC 3 UC 4	6.74-8.64	a, b
FR-3	Dipping/Immersion	Internal building timbers	NP 1	UC 2	0.309-0.322*	h
FR-4	Pressure process (autoclave)	Internal joinery, internal building timbers, exterior walls and joinery, fence rails / decking boards, posts, poles	NP 5 NP 3	UC 4 UC 3	7.5*	NI
DE-6	Pressure process (autoclave)	Poles, sleepers, posts	NP 5 NP 4 NP 3 Others	UC 4 UC 3	14.5	g, c
FR-5	Dipping/Immersion	Internal building timbers	NP 1	UC 2	1.005-1.034	NI
FI-1	Pressure process (autoclave)	Exterior walls and joinery, fence rails / decking boards, poles	NP 5	UC 3 UC 4	0.8*	g
FR-2	Pressure process (autoclave)	Exterior walls and joinery, fence rails / decking boards, poles	NP 5	UC 4	8.5-8.9*	c

* Calculated from reported data.
NB:
NI: No information provided.
Source: [236, TWG 2017]

15.3.2.3 Creosote consumption

Creosotes are distillate fractions consisting of a multitude of chemical compounds. They are differentiated into three types (types A, B and C, according to EN 13991) with different vapour pressures. According to the IED, the fraction of creosote which exceeds the value of 0.01 kPa vapour pressure at 293.15 K shall be considered a VOC. The VOCs are the low-boiling fraction of the creosote [148, COM 2009].

The use of creosote is restricted to wood for outdoor applications with special requirements (ground contact), e.g. posts, poles, fencing or sleepers (Directive 76/769/EEC), due to its classification as a carcinogenic Category 2 substance because of its benzo[a]pyrene content. According to Directive 2001/90/EC, if the creosote contains less than 0.005 % (by mass) benzo[a]pyrene and less than 3 % (by mass) water-extractable phenols, it may be used, but only in industrial installations or by professionals. Therefore Type A creosote, which can now contain 0.005 % to 0.05 % and formerly contained up to 0.1 % benzo[a]pyrene, is banned in the EU [148, COM 2009].

Type B creosote is currently the most widely used oil-based wood preservative used, with an average VOC content of 20 % and less than 0.005 % benzo[a]pyrene.

Type C creosote, with a much reduced VOC content (~ 2 %), and a content of less than 0.005 % benzo[a]pyrene has a high viscosity and high crystallisation temperature. Therefore it is necessary for the storage and impregnation system to be heated. The advantages are reduced odour and a reduced tendency for the wood to sweat [148, COM 2009].

A range of 40 kg to 150 kg of creosote is needed for the impregnation of 1 m^3 of wood [148, COM 2009].

Some exemplary data for creosote plants applying pressure treatment or hot-cold bath treatment as provided in a BAT study submitted by Germany are presented in Table 15.12 below. As can be seen, creosote consumption in pressure and non-pressure processes may differ. While in hot-cold bath treatment only the surface of wood is impregnated, not the whole diameter, the penetration depth of pressure processes is much deeper than for non-pressure processes. The processes used for impregnation and their efficiencies depend on the product specifications. The classification of preservative retention and penetration is defined in the related standard (i.e. EN 351-1).

Table 15.12: Exemplary plant data for creosote treatment plants

Plant data	Unit	Range for hot-cold bath treatment process	Range for pressure processes
Preservatives used		Impregnating oil (Grades B and C according to DIN EN 13991)	Impregnating oil (Grades B and C according to DIN EN 13991)
Volume of treatment cylinder or tank	m^3	10-15	20-100
Impregnating oil consumption (1)	kg/h	15-18	34-116 (e.g. for wooden posts or paddock fence elements) 58-211 (for railway sleepers)
Timber throughput (2)	m^3/h	0.16-0.21 (related to treated components)	0.5-0.9 (e.g. for wooden posts or paddock fence elements) 1.5-2.4 (for railway sleepers)

(1) The impregnating oil consumption indicated relates to the timber volume that can be treated within 24 hours, depending, among other factors, on the impregnation process and the wood species.
(2) The timber throughput indicated relates to the timber volume that can be treated within 24 hours, depending, among other factors, on the impregnation process and the wood species.
Source: [231, Germany 2013]

The specific creosote consumption (i.e. consumption of creosote per m^3 of wood treated) reported during the data collection for this BREF (2017) for pressure treatment processes is summarised in Table 15.13. For non-pressure processes, no data were reported.

Table 15.13: Reported specific creosote consumption for creosote pressure treatment (reporting period 2014-2016)

Plant	Commodities	Wood species treated	Creosote type	Penetration class (EN 351)	Use class	Creosote consumption (kg/m^3)
PL-1	Sleepers, wooden bearers	Beech, pine, oak	B, C	NP 5	UC 4	85-94
UK-1	Poles, sleepers, posts, fence rails / decking boards	Pine, Douglas fir, larch, spruce	NI	NP 5	UC 4	141-213 (1)
SE-1	Poles, posts, sleepers	Pine	B	NP 5	UC 4	91-101
FR-1	Sleepers	Oak	C	NP 5	UC 4	33-36
DE-5	Sleepers	Beech, oak	C	NP 6, NP 4	UC 4	77-89
FR-2	Poles	Spruce	B	NP 4	UC 4	141-163

(1) Calculated from reported data. The upper end seems atypically high, compared to 141 kg/m^3 and 143 kg/m^3 reported for the other years.
NB:
NI: No information provided.
Source: [236, TWG 2017]

15.3.2.4 Water consumption

Water is used for preparing the treatment solution in water-based wood preservation, for steam production for drying wood, for steam fixation and for heating creosote.

The specific water consumption reported during the data collection for this BREF (2017) for water-based wood preservation plants is summarised in Table 15.14.

Table 15.14: Reported specific water consumption for water-based treatment processes for 2014-2016

Plant	Specific water consumption (m^3/m^3 treated wood)
DK-1	0.308
PL-1	0.316-0.331
UK-2 (Line 1)	0.100-0.127
UK-2 (Line 2)	0.012
UK-3	0.012
SE-2	0.131-0.136
SE-3	0.168-0.190
SE-1	0.357-0.360
FR-3	0.022-0.027*
FR-4 (Line 1)	0.299-0.300*
FR-4 (Line 2)	0.069-0.07*
FI-1	0.365-0.372*
DE-6	0.300
FR-5	0.017-0.018
DE-9	0.04
UK-4	0.126*

* Calculated from reported data.
Source: [236, TWG 2017]

15.3.2.5 Solvent consumption

Solvent-based preservatives contain approximately 5 % active ingredients (insecticides, fungicides or water-repellents) and 95 % organic solvent.

Nowadays, the so-called LOSP - light organic solvent preservatives - are used. In these preservatives, organic solvents such as white spirit or other petroleum-based hydrocarbons are used as solvents to carry the active ingredients (e.g. fungicides, insecticides, water-repellents) into the wood. White spirit consists mainly (> 80 %) of C_9-C_{11} hydrocarbons (aliphatics, alicyclics and aromatics); the remainder is largely C_7-C_8 and C_{12} hydrocarbons [148, COM 2009].

No solvent-based treatment plant took part in the data collection for the review of this BREF. Therefore, no data can be provided on the solvent consumption of such WPC plants.

A water-based plant and the supercritical CO_2 plant [Plant DK-2 in [236, TWG 2017]] provided information on solvent consumption, albeit without an explanation of what the solvents are used for. The water-based plant reported a specific organic solvent consumption of 0.033 kg/m^3 of treated wood; the majority of this amount (95 %) represents dipropylene glycol monomethyl ether, the rest is acetic acid. The CO_2 plant reported a specific solvent consumption of 0.8 kg/m^3 of treated wood, basically glycol ether.

It should be noted that biocidal products used for water-based wood preservation may contain some solvents, but no specific information or data were provided.

15.3.2.6 Other impregnating chemicals consumption

If the enhancement agents used in wood hydrophobisation contain either aqueous emulsions or melts of hydrophobisation agents, no relevant emissions are expected from this process. However, no data from dedicated studies are currently available.

If liquid organic hydrophobisation agents (e.g. paraffins) are used, special aspects with regard to VOCs need to be considered [230, VDI 2014] [231, Germany 2013].

15.3.2.7 Auxiliary materials consumption

Oil, grease and lubricants are used in very small quantities in WPC [231, Germany 2013].

15.3.2.8 Energy consumption

The energy consumption of a WPC plant depends on the plant type and the process(es) applied. The TWG identified energy consumption and efficiency for creosote processes and autoclave processes as a key environmental issue (KEI). It was concluded to include in the information and data collection energy consumption (total consumption and specific/production-related consumption in kWh/m^3 of wood/wood product) and energy efficiency together with the relevant contextual information (including the process boundaries used). However, very few data were submitted on these issues.

Table 15.15 provides an overview of the data on specific energy consumption reported during the WPC 2017 data collection. In general, energy is used for generation of pressure/vacuum during treatment, heating of preservative solution, the off-gas treatment system and transportation/charging of wood.

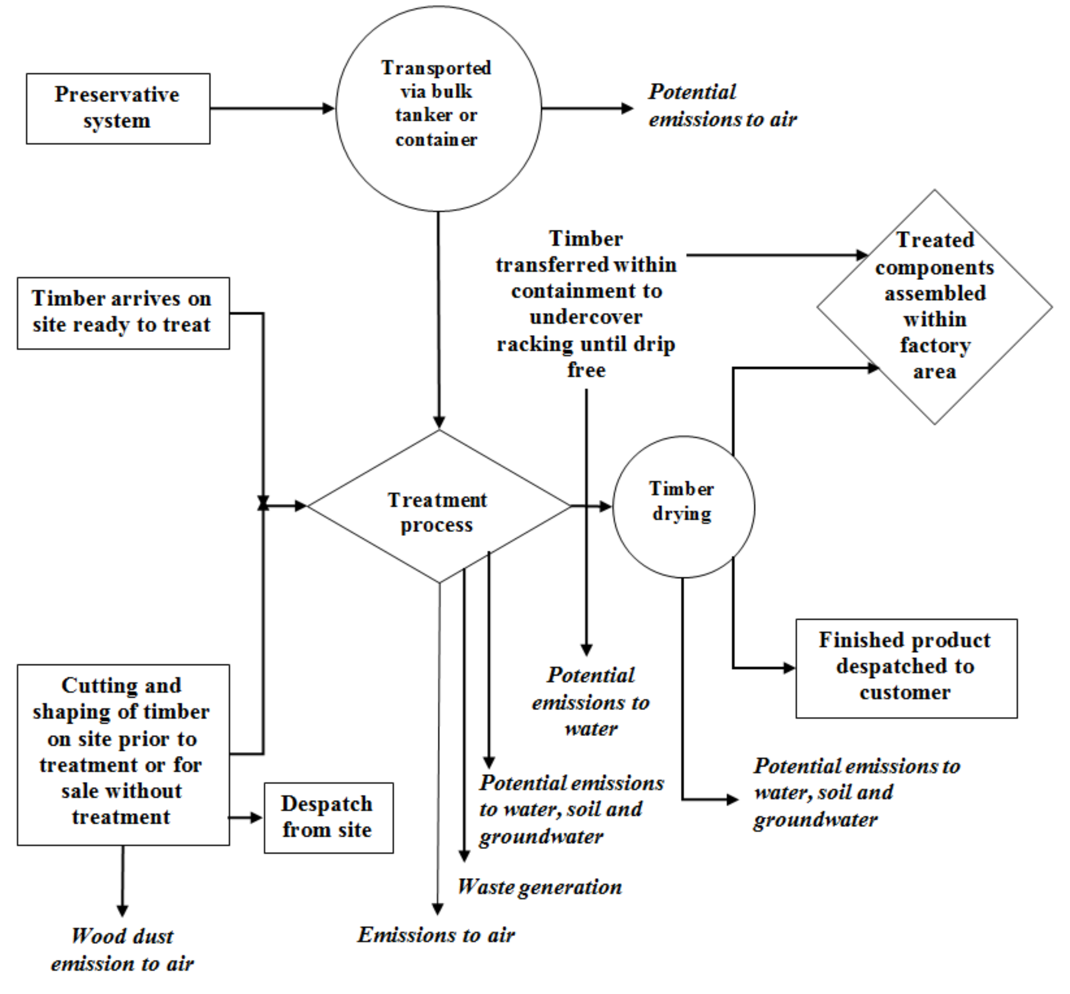
Table 15.15: Reported specific energy consumption for wood preservation (for the period 2014-2016)

Plant	**Specific energy consumption (kWh/m^3 treated wood)**
DK-2	20
PL-1	9.75-10.69
UK-3	0.7-1.1
IT-1	12.5-20.5
IT-2	91.04
SE-2	39-61
SE-3	8.3-9.6
DE-5	143.2-177.1
DE-6	25
Source: [236, TWG 2017]	

15.3.3 Outputs and emissions

15.3.3.1 General overview of emissions

Figure 15.12 presents possible emissions and releases from WPC plants.



Source: Adopted from [235, UK DEFRA 2013]

Figure 15.12: Flow diagram of a typical wood preservation installation showing consumption and emissions

15.3.3.2 Emissions to soil and groundwater

The preservatives applied in this industry are by nature ecotoxic. The industry has a history of using POPs and/or PBTs. The industry has been a significant source of some POPs, such as PAHs and PCP. PAH emissions from creosote use are important. It was reported in 1999 that wood preservation contributed 30 % of the total EU-15 POP emissions [99, UKHSE 2006] [100, EEA 1999].

While the use and emission of these substances has decreased due to increasing legislation and industry changes, substances such as creosote and copper salts are still in use.

Moves to substances that are less harmful to human health (in manufacture and application) have led to the use of substances such as pyrethroids (e.g. permethrin). These can have a high aquatic toxicity.

All chemicals (solvents, creosote, active substances/biocides, additives, hydrophobing agents, fire-retardants, etc.) used in the wood preservation process bear the risk of being emitted to soil and eventually to groundwater as accidental releases from the processes. Chemicals that are no longer used may also still be emitted to groundwater if there is contaminated soil on site from previous WPC plant operations.

The information on potential pollutants and parameters monitored in soil and/or groundwater which was provided during the WPC 2017 data collection is summarised in Table 15.24 and Table 15.25.

15.3.3.3 Emissions to water

In general, waste water can arise as surface run-off water, accidental releases (drips or spillages) of chemicals used in wood preservation and firefighting water. Any chemical (or constituents thereof) used in the wood preservation process may be a pollutant present in the waste water.

A summary of the information on emissions to water from WPC plants provided during the WPC 2017 data collection is given in Table 15.16. For information on applied waste water treatment techniques, see Section 15.4.10.

Table 15.16: Emissions to water from WPC plants

Plant	Parameter (unit)	Monitoring frequency	Year	Ave.	Max.
UK-1	Cu (mg/l)	NI	2016	0.017	NI
UK-1	Cr (mg/l)	NI	2016	< 0.002	NI
UK-1	PAHs (mg/l)	NI	2016	0.059	NI
UK-1	Benzo[a]pyrene (mg/l)	NI	2016	< 0.01	NI
SE-1	Cu (mg/l)	2/yr	2016	0.47	NI
SE-1	Cr (mg/l)	2/yr	2016	0.0129	NI
SE-1	PAHs (mg/l)	2/yr	2016	0.009	NI
SE-1	Benzo[a]pyrene (µg/l)	2/yr	2016	0.0135	NI
SE-1	HOI [oil] (mg/l)	2/yr	2016	0.1495	NI
SE-1	As (mg/l)	2/yr	2016	0.0148	NI
SE-1	PAH carcinogenic (µg/l)	2/yr	2016	0.165	NI
SE-1	Cu (mg/l)	2/yr	2015	0.12	NI
SE-1	Cr (mg/l)	2/yr	2015	0.0022	NI
SE-1	PAHs (mg/l)	2/yr	2015	0.013	NI
SE-1	Benzo[a]pyrene (µg/l)	2/yr	2015	0.01	NI
SE-1	HOI [oil] (mg/l)	2/yr	2015	0.201	NI
SE-1	As (mg/l)	2/yr	2015	0.0058	NI
SE-1	PAH carcinogenic (µg/l)	2/y	2015	0.064	NI
SE-1	Cu (mg/l)	2/yr	2014	0.101	NI
SE-1	Cr (mg/l)	2/yr	2014	0.0016	NI
SE-1	PAHs (mg/l)	2/yr	2014	0.022	NI
SE-1	Benzo[a]pyrene (µg/l)	2/yr	2014	0.034	NI
SE-1	HOI [oil] (mg/l)	2/yr	2014	0.11	NI
SE-1	As (mg/l)	2/yr	2014	0.0053	NI
SE-1	PAH carcinogenic (µg/l)	2/yr	2014	0.5	NI
DE-5	Cu (mg/l)	NI	2016	1. 0.29 2. 0.23	1. 0.38 2. 0.24
DE-5	Cr (mg/l)	NI	2016	1. < 0.01 2. < 0.01	NI
DE-5	PAHs (mg/l)	1/yr	2016	81.8	NI
DE-5	Benzo[a]pyrene (µg/l)	1/yr	2016	< 0.01	NI
DE-5	HOI [oil] (mg/l)	NI	2016	1. < 5 2. < 5	NI
DE-5	Least volatile lipophilic substances (mg/l)	NI	2016	1. 18.8 2. 14.4	1. 31 2. 39
DE-5	Phenol index (mg/l)	NI	2016	1. 1.28 2. 0.77	1. 1.7
DE-5	COD (mg/l)	NI	2016	1. 600 2. 281	1. 630

Source: [236, TWG 2017]

15.3.3.4 Emissions to air

Emissions to air may arise from solvent-based processes and wood preservation using creosote due to the volatile compounds in the preservatives (e.g. VOCs, PAHs, odour, CMR substances, SVHC) or when off-gas treatment by thermal oxidation is applied (NO_X and CO).

Aerosols (of preservatives) may be emitted for all wood preservative types (WB, SB and C) when preservatives are sprayed or at the outlet of vacuum pumps, if some of the preservative solution is extracted.

Heating of impregnating chemicals such as oil or wax may result in organic compound emissions to air.

Emissions to air from vehicles (transport of wood on site) are considered not WPC-specific and of minor importance.

15.3.3.4.1 Emissions to air from solvent-based and creosote wood preservation

VOC emissions

The main emission source is from the solvent content of the applied substances. Solvents that remain in the wood after complete drying evaporate over longer periods of time. Fugitive emissions occur during handling, application and drying stages. However, the majority of the emissions occur during the drying process.

At the EU-25 level in 2000, (according to the RAINS model) NMVOC emissions were 54.9 kt, representing 0.5 % of total NMVOC emissions (the total estimated EU-15 emission was 47.5 kt/yr in 1990). Total volume of wood treated in the industry was 11.5 million m^3, and the average emission factor was about 4.8 kg NMVOC/m^3, meaning that emissions from this sector were already partly abated in the EU-25 (the unabated emission factor being 19.8 kg/m^3, see Table 15.17). The contribution to the total EU-15 VOC emissions varied significantly from country to country [91, EGTEI 2005].

The options for reducing VOC emissions by primary (in-process) measures and secondary (end-of-pipe) measures have been estimated at the European level. Available data from 2005 which were taken from EGTEI's large reference installation [91, EGTEI 2005]:

- wood volume to be treated: 5 000 m^3/yr;
- solvent input: 99 t/yr;
- full load hours: 6 000 h/yr;
- flow rate: 22 200 m^3/h.

Table 15.17: Wood preservation default emission factors (EF), abatement efficiencies and costs for each combination

PMC (Primary measure code) (see Table 15.18)	**SMC (Secondary measure code)** (see Table 15.19)	**NMVOC EF (kg/m^3)**
00	00	19.80
00	01	7.30
00	02	7.30
01	00	16.60
01	01	6.10
01	02	6.10
02	00	11.00
03	00	0.25
04	00	0.15

NB:
EF: Emission factors.
Source: [91, EGTEI 2005]

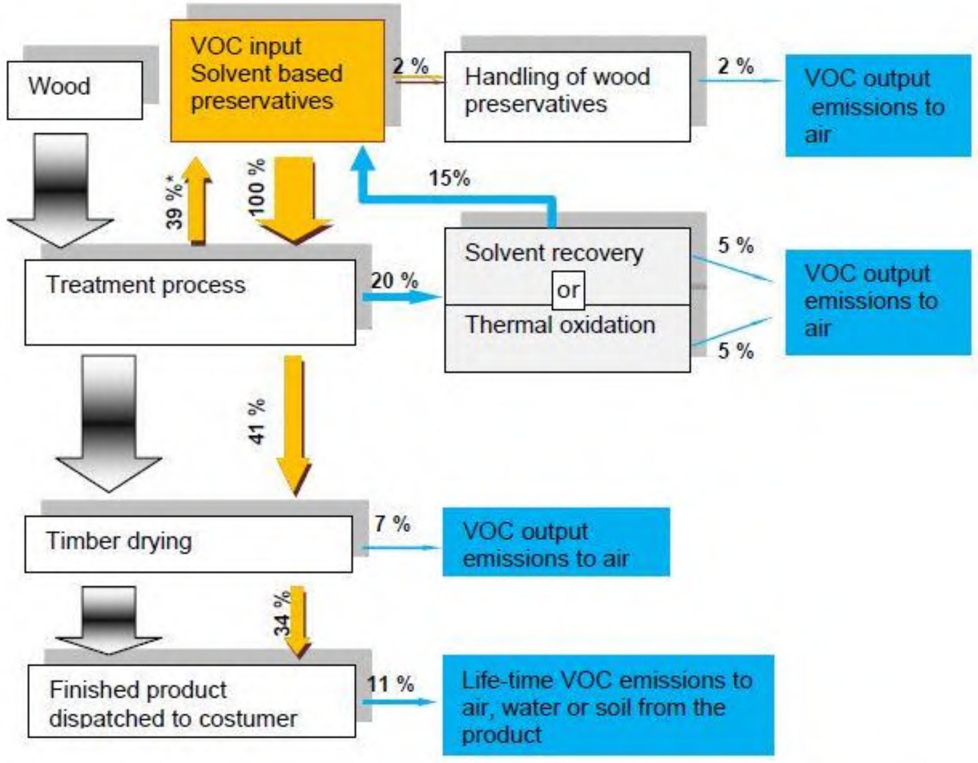
Table 15.18: Wood preservation: Primary abatement measures

PMC (Primary measure Code)	Description
00	100 % solvent-based preservatives conventional application techniques (dipping, brushing, spraying)
01	100 % solvent-based preservatives improved application technique (vacuum preservation system)
02	Process optimisation 100 % more concentrated solvent-based preservatives improved application technique (vacuum preservation system)
03	100 % water-based preservatives conventional application techniques (dipping, brushing, spraying)
04	100 % water-based preservatives improved application technique (vacuum preservation system)
Source: [91, EGTEI 2005]	

Table 15.19: Wood preservation: Secondary abatement measures

SMC (Secondary measure code)	Description
00	No secondary measure
01	Thermal oxidation
02	Adsorption and solvent recovery
Source: [91, EGTEI 2005]	

The flow chart in Figure 15.13 illustrates the process steps for wood impregnation using solvent-based products and shows where VOC emissions can occur. It also provides an indication of the percentage of solvent that is emitted from each process or that remains in the products. In the case of creosote the flow chart looks similar, but solvent recovery is not possible.



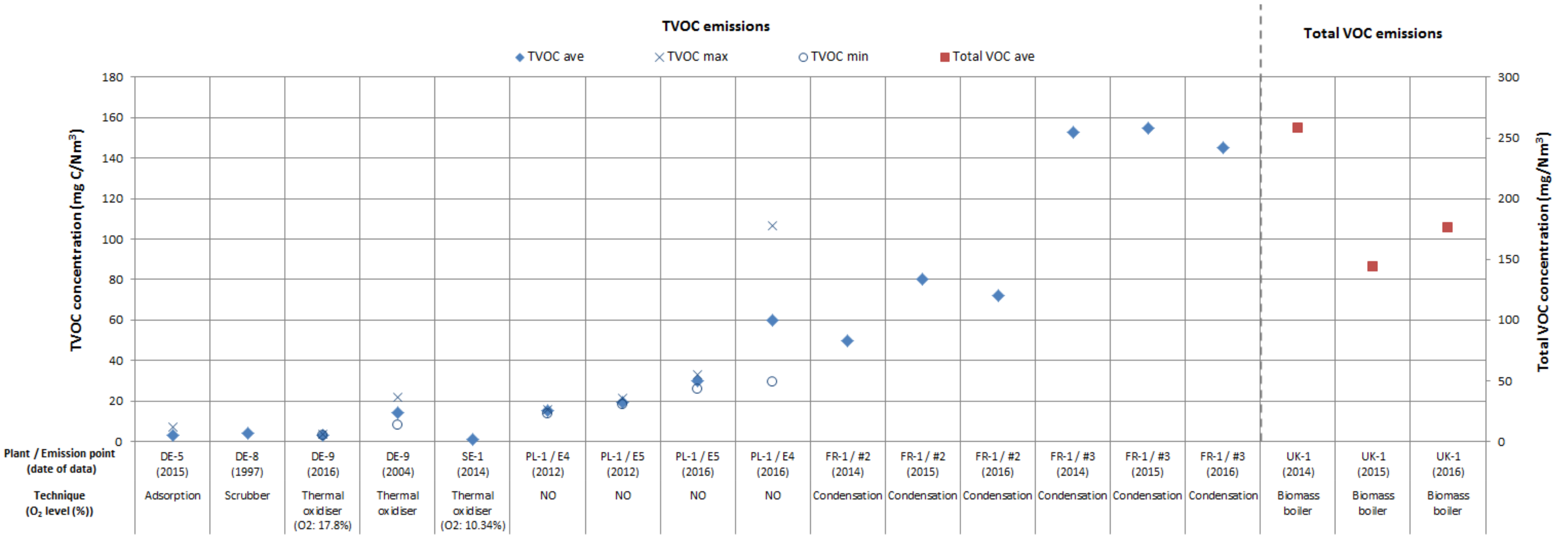
* The flow chart shows the input of VOC preservative and the 39 % excess, not taken up by the wood, which is pumped back into the storage tank

Source: [148, COM 2009]

Figure 15.13: Typical VOC inputs and outputs in wood impregnation processes using solvent-based preservatives

Approximately one third of the solvent that remains in the wood after drying at the wood preservation plant will evaporate over time, but the other two thirds will stay in the wood over its working life.

During the WPC 2017 data collection [236, TWG 2017], information was provided on VOC emissions from seven plants applying creosote treatment. The data were provided as TVOC emissions (in mg C/Nm^3) or as total VOC emissions (in mg/Nm^3). The emission range reported for TVOC was 1.00 mg C/Nm^3 to 154.9 mg C/Nm^3. One plant not applying any VOC treatment technique reported measurement results for the loading and unloading steps of the autoclave in the range of 13.64 mg C/Nm^3 to 106.52 mg C/Nm^3. Plants that are applying treatment techniques such as a thermal oxidiser, adsorption and a scrubber, provided measurement results in the range of 1-22 mg C/Nm^3 (in which the upper level refers to the maximum value of a measurement from 2004). For one of these plants (DE-5), detailed information provided for the measurements shows that, based on eight single measurements for different process steps of the creosote treatment (i.e. unloading and loading of wood, pressure period, loading of vessel with creosote – flooding –, reconditioning of creosote, heating of creosote, vacuum generation in vessel, vacuum period), measurement results in the range of 0.8 mg/Nm^3 to 6.9 mg/Nm^3 are reported. For another plant applying condensation as an abatement technique, average emission values in the range of 49.7 mg C/Nm^3 to 154.9 mg C/Nm^3 were reported for two autoclaves. One plant incinerating the waste gases from the creosote plant together with uncontaminated wood waste in a biomass boiler reported total VOC values ranging from 144.2 mg/Nm^3 to 258.1 mg/Nm^3 (without information on the oxygen level in the waste gas of the biomass boiler). The information on VOC emissions to air from creosote plants as reported during the WPC 2017 data collection is shown in Figure 15.14. No information on VOC emissions from solvent-based plants was submitted.

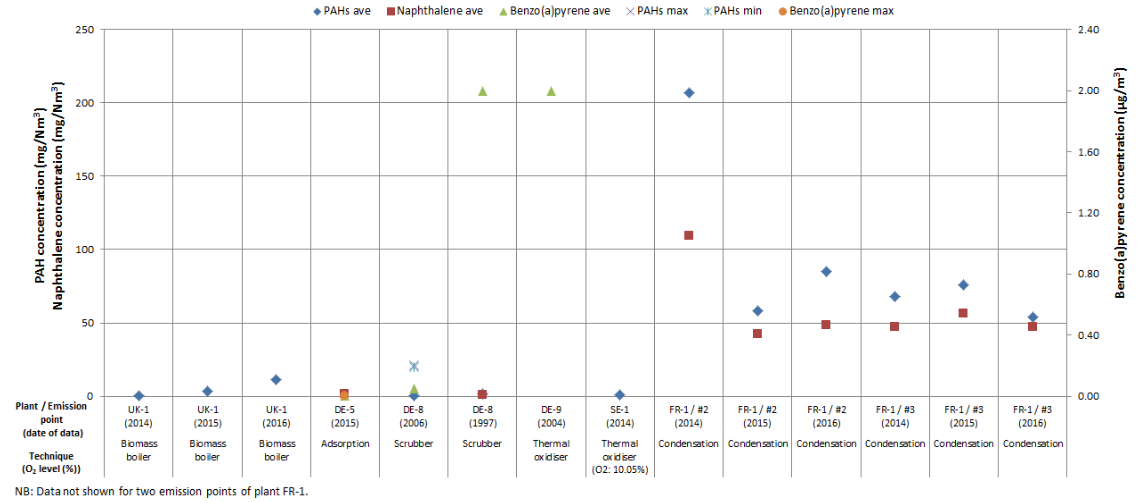


Source: [236, TWG 2017]

Figure 15.14: Reported VOC emissions in waste gases from creosote plants

PAHs

During the WPC 2017 data collection [236, TWG 2017], information was provided on PAHs, naphthalene and benzo[a]pyrene emissions for five plants applying creosote treatment. Reported emission values for PAHs range from < 1 mg/Nm^3 to 85.1 mg/Nm^3 (with one extreme value of 206.6 mg/Nm^3 reported). The data compilation in Figure 15.15 shows that plants applying abatement techniques make up the lower end of the range, with four plants reporting values of 0.2 mg/Nm^3 and 1.38 mg/Nm^3 (for a scrubber) and 1 mg/Nm^3 (at a 10.5 % O_2 level for a thermal oxidiser) and up to 11.1 mg/Nm^3 (for combustion in a biomass boiler, without information on the O_2 levels). The one plant reporting PAH values (for two emission points) and applying condensation as an abatement technique shows a clearly higher emission range starting from 53.8 mg/Nm^3. For naphthalene, two plants with abatement that submitted data (one with adsorption, the other with a scrubber) reported values of 1.2 mg/Nm^3 and < 1.9 mg/Nm^3, while the plant applying condensation as an abatement system reports a range of 42.3-56.6 mg/Nm^3 (with one extreme value of 109.4 mg/Nm^3, corresponding to the same measurement as the peak value for PAHs above).



Source: [236, TWG 2017]

Figure 15.15: Reported PAH, naphthalene and benzo[a]pyrene emissions in waste gases from creosote plants

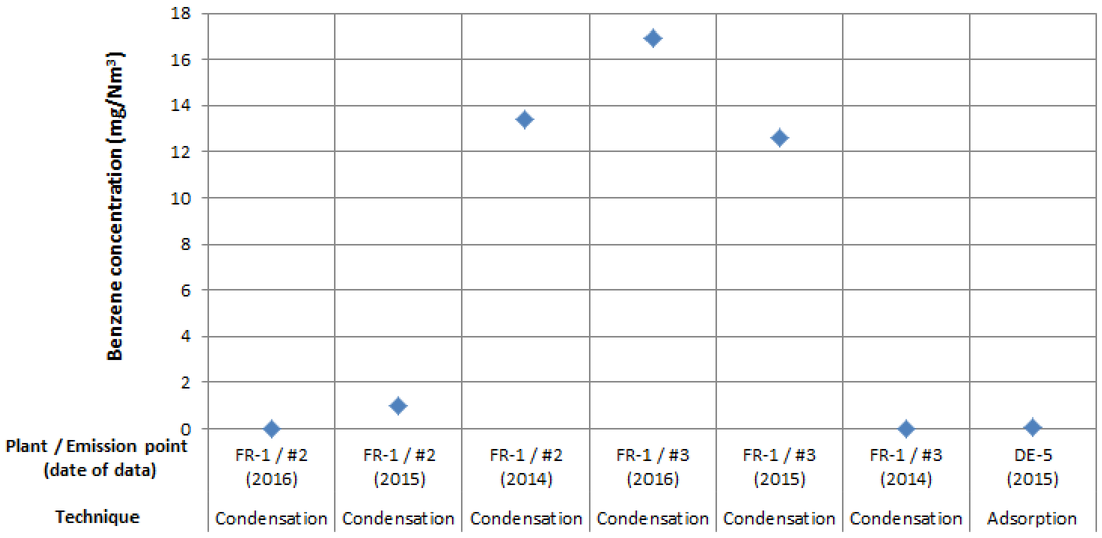
During the kick-off meeting, the TWG concluded to include in the information and data collection fugitive emissions of PAHs. However, no information on fugitive emissions of PAHs was submitted.

(Other) CMR substances

During the kick-off meeting, the TWG identified emissions of CMR substances to air as a KEI for solvent-based (SB) and creosote plants. No information was submitted for SB plants.

Two creosote plants provided information on benzene emissions (see Figure 15.16). Values were 0.06 mg/Nm^3 for the plant with adsorption installed, and ranging from zero to 16.9 mg/Nm^3 for the plant (for two emission points) applying condensation as an abatement technique.

One plant also provided data on phenol emissions; the value measured in 2015 was < 0.032 mg/Nm^3.



Source: [236, TWG 2017]

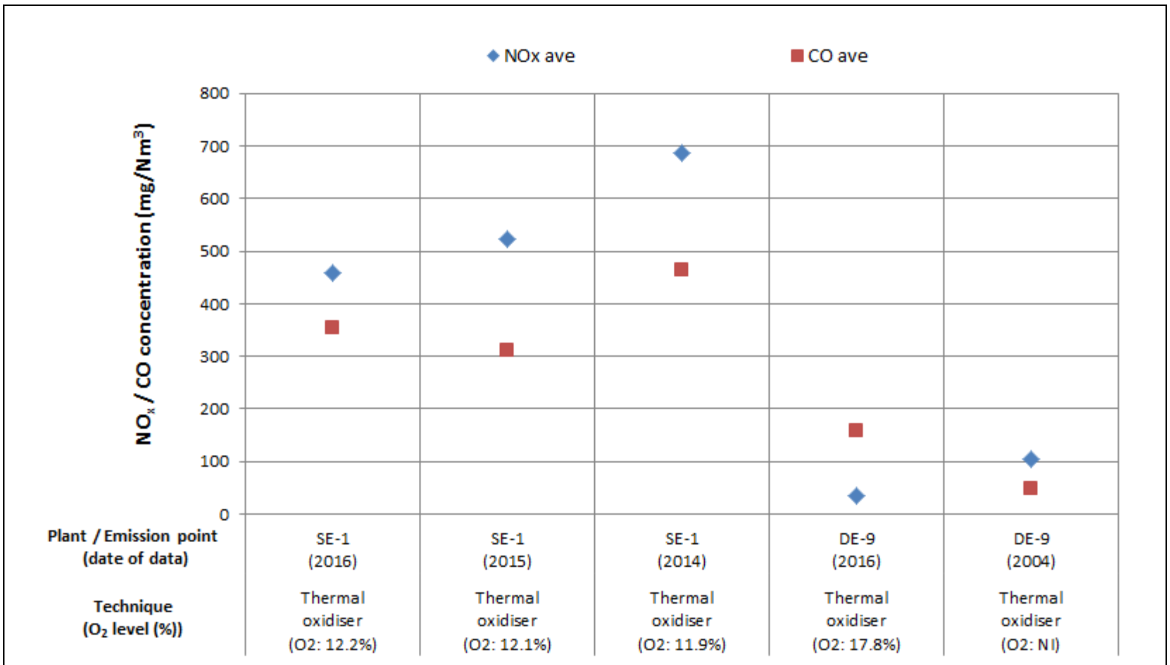
Figure 15.16: Reported benzene emissions in waste gases from creosote plants

During the kick-off meeting, the TWG concluded to include in the information and data collection fugitive emissions of benzene. However, no information on fugitive emissions of benzene was submitted.

NO_X and CO emissions

NO_X and CO emissions are not emitted from the wood preservation process itself, but may be relevant for plants applying thermal oxidation or other combustion processes to reduce VOC emissions in waste gases.

Two of the creosote plants that took part in the data collection with thermal oxidisers provided data on NO_X and CO emission values (see Figure 15.17). NO_X emissions range from 35 mg/Nm^3 to 686 mg/Nm^3 (for the upper end of the range an O_2 level of 11.9 % was reported) with corresponding CO levels of 158 mg/Nm^3 and 464 mg/Nm^3, respectively. Also, lower CO values (49 mg/Nm^3 and 312 mg/Nm^3) were reported.



Source: [236, TWG 2017]

Figure 15.17: Reported NOx and CO emissions in waste gases from creosote plants

Odour

During the kick-off meeting the TWG concluded that odour, together with emissions to air, is a KEI for plants applying solvent-based preservatives and creosote treatment. However, no information was submitted on odour.

No information was submitted for solvent-based plants during the WPC 2017 data collection [236, TWG 2017].

15.3.3.4.2 Other emissions to air from preservation of wood and wood products with chemicals

Aerosols

Aerosol and vapour emissions to air from non-pressure and pressure processes (including the treatment vessel, cylinder door, process tank, work tank vents, etc.) were identified at the kick-off meeting as a KEI for the WPC sector as a whole, but no data were submitted.

Some aerosols are generated during the final phases of the pressure treatment process, especially at the end of the final vacuum period and the return of the internal pressure in the treatment vessel back to atmospheric pressure [243, EOS 2016].

15.3.3.5 Waste generation

Wastes arising from timber treatment plants may include:

- redundant preservative solution;
- sludge and debris from tanks;
- sawdust and other materials which have been used to soak up spills;
- redundant containers that still contain residues of the product;
- redundant equipment (prior to decontamination);
- contaminated soil / dust / dirt.

The information on waste types and amounts generated which was provided during the WPC 2017 data collection is summarised in Table 15.20.

Table 15.20: Specific waste generation values based on the reported waste types and amounts for wood preservation of wood and wood products with chemicals

Plant	Waste type	Specific waste generation (kg/m^3 treated wood)			
		2014	2015	2016	Average over three-year period
DK-2	Sludges from regeneration system	0.248	0.143	0.115	0.152
DK-1	Sludges from cleaning	-	-	0.233	0.233
PL-1	Furnace ash, wood packaging, mineral engine, gear and lubricating oils, sorbents, filter materials, oil filters, used electrical and electronic equipment, contaminated wood, plastic packaging, worn tyres	0.732	0.216	0.075	0.344
UK-1	Treated timber, items contaminated with preservatives, non-hazardous waste, absorbents, WWTP sludge	4.18	2.91	4.81	3.96
UK-3	Operating residues, plastic packaging, damaged wood waste	0.544	0.529	0.635	0.559
IT-2	Sludges, packaging materials, adsorbents, filter materials, used tyres, mineral oils, other emulsions, solvent and solvent mixtures	81.16	25.31	29.33	44.45
SE-2	Sludges from cleaning, items contaminated with preservatives	0.025	0.034	0.074	0.045
SE-3	Dust and sludges from cleaning	0.059	-	-	0.059
SE-1	Sludges from cleaning	-	0.035	0.454	0.251
FR-3	Sludges and debris from tanks and treatment process	0.024	-	-	0.024
FR-4	Hazardous waste from cleaning	0.021	0.018	0.015	0.018
FR-1	Waste water, solid waste from cleaning, oil waste	20.13	10.57	9.16	12.99
FI-1	Treated wood, plastic, sawdust	8.58	8.48	9.66	8.90
DE-9	Treated wood residues	3.545	3.545	3.545	3.545
DE-5	Spillages, sludge, hazardous waste from cleaning	3.821	5.832	4.459	4.731
DE-6	Sludges from treatment process	0.118	0.105	0.105	0.109
DE-8	Treated wood and contaminated residues (dust)	-	-	0.513	0.513
FR-5	Sludges	0.009	-	-	0.009
FR-2	Treated wood	0.025	-	0.023	0.024

NB:
For Plant PL-1, additional waste categories reported as follows: 12.7 kg/m^3 sawdust for 2014 and 4.25 kg/m^3 contaminated water for 2016.
For Plant IT-2, additional waste category reported as follows: 20.1 kg/m^3 wooden packaging as an average for the period of 2014-2016.
For Plant FR-1, additional waste categories reported as follows: 4.02 kg/m^3 and 49.29 kg/m^3 soil contaminated with creosote for 2015 and 2016 respectively.
Source: [236, TWG 2017]

15.4 Techniques to consider in the determination of BAT for preservation of wood and wood products with chemicals

15.4.1 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 15.18).

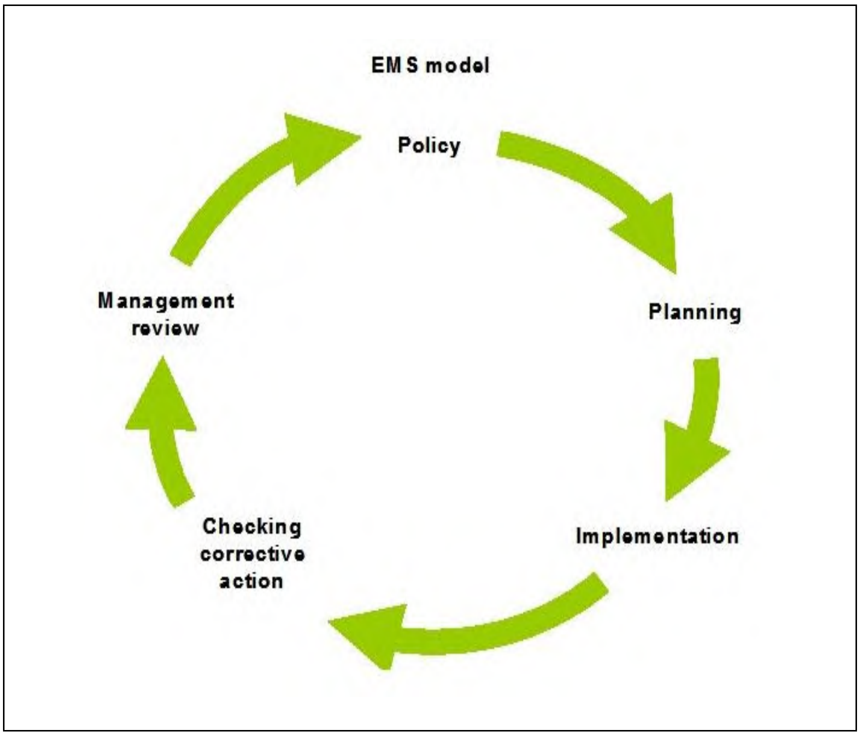


Figure 15.18: Continuous improvement in an EMS model

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, can give higher credibility to the EMS especially when subjected to a properly performed external verification. The European Union eco-management and audit scheme (EMAS) according to Regulation (EC) No 1221/2009 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 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 features:

i. commitment, leadership, and accountability of the management, including senior management, to the implementation of an effective EMS;
ii. an analysis that includes the determination of the organisation's context, the identification of the needs and expectations of interested parties, the identification of characteristics of the installation that are associated with possible risks for the environment (or human health) as well as of the applicable legal requirements relating to the environment;
iii. development of an environmental policy that includes the continuous improvement of the environmental performance of the installation;
iv. establishing objectives and performance indicators in relation to significant environmental aspects, including safeguarding compliance with applicable legal requirements;
v. planning, and implementing the necessary procedures and actions (including corrective and preventive actions where needed), to achieve the environmental objectives and avoid environmental risks;
vi. determination of structures, roles and responsibilities in relation to environmental aspects and objectives and provision of the financial and human resources needed;
vii. ensuring the necessary competence and awareness of staff whose work may affect the environmental performance of the installation (e.g. by providing information and training);
viii. internal and external communication;
ix. fostering employee involvement in good environmental management practices;
x. establishing and maintaining a management manual and written procedures to control activities with significant environmental impact as well as relevant records;
xi. effective operational planning and process control;
xii. implementation of appropriate maintenance programmes;
xiii. emergency preparedness and response protocols, including the prevention and/or mitigation of the adverse (environmental) impacts of emergency situations;
xiv. when (re)designing a (new) installation or a part thereof, consideration of its environmental impacts throughout its life, which includes construction, maintenance, operation and decommissioning;
xv. implementation of a monitoring and measurement programme; if necessary, information can be found in the Reference Report on Monitoring of Emissions to Air and Water from IED Installations;
xvi. application of sectoral benchmarking on a regular basis;
xvii. periodic independent (as far as practicable), internal auditing and periodic, independent external auditing in order to assess the environmental performance and to determine whether or not the EMS conforms to planned arrangements and has been properly implemented and maintained;

xviii. evaluation of causes for nonconformities, implementation of corrective actions in response to nonconformities, review of the effectiveness of corrective actions, and determination of whether similar nonconformities exist or could potentially occur;

xix. periodic review, by senior management, of the EMS and its continuing suitability, adequacy and effectiveness;

xx. following and taking into account the development of cleaner techniques.

Specifically for wood preservation with chemicals, BAT is also to incorporate the following features in the EMS:

i. Keeping up to date with the developments in biocidal products and in associated legislation (e.g. authorisation of products under the BPR) with a view to using the most environmentally friendly processes.

ii. Inclusion of a solvent mass balance for solvent-based and creosote treatment.

iii. Identification and listing of all environmentally critical process and abatement equipment (whose failure could impact on the environment). The list of critical equipment is kept up to date.

iv. Inclusion of plans for the prevention and control of leaks and spillages, including waste management guidelines for dealing with waste arising from spillage control.

v. Recording of accidental leakages and spillages, and improvement plans (counter measures).

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

No information submitted.

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 level of detail and the degree of formalisation of the EMS will generally 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 accurately determine 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 [250, IAF 2010].

Driving force 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.

Reference literature
[250, IAF 2010] [251, EU 2009] [252, COM 2010] [253, COM 2015] [254, CEN 2015]

15.4.2 Substitution of harmful / hazardous substances

15.4.2.1 Use of water-based preservatives

Description
Solvent-based preservatives or creosote are replaced by water-based preservatives. Water acts as the carrier for the biocides.

Technical description
Water-based low-pressure processes mainly substitute solvent-based preservative systems while water-based high-pressure processes are suitable to substitute creosote-using ones. Water-based treatments can be used instead of creosote for some end uses up to a 30-year life expectancy (and longer with the case-by-case approval of the preservative manufacturer). Examples are medium-life fencing, cladding of agricultural buildings, some horticultural uses [148, COM 2009].

Water-based preservatives can also be used in open impregnation systems, e.g. in dipping installations [148, COM 2009].

Achieved environmental benefits

- No use of creosote or solvents.
- Emissions of solvents (i.e. VOCs) are avoided.

Environmental performance and operational data
Switching from solvent-based preservatives to water-based systems can achieve a VOC reduction approaching 100 %, or, for water-based microemulsion systems, a reduction of 99 % [148, COM 2009].

Consumption and emission levels for wood and wood products preservation using water-based treatment chemicals are detailed in Section 15.3.

Technical considerations relevant to applicability

- Applicable to plants using solvent-based preservatives or creosote.
- In some cases the quality requirements of the wood/wood product may not be achievable with water-based preservatives, e.g. due to the swelling of the wood, which must be avoided when treating certain finished products.
- In addition, timber treatments with higher levels of copper (ACQ and CuAz) are more corrosive [148, COM 2009].

Economics
The process of impregnation of solvent-based and water-based preservatives is very similar with no significant economic differences.

In a typical new installation, wood is treated in an 18 m^3 treatment vessel with a charge capacity of 14 m^3 of wood. The impregnation cycle takes 4 hours and can therefore be repeated six times a day due to 24-hour shift work. With 250 working days, a yearly production of about 20 000 m^3 can be achieved. Depending on the intended application, the raw material costs are between EUR 10/m^3 and EUR 30/m^3, energy costs are negligible and water costs are EUR 0.5-1.5/m^3. The investment costs for this plant are about EUR 250 000. Depending on the preservative type, the impregnation costs can vary between EUR 20/m^3 and EUR 40/m^3 [148, COM 2009].

Driving force for implementation
Reduction of environmental risks.

Example plants
Plants DE-6, FR-5, IT-2, UK-2 and UK-4 in [236, TWG 2017]

Reference literature
[148, COM 2009] [236, TWG 2017]

15.4.2.2 Substitution of treatment chemicals with others that have a lower environmental impact

Description
Substitution of treatment chemicals currently in use with less hazardous ones based on a regular (e.g. annual) check aiming at identifying potentially new available and safer alternatives.

Technical description
Information for two example plants was provided and is given below.

Example plant: IT-1 (WB plant) in [236, TWG 2017]
CCA is substituted with other water-based biocides (i.e. type g of Table 15.10).

Example plant: DE-3 in [231, Germany 2013]
The plant converted the impregnation process from chrome-containing wood preservatives to chromium-free in 2010. Water-soluble, liquid, fixating wood preservatives are used on the basis of copper complex compounds and a quaternary ammonium compound.

The impregnation installation and the impregnating process needed to be adapted to the applied preservatives (e.g. structural measures, reduced vessel filling level due to formation of foam, respecting the process parameters).

Achieved environmental benefits
The chemicals used have less direct impact in the event of emissions. Less hazardous waste is produced with regards to the life cycle of the products.

Example plant: DE-3 in [231, Germany 2013]
The chrome-free copper-containing preservative is not mobile, i.e. it has no creep properties, even in the wood. Chromium-free preservatives are, in contrast to chromium-containing products, immobile in the soil. Chromium-containing wood preservatives can cause environmental pollution of the groundwater and related contaminated site, due to the mobile properties of chromium(VI).

The chrome-free wood preservatives are self-fixing and the fixing process (binding on the wood fibre) is relatively fast: after 12 hours ~ 97 %; after 48 hours ~ 99 %.

Environmental performance and operational data

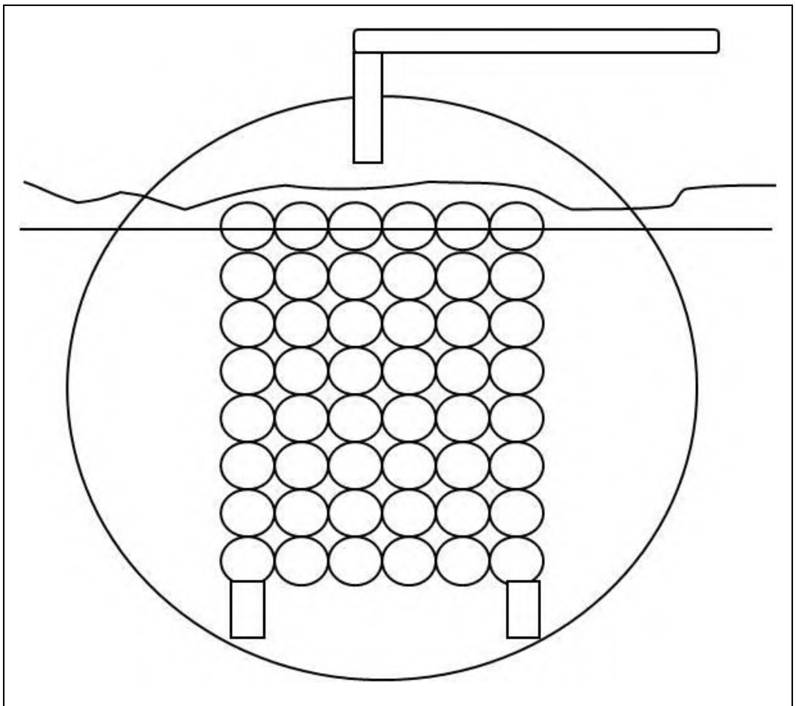
Example plant: DE-3 in [231, Germany 2013]

Due to the properties of chrome-free preservatives, the system parameters have to be more accurately followed, as it was before the substitution (this requires additional controlling measures such as a viscometer, electrical measurement, switching from the acidic (pH 3-4) to alkaline medium (pH 10.2–10.4)).

In the container containing wood preservative, the salt components can sink to the bottom of the tank, resulting in partial segregation. After longer non-operating times (e.g. during the weekends), the container contents need to be stirred before use in order to mix the wood preservative components [231, Germany 2013].

In Plant DE-3 which uses chromium-free wood preservatives, a vacuum must be gradually applied to reduce the foaming of the alkaline medium. Later on, a stronger vacuum is required to reach the required depth of impregnation (as the chromium-free preservatives have no creep properties, the stronger vacuum is required to reach the heartwood area by creeping, for example the remaining 5 mm).

Experience from Plant DE-3 has shown that the filling level of the impregnating boiler must be reduced due to the increased formation of foam resulting from the application of chromium-free wood preservatives (approximately 0.5 m less filling). In addition, it has to be checked that there are no dry spots on the top edges of the impregnation boiler (due to the lower filling level, the wood preservative does not reaches the wood) and that the wood is completely impregnated. The filling level of the impregnation boiler has to be precisely set in advance of the impregnation process and the impregnation boiler capacity can be exploited to a slightly lesser degree (reduced production capacity, see sketch below).



Source: [231, Germany 2013]

Figure 15.19: Reduction of filling level (example plant DE-3)

Cross-media effects

There is a lower degree of capacity utilisation in the installation through reduced filling level of the impregnating boiler. In the case of formation of dry areas, the wood must be repeatedly treated.

After service life, the impregnated wood products can be incinerated for energy use in an appropriate combustion plant. Chrome-free wood preservative induces chromium-free incineration ash [231, Germany 2013].

Technical considerations relevant to applicability

For the vacuum-pressure impregnation, there are generally no restrictions for the application of chromium-free preservatives. The following aspects, *inter alia*, have to be respected:

- increased, relatively strong foaming;
- accurate adjustment of the process parameters and necessity for additional control measures/instruments;
- lower filling level and thus lower production capacity;
- application of vacuum must be used at a different location, if necessary;
- corrosion or incrustations may occur.

The constraints cannot be excluded by application of other impregnation processes, e.g. the alternating pressure process there is also significant formation of foam. In this case, a precise selection of the adequate impregnating agent and impregnation process is required (for example, in collaboration with the wood preservative manufacturer) [231, Germany 2013].

For poles, for instance, it is applicable only according to the sector’s standard requirements and at the customer’s request. [Plant IT-1 in [236, TWG 2017]].

In general, substitution may be restricted due to product quality requirements or specifications.

Economics

Example plant: DE-3 in [231, Germany 2013]

The chromium-free preservative is about 30 % more expensive. Only small investments are required for the system adaptation (vacuum-pressure impregnation) which usually does not go significantly beyond the normal operating expenses (e.g. substitution of oil-cooled pumps with water-cooled pumps due to foam formation; replacement of corroded/encrusted lines/seal) [231, Germany 2013].

Driving force for implementation

Requirements under the BPR [231, Germany 2013].

Example plants

Plants DE-6, DE-9, FI-1, FR-5, FR-1, FR-3, FR-4, IT-2, IT-1, SE-2, SE-3, UK-2, UK-4, DK-2 in [236, TWG 2017] and Plant DE-3 in [231, Germany 2013].

Reference literature

[231, Germany 2013] [236, TWG 2017]

15.4.2.3 Use of low-volatility impregnating oils / Grade C creosote

Description

Substitution of Grade B creosote with Grade C creosote.

Technical description

The impregnation process is changed from impregnation with Grade B creosote to Grade C creosote.

Achieved environmental benefits
Reduced emission of VOCs, PAHs and odour.

Technical considerations relevant to applicability
Grade C creosote may not be applicable in the case of cold climatic conditions.

Grade C creosote is characterised by its higher crystallisation temperature compared to Grade B creosote. Therefore, when using Grade C creosote, the storage tanks and transportation system (e.g. pipes) are heated 20 °C above the determined crystallisation point.

Driving force for implementation
Reduction of environmental risks.

Example plants
Plants DE-5, DE-9, DE-8, FR-1, PL-1 and UK-1 in [236, TWG 2017].

Reference literature
[231, Germany 2013] [DE comment #378 in [212, TWG 2018]] [236, TWG 2017]

15.4.3 Soil, water and groundwater protection and material management

15.4.3.1 Appropriate plant design and layout

Description
The selection of an appropriate plant design and layout to control the generation of possible emissions to soil, water and groundwater.

Technical description
An appropriate plant design and layout includes:

- floor in the plant sloping towards a well or spill storage tank;
- roofed treatment area;
- level, impervious, paved traffic ways in delivery area;
- technically tight pumps, flanged joints, valves and feeders.

Achieved environmental benefits
Reduction of emissions to soil, water and groundwater.

Technical considerations relevant to applicability
Some design features, e.g. when affecting the floor/foundation underneath the plant, are best considered during the design stage of a plant; retrofitting existing plants requires interruption of production and space availability.

Driving force for implementation
Soil and groundwater protection.

Example plants
Reported by the majority of the plants in the data collection.

Reference literature
[236, TWG 2017]

15.4.3.2 Plant and equipment containment or bund

Description

The parts of the plant in which treatment chemicals are stored or handled, i.e. treatment chemicals storage area, treatment, post-treatment conditioning and interim storage areas (comprising treatment vessel, working vessel, unloading/pull-out facilities, dripping/drying area, cooling zone), pipes and ductwork for treatment chemicals, and creosote (re)conditioning facilities, are contained or bunded. Containments and bunds have impermeable surfaces, are resistant to treatment chemicals and have sufficient capacity to capture and hold the volumes handled or stored in the plant equipment. The liquids in the containments/bunds are collected to recover the treatment chemicals for their reuse in the treatment chemicals' system. Sludge generated in the collection system is disposed of as hazardous waste.

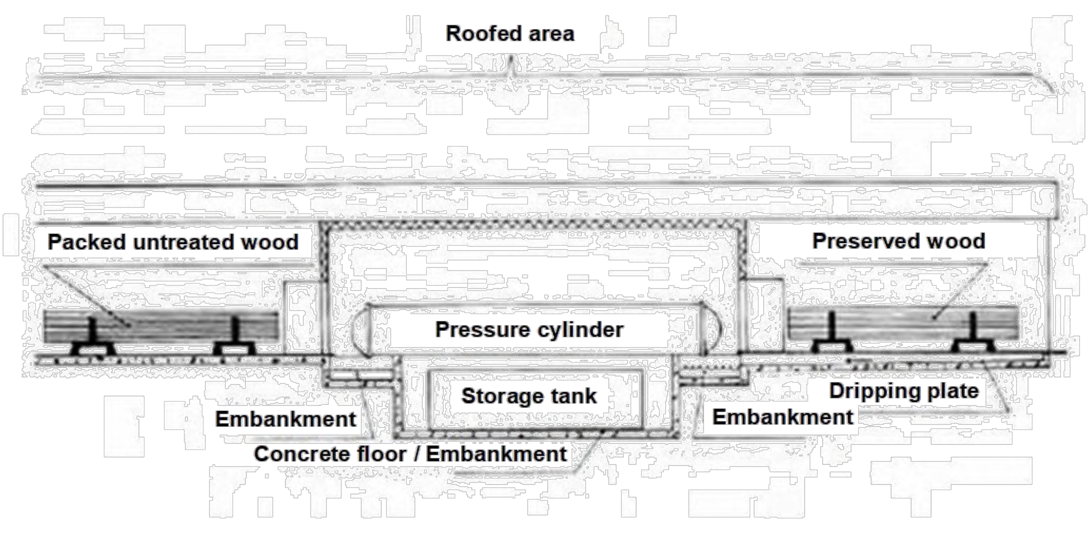
Technical description

Containments or bunds are designed to contain (larger amounts of) wood preservatives (chemicals) in the event of unpredicted leakage, rupture or failure of tanks, accidental spills, etc. The containment/bund should fulfil the following design features:

- capacity to retain all preservative solution (chemicals) in case of leakage or accident;
- impervious and resistant to the chemicals (preservative used) and sealed either by impermeable surfaces or impermeable coating systems;
- able to withstand the static pressure of the liquids (volume) to be captured.

One source suggested that the bund for plants with a single storage tank should be constructed with a capacity of at least 110 % of the preservative (chemical) storage capacity. For multiple tanks in the same containment or bund, it should be 110 % of capacity of the largest tank or 25 % of the total volume that could be stored in all tanks in the containment/bund - whichever is greater. In other scenarios (e.g. storage of preservative in drums), it should be at least 25 % of the total volume that could be stored at any time [241, EWPM/WEI 2016].

The containment area or bund can - depending on the site layout - incorporate the whole plant or consists of separate dedicated containments for parts of the WPC plant, e.g. containment of the wood preservative delivery, storage and mixing area, treatment vessel(s) and associated loading/unloading areas. Examples of potential designs are given in Figure 15.20, Figure 15.21 and Figure 15.22 below.



Source: [244, Norden 2014]

Figure 15.20: Schematic showing various options of precautionary measures (containment, drip pads, roof covers

Primary Security Containment (Bund)

Primary Security Containment (Bund)

The impermeable bund may also form the foundation for the treatment plant with a capacity to hold the designated additional volume over the installation chemical storage capacity. This ensures all chemical would be contained within the primary security bund should a plant storage tank fail.

The bund is a high percentage of the installation cost and some operators opt to build the bund with additional capacity for future development as shown here.

Source: [241, EWPM/WEI 2016]

Figure 15.21: Design examples for process containment

Treatment plant installed in Primary Security Containment (Bund)

High pressure treatment plant during construction phase installed within the bund

Source: [241, EWPM/WEI 2016]

Figure 15.22: Design examples for process containment

Achieved environmental benefits

Prevention or reduction of emissions to soil and groundwater.

Technical considerations relevant to applicability

Applicable to new plants or major upgrades of existing plants.

Retrofitting existing plants requires activity interruption and space availability near and under the treatment lines. The incompatibility with wood handling systems may limit the application to loading/unloading areas in the case of handling machines (instead of automatic systems) as the containment may limit the access of handling machines to loading/unloading areas [Plant IT-1 in [236, TWG 2017]].

Driving force for implementation
Soil and groundwater protection.

Example plants

- Containment of treatment plant and associated loading/unloading areas: PL-1, UK-1, UK-2, UK-3, UK-4, SE-3, FI-1, DE-5, DE-6, DE-7 and IT-2 in [236, TWG 2017].
- Containment of wood preservative delivery, storage and mixing area: PL-1, UK-1, UK-2, UK-3, UK-4, IT-1, SE-3, FR-3, FR-4, FR-1, FI-1, DE-9, DE-5, DE-8, DE-6, IT-2 and FR-5 in [236, TWG 2017].
- Containment of holding area of treated timber etc.: PL-1, UK-1, UK-2, UK-3, UK-4, SE-2, SE-3, FR-3, FR-4, FR-1, DE-5, DE-6, IT-2 and FR-5 in [236, TWG 2017].

Reference literature
[236, TWG 2017] [241, EWPM/WEI 2016]

15.4.3.3 Use of mobile absorbent systems

Description
When handling treatment chemicals (e.g. unloading of treatment chemicals from the vessels, moving the treatment chemicals in containers), possible spills are avoided by using absorbent materials.

Technical description
Absorbent materials (i.e. spill kits, pads, rolls, etc.) are used in such ways to contain dripping as a preventive measure during handling of treatment chemicals (e.g. unloading of treatment chemicals from the vessels, moving the treatment chemicals in containers). An example is positioning absorbent rolls on sides of the unloading pipe.

Achieved environmental benefits
Prevention or reduction of emissions to soil and groundwater.

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation

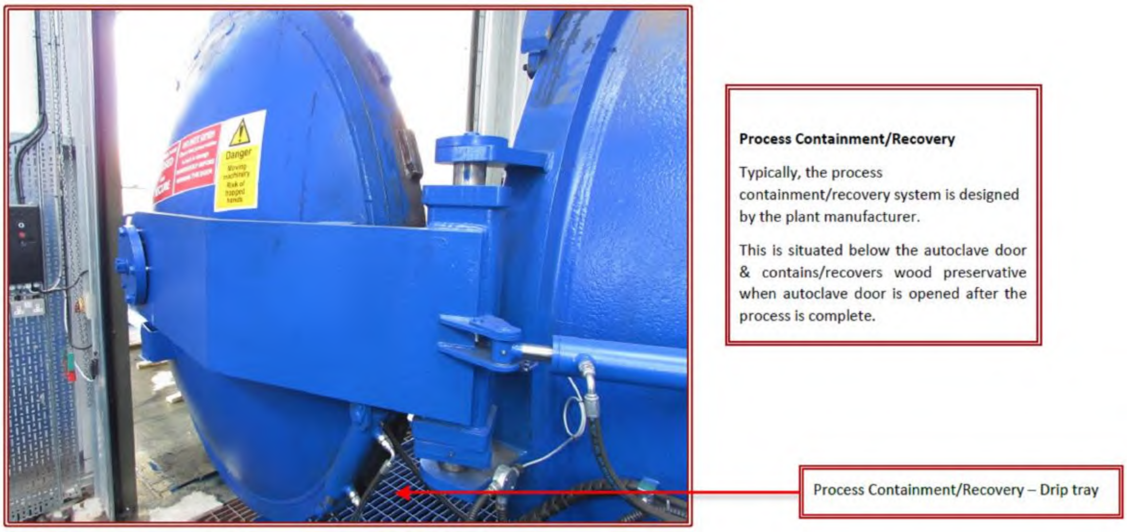
- Soil and groundwater protection.
- Workplace health and safety objectives including reduced risks of associated accidents, e.g. preventing slippery floors.

15.4.3.4 Drip trays

Description
A drip tray (made of treatment-chemical-resistant material) is used for collecting and recovering drips and spills of treatment chemicals as a local containment. It is placed under critical equipment or processes where drips may occur (i.e. valves, inlets/outlets of storage tanks, treatment vessels, working tanks, unloading/pull-out zones, handling of freshly treated wood, cooling/drying zone). The liquids in the drip trays are collected to recover the treatment chemicals for their reuse in the treatment chemicals' system. Sludge generated in the collection system is disposed of as hazardous waste.

Technical description

To collect and recover wood preservatives (chemicals) from process steps where dripping may occur (e.g. when opening the autoclaves, unloading the treatment vessel (pressure and non-pressure), or from freshly treated wood after transfer from the treatment vessel loading system), drip trays are installed (also referred to as drip pans, drip pads or collecting trays). Unlike containments and bunds, drip trays are smaller and designed to collect drips and spillages, rather than total tank volumes, during normal operation. Drip trays are designed in such a way that transport vehicles (e.g. forklifts) are not in contact with the potentially contaminated surfaces of the drip trays to prevent cross-contamination with treatment chemicals. Examples of potential drip tray configurations are shown in Figure 15.23 and Figure 15.24.



Process Containment/Recovery

Typically, the process containment/recovery system is designed by the plant manufacturer.

This is situated below the autoclave door & contains/recovers wood preservative when autoclave door is opened after the process is complete.

Process Containment/Recovery – Drip tray

Source: [241, EWPM/WEI 2016]

Figure 15.23: Example of a drip tray underneath an autoclave door

Process Containment/Recovery – Treatment plant loading system with an example of drip Containment/Recovery. Other processes and/or devices may be operated/installed to achieve the same.

Source: [241, EWPM/WEI 2016]

Figure 15.24: Example of a drip tray incorporated into the unloading system (beneath pull-out)

Achieved environmental benefits

Prevention or reduction of emissions to soil and groundwater.

Technical considerations relevant to applicability

Generally applicable.

Driving force for implementation

Soil and groundwater protection.

Example plants

Use of drip trays during discharge of treatment vessel (pressure and non-pressure) is reported by the majority of the plants. Use of drip trays in other process steps such as cooling and fixation (working area) is also reported by several plants in the data collection: UK-1, UK-4, SE-2, SE-3, FR-1, FI-1, DE-5, DE-8, IT-1, IT-2 and DE-7 in [236, TWG 2017].

Reference literature

[231, Germany 2013] [236, TWG 2017]

15.4.3.5 Impermeable floors and spill and surface run-off collection with reuse

Description

Floors of areas which are not contained or bunded, and where drips, spills, accidental releases or leaching of treatment chemicals may occur (e.g. for the storage of treated wood in the event that it is required in the BPR authorisation for the wood preservative used for the treatment) are impermeable to the substances concerned. The liquids on the floors are collected to recover the treatment chemicals for their reuse in the treatment chemicals' system. Sludge generated in the collection system is disposed of as hazardous waste.

Technical description

The floor in the areas where drippage, spills or accidental releases of preservatives/treatment chemicals or solvents may occur is sealed, and spills and/or surface run-off water is collected and used/reused in the preservative system. Techniques for the prevention of contamination of rain and surface run-off water are detailed in Section 15.4.10.1.

Information on several examples was provided and is given below.

Example plant: DE-1 (mixed plant with WB and C treatment) in [231, Germany 2013]

The floor where the extraction rails of the installation are located is extensively sealed (1 500 m^2). The rainwater from the sealed extraction rail area is collected in a 50 m^3 cistern over an oil-sludge collector and used as process water. The oil-sludge collector is cleaned regularly and accumulated waste is disposed of properly (European Waste Catalogue Code 13 08 99*; variable quantities depending on waste formation). If the capacity of the cistern is not enough, there is the possibility of storing rainwater in a wagon. If the cistern is full in the event of heavy rain, the surface water in the cistern is directed into the drainage channel.

The floor sealing consists of a double-bottom plate of water-impervious concrete. The detention reservoir is made of water-impervious concrete.

Example plant: DE-2 (WB plant) in [231, Germany 2013]

The extraction rail area and storage area for freshly treated wood is sealed (approximately 2 500 m^2) and supplied with an inlet channel. Dripping water flows either into a drip tray or into the inlet channel. The dripping water from the inlet channel is conducted over the drainage channel, oil-sludge collector and pipes and lines to a collecting tray (50 m^3) and returned back to the process.

The floor sealing consists of water-impervious concrete with an upper and lower steel mesh (thickness approximately 20 cm).

The sealed surface is covered and protected on the sides from rain. The extraction rail area and the storage surface are sloped to allow flowing liquids to drain into the drip tray or inlet channel and from there pass over the oil-sludge collector, pipes and lines into the collecting tray (50 m^3). The oil-sludge collector is regularly cleaned and the accumulated waste disposed of accordingly (about 750 kg/year).

The collecting container is a double-walled underground tank coated with an epoxy resin coating resistant to impregnating solution. The pump placed in the container is controlled over one float indicator, and, when it reaches a certain level, the collected liquid is pumped back into the impregnation installation. An acoustic warning signals a pump malfunction.

Example plant: DE-3 (WB plant) in [231, Germany 2013]
The roads on the premises are flat and fixed. The floor where the extraction rails are located is extensively sealed. The seal consists of the following layers:

- ≥ 3 cm of asphalt concrete;
- ≥ 15 cm bituminous base;
- 20-30 cm gravel base (partly available).

The dripping water and rainwater are led via the drainage channel to the collecting container and used as process water (approximately 2.5 % inclination). If necessary, the water (along with roof run-off water) can be intermediately stored in designated tanks. Beside the roof run-off water and the water collected from the sealed area, no additional process water is used in the installation.

The collecting container made of water-resistant concrete serves as a buffer. The return of the water to the impregnating process is done automatically (automatic return at a certain water level in the collecting container by means of a float indicator and submerge pump (1.85 kW)).

Example plant: DE-4 (WB plant) in [231, Germany 2013]
The entire floor area of the installation's workspace is paved (approximately 40 m^2). The draining water runs back into the trough.

The floor sealing is made of concrete. The concrete surface is also covered and protected on the sides against rain. The extraction rail area and the area for draining are inclined to facilitate back flow of discharged liquids in the drip tray.

Achieved environmental benefits

- Prevention of soil contamination by preservatives (via dripping).
- Reduction of fresh water consumption when reusing collected water.
- Reduction of waste water volume [231, Germany 2013].

Environmental performance and operational data

The technique must be maintained (cleaning of the oil and sludge trap and disposal of the waste) regularly and is checked regularly (e.g. every 5 years) by an approved certifying body. Before each technical inspection, the collecting container needs to be emptied and cleaned.

Plant DE-3 indicated that the collected water is even more suitable for the impregnation process than the well water (due to the high proportion of precipitation water, which is essentially demineralised water). The well water has a lower pH value of 6.14 and a moderate nitrate pollution of 19.9 mg/l. It can be described as 'metallic'. The pH value of the wood-preserving salt solution is 10.2 to 10.4.

Rainwater falling on the sealed surfaces and on the roof can be used as process water. In the case of plants DE-1 and DE-3, large areas of the sealed surfaces are not covered with a roof. This can save significant amounts of fresh water (DE-1: 570 m^3; DE-3: 2 550 m^3) [231, Germany 2013].

Cross-media effects

In principle, any soil sealing / surface sealing has a negative effect on the natural hydrological structure, since precipitation can no longer penetrate the soil. However, in the examples described above, the environmental benefits of preventing soil contamination prevail [231, Germany 2013].

Technical considerations relevant to applicability

Applicable to new and existing plants.

In some cases of WB plants in which process control is based on conductivity monitoring of chemical solution, reuse of water (particularly rainwater) is difficult, because it changes the conductivity range of the solution too much, so process control is not efficient [Plant IT-1 in [236, TWG 2017]].

In plants where no water-based preservatives are used, there is no need for process water (no potential for reuse). The effluents then need to be treated, e.g. in a waste water treatment plant, or properly disposed of as liquid waste [231, Germany 2013].

Economics

- Avoidance of costs for the elimination of environmental damage [231, Germany 2013].
- Reduced costs for water and waste water treatment.

Example plant: DE-1 in [231, Germany 2013]

Cost savings for impregnation due to water savings of approximately 570 m^3 per year.

Example plant: DE-2 in [231, Germany 2013]

- Costs for soil sealing / collecting bunker: estimated at around EUR 800/m2.
- Approximate operating and maintenance costs (personnel, spare parts, certification, etc.): every 5 years about EUR 6 000 (EUR 3 000 for technical certification by approved certifying bodies; the same amount to prepare for testing).

Example plant: DE-3 in [231, Germany 2013]

- Investment costs for soil sealing and collecting bunker: EUR 85/m2 in 1998 (including sand blasting); approximately EUR 24 000 for the collecting bunker with a total amount of 125 pressure piping connection (production costs in 1998).
- Approximate annual operating and maintenance costs (personnel, spare parts, certification, etc.): EUR 8 000/yr.
- Annual cost savings by reducing water consumption (2 550 m3/yr): the self-provision of water through the installation's well is up to a certain level of annual water consumption free of charge. This allowance is exceeded by an additional use of water for the impregnation and an additional water abstraction charge (in 2011: EUR 0.045/m3 has to be paid for the process water).

Example plant: DE-4 in [231, Germany 2013]

No information provided.

Driving force for implementation

- Regulatory requirements (operating permit).

- Prevention of soil and water contamination.
- Water savings and better water quality for the impregnation process.
- Reduction of operating costs.
- Independence from fresh water sources [231, Germany 2013].

Example plants

Plants DK-1, PL-1, UK-2, UK-3, UK-4, IT-1, SE-2, SE-3, FR-3, FR-4, FI-1, DE-9, DE-8, DE-6, IT-2, DE-7 and FR-5 in [236, TWG 2017] and DE-1, DE-2, DE-3 and DE-4 in [231, Germany 2013].

Reference literature

[231, Germany 2013] [236, TWG 2017]

15.4.3.6 Prevention and detection of leaks from underground storage and ductwork for harmful/hazardous substances and record-keeping

Description

The use of underground components is minimised. When underground components are used for the storage of harmful/hazardous substances, secondary containment (e.g. double-walled containment) is put in place. Underground components are equipped with leak detection devices.

Risk-based and regular monitoring of underground storage and ductwork is carried out to identify potential leakages; when necessary, leaking equipment is repaired. A record is kept of incidents that may cause soil and/or groundwater pollution.

Technical description

Underground storage tanks are either double-walled or single-walled combined with sufficiently large containment. Underground components (e.g. storage tanks, pipelines and ductwork) are equipped with leak detection devices.

Underground components are regularly monitored using a risk-based approach; deficiencies are identified and corrected accordingly. Continual records and documentation of incidents that may cause soil and/or groundwater pollution are kept.

More details are given in the Emissions from Storage (EFS) BREF [44, COM 2006].

Achieved environmental benefits

Reduction of emissions to soil and groundwater.

Technical considerations relevant to applicability

Generally applicable.

Driving force for implementation

Reduction of environmental risks.

Example plants

Plants SE-3, FR-1, FI-1 and DE-8 in [236, TWG 2017].

Reference literature

[44, COM 2006] [236, TWG 2017]

15.4.3.7 Warning systems for equipment identified as ‘critical’

Description
‘Critical’ equipment is equipped with warning systems to indicate malfunctions.

Technical description
All environmentally critical process equipment, whose failure could have an impact on the environment, is identified and equipped with warning systems to indicate malfunctions.

Achieved environmental benefits
Prevents or reduces emissions to soil and groundwater.

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation
Reduction of environmental risks.

15.4.3.8 Use of an efficient preservative application system

Description
Application systems where the wood is immersed in the preservative solution are more efficient than, for example, spraying. The application efficiency of vacuum processes (closed system) is close to 100 %. The selection of the application system takes into account the use class and the penetration level needed.

Technical description
Different preservative application systems vary in their application efficiency (i.e. the amount of preservative used to achieve certain retention in the wood; how much of the preservative solution actually affects the wood during the treatment procedure). Application systems where the wood is immersed in the preservative solution are more efficient than, for example, spraying. The application efficiency for dipping and brushing is close to 90 %, and using the vacuum process with full containment is close to 100 %. Spraying has a much lower efficiency, i.e. from 10 % to 50 %.

Achieved environmental benefits
Improved resource efficiency and reduction of environmental risks associated with the use of treatment chemicals.

Technical considerations relevant to applicability
Only applicable to new plants or major plant upgrades.

Driving force for implementation
Reduction of environmental risks.

Example plants
Plants DK-2 and UK-1 in [236, TWG 2017].

Reference literature
[236, TWG 2017]

15.4.3.9 Control and optimisation of the consumption of the treatment chemicals for the specific end use of the wood/wood product

Description

Control and optimisation of the consumption of the treatment chemicals by: a) weighing the wood/wood products before and after impregnation; or b) determining the amount of preservative solution during and after impregnation. The consumption of the treatment chemicals follows suppliers' recommendations and does not lead to exceedances of the retention requirements (e.g. set in product quality standards).

Technical description

Consumption of treatment chemicals is controlled through a) weighing the wood/wood product (e.g. poles) before and after impregnation or b) determining the amount of preservative solution during and after impregnation [Plant IT-1 in [236, TWG 2017]].

The amount of treatment chemical introduced in the wood should be within the range required by product quality standards (e.g. use class, penetration class) and the retention amount for treatment chemicals proposed by supplier.

Achieved environmental benefits

Improved resource efficiency and reduction of environmental risks associated with the use of treatment chemicals.

Driving force for implementation

Increased yield and improved product quality.

Example plants

Plants DE-6, DE-5, DE-9, DE-8, FI-1, FR-5, FR-4, IT-2, IT-1, PL-1, SE-2, SE-3, UK-1, UK-3 and UK-4 in [236, TWG 2017].

Reference literature

[236, TWG 2017]

15.4.3.10 Solvent mass balance

Description

The compilation, at least once every year, of the organic solvent inputs and outputs of a plant as defined in Part 7(2) of Annex VII to Directive 2010/75/EU.

Technical description

No WPC-specific information provided. For general information on solvent mass balances, see Section 17.3.1.

Achieved environmental benefits

Estimation and control of fugitive emissions and reduction of environmental risks.

Technical considerations relevant to applicability

Only applicable to plants using solvent-based treatment chemicals or creosote.

Driving force for implementation

Better knowledge of emissions and assessment of necessary actions.

15.4.3.11 Regular inspection and maintenance of plant and equipment

Description
The plant and the equipment are regularly inspected and serviced to ensure proper functioning; this includes in particular checking the integrity and/or leak-free status of valves, pumps, pipes, tanks, pressure vessels, drip trays, and containments/bunds and the proper functioning of warning systems.

Technical description
Regular inspection and maintenance of the installation and equipment are fully integrated in a plant's quality management system. A number of aspects of the plant design, installation and operation are subject to the need for regular inspection and maintenance [243, EOS 2016].

Key aspects include:

- the integrity of the (dipping) tank or the pressure vessel;
- the electrical safety of the plant equipment;
- the leak-free status of valves and pipes;
- ensuring the capacity of the bund and foundations are not compromised and are adequate in the event of a catastrophic loss of preservative from the treatment vessel or storage tanks into the bund area;
- the integrity of the door seal (for autoclaves);
- visual examination of the tightness of the retention tank;
- regular checks of the tightness of pressure tanks;
- a planned written scheme of maintenance;
- records of the maintenance and inspections of all routine maintenance, periodic servicing, examinations and remedial work [243, EOS 2016].

Achieved environmental benefits
Prevention of emissions to soil and groundwater.

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation
Reduction of environmental risks, improvement of operating conditions.

Example plants
Widely applied, reported by the majority of the plants.

Reference literature
[243, EOS 2016] [236, TWG 2017]

15.4.3.12 Dedicated transport vehicles for potentially contaminated areas

Description
Vehicles used to transport the wood/wood products in potentially contaminated areas (e.g. treatment areas) are confined to these areas and are not used in other, non-contaminated areas of the plant to prevent cross-contamination with treatment chemicals.

Technical description
In cases where wood/wood products are transported by vehicles (forklifts etc.), these vehicles will eventually become contaminated with treatment solution. Dedicated vehicles are used to transport the wood/wood products in potentially contaminated areas (e.g. treatment areas).

These are retained in the wood treatment area in order not to carry over any preservative solutions to uncontaminated areas. Before removing the vehicles, e.g. for maintenance, they have to be washed down with clean water. The cleaning water is added to the treatment system [235, UK DEFRA 2013].

Achieved environmental benefits
Soil contamination is limited to confined areas.

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation
Reduction of environmental risks.

Example plants
Plants IT-1, PL-1, SE-3, DE-5 in [236, TWG 2017].

Reference literature
[235, UK DEFRA 2013] [236, TWG 2017]

15.4.3.13 Crane system for handling wood

Description
In place of a dedicated transport vehicle, an overhead crane system is used to transport wood packs to and from treatment, drying and dispatch to prevent cross-contamination with treatment chemicals [Plant UK-4 in [236, TWG 2017]].

Technical description
This technique is an overhead crane system operating across the full roof area of the treatment shed. The crane is operated from a roof gondolier operations room which ensures that staff are not in the working areas [Plant UK-4 in [236, TWG 2017]].

The lift system allows for greater densities of wood packs and allows full use of the treatment shed as drive routes are not required and pedestrian access is limited to ‘safe areas’. Greater numbers of wood packs reduce the area of shed required for post-treatment drying with the associated reduction in resource use [Plant UK-4 in [236, TWG 2017]].

Roof-mounted crane systems are universally used in the handling of heavy loads within many industries. The use of this technology within the WPC sector in the UK is unusual due to a traditional reliance on vehicles; however, with a shift in focus to the prevention of chemical dragout by vehicles, these systems could become ubiquitous [Plant UK-4 in [236, TWG 2017]].

Achieved environmental benefits
Soil contamination is limited to confined areas.

The use of electrical energy replaces the use of fossil fuels used to power a vehicle. There is a reduction in the release of emissions from vehicles and also reduced on-site storage of fuels and the potential associated impact [Plant UK-4 in [236, TWG 2017]].

Environmental performance and operational data
Data are not available to identify the energy requirements of this system due to limited submetering of use on site [Plant UK-4 in [236, TWG 2017]].

Technical considerations relevant to applicability
Generally applicable.

Economics
Cost differences between vehicle purchase and operation against crane system costs are unknown [Plant UK-4 in [236, TWG 2017]].

Driving force for implementation

- Increased density of wood handled within a treatment shed.
- Safety of personnel due to elimination of vehicle movements and need to operate close to treatment chemicals [Plant UK-4 in [236, TWG 2017]].

Example plants
UK-4 in [236, TWG 2017].

Reference literature
[236, TWG 2017]

15.4.3.14 Restricted access to contaminated / potentially contaminated areas and/or provision of grit walkways

Description
Stopping personnel from walking through areas where drips may occur and/or providing grit walkways (no contact of footwear with spills) prevents treatment chemicals/contamination being transferred to non-contaminated areas.

Achieved environmental benefits
Soil contamination is limited to confined areas.

Technical considerations relevant to applicability
Generally applicable.

Reference literature
[243, EOS 2016]

15.4.3.15 Wood pack management (trace) system

Description
A wood pack management (trace) system allows the audit of pack movements: recording when packs are processed, removed from the vessel and placed within the process area to allow dripping. It is used to prevent packs being moved off the impervious contained and drained area while they may still release preservatives [235, UK DEFRA 2013].

Technical description
The reasons for using trace systems are twofold [235, UK DEFRA 2013]:

- To monitor the production process and stack management. This may be part of a quality management system.
- To check on specific time constraints or characteristics of the timber which form part of the production process, for example the post-treatment conditioning period.

The wood packs are usually traced by tags. The parameters and the characteristics of the treatment are monitored [243, EOS 2016].

Achieved environmental benefits
Prevention of emissions to soil and groundwater.

Technical considerations relevant to applicability
Generally applicable.

Economics
Wood packs are currently tagged for identification for processing and tracking – costs only relate to recording of deemed dry status.

Driving force for implementation
Recording and tracking of post-treatment conditioning period helps both regulators and operators to trace the wood packs.

Example plants
Plants UK-1, UK-3, UK-4, SE-2, DE-9, DE-5, DE-6, IT-2 and FR-5 in [236, TWG 2017].

Reference literature
[235, UK DEFRA 2013] [236, TWG 2017] [243, EOS 2016]

15.4.4 Delivery, storage and handling of treatment chemicals

15.4.4.1 Back-venting

Description
Also referred to as vapour balancing. Vapours of solvents or creosote which are displaced from the receiving tank during filling are collected and returned to the tank or truck from which the liquid is delivered.

Technical description
Emissions to air, especially VOCs, are controlled by back-venting displaced air to the delivery tank during filling of tanks (also referred to as vapour balancing). Vapours of solvents or creosote which are displaced from the 'receiving tank' during filling are collected and returned to the tank or truck from which the liquid is delivered ('delivery tank'). Such balancing systems require the receiving and delivery tanks to be of the fixed-roof type to permit vapour collection and transfer.
More details are given in the EFS BREF [44, COM 2006].

Achieved environmental benefits
Reduction of emissions to air, especially VOCs.

Cross-media effects
Energy consumption.

Technical considerations relevant to applicability
Applicable to plants using solvent-based preservatives or creosote.

Driving force for implementation
Environmental legislation and workplace health and safety.

Example plants
Plants DE-5 and DE-8 in [236, TWG 2017].

Reference literature
[44, COM 2006] [236, TWG 2017]

15.4.4.2 Capture of displaced air

Description
Vapours of solvents or creosote which are displaced from the receiving tank during filling are collected and led to a treatment unit, e.g. an activated carbon filter or a thermal oxidation unit.

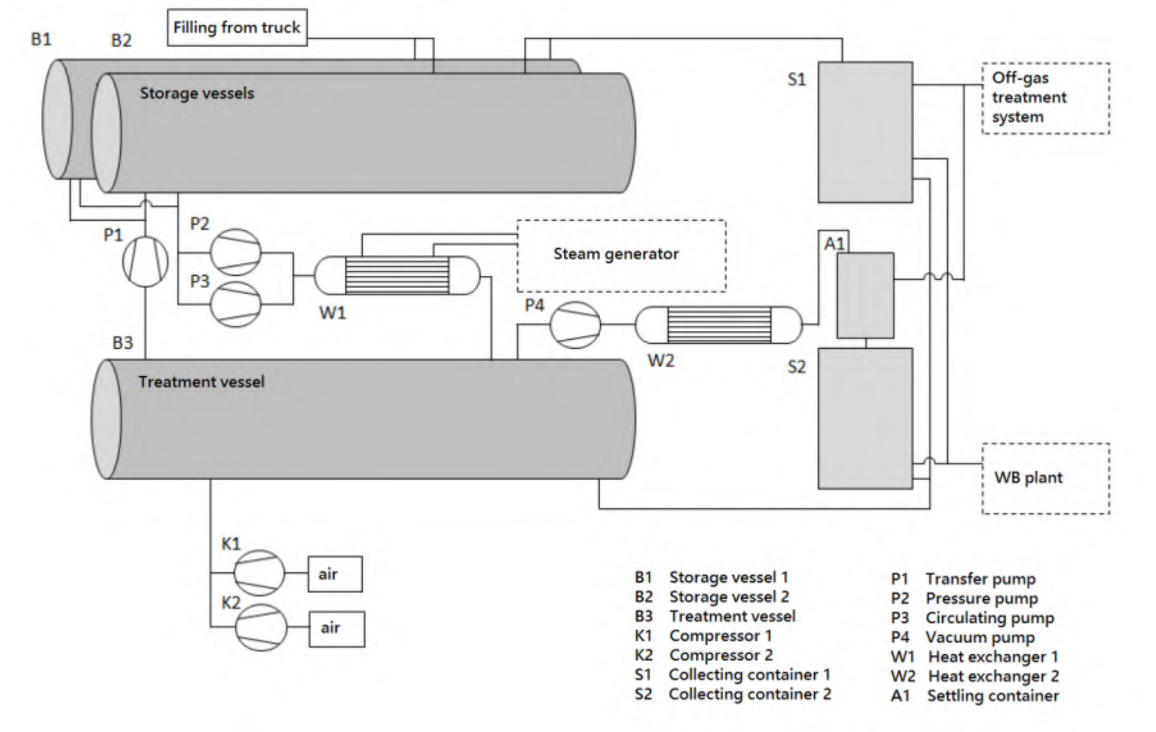
Technical description
Emissions to air, especially VOCs, are controlled by capture and treatment of air that is displaced from a tank during filling. Vapours of solvents and creosote which are displaced from the 'receiving tank' during filling are collected and led to a treatment unit, e.g. activated carbon filter or thermal oxidation unit (treating emissions from the impregnation process).

Example plant: DE-1 (mixed: WB and C plant) in [231, Germany 2013]
In the creosote treatment line, the storage tanks are filled by means of trucks. The air which is displaced during the filling of the storage containers (and during the back-pumping of the tar oil from the working container) is conducted to a collecting container (S1) in which the gas, water and tar oil are separated. The three phases are treated differently:

The gas phase is cleaned in a thermal off-gas treatment system.

The water (approximately 0.5-1 m^3 per load depending on the wood moisture) is pumped to the Korasit CK production line and used there or in rare cases it is disposed of as waste by tanker (waste code number 130899*, 40 m^3/year, declaration analysis available/required).

The tar oil is returned to the system by means of a vacuum in the working tank.



Source: [231, Germany 2013]

Figure 15.25: Schematic of the creosote pressure treatment plant DE 1

Achieved environmental benefits
Reduction of emissions to air, especially VOCs.

Cross-media effects
Energy consumption.

Technical considerations relevant to applicability
Applicable to plants using solvent-based preservatives or creosote.

Driving force for implementation
Environmental legislation and workplace health and safety.

Example plants
Plants DE 1 in [231, Germany 2013] and DE-5, UK-1 in [236, TWG 2017].

Reference literature
[231, Germany 2013] [236, TWG 2017]

15.4.4.3 Submerged loading or bottom loading

Description
Submerged and bottom loading can decrease the VOC emissions to air while loading tanks. In the case of submerged loading, the fill pipe is extended nearly to the bottom of the tank so that the fill pipe opening is below the liquid surface most of the time. In the case of bottom loading, the fill pipe is attached to the tank bottom.

Achieved environmental benefits
Reduction of emissions to air, especially VOCs.

Technical considerations relevant to applicability
Applicable to plants using solvent-based preservatives or creosote.

Driving force for implementation
Reduction of environmental risks.

Example plants
Plants PL-1, UK-2, UK-3, DE-8 and DE-9 in [236, TWG 2017].

Reference literature
[236, TWG 2017]

15.4.4.4 Filling pipe installed high enough above the fluid surface

Description
Filling pipe (for preservative solution) installed high enough above the fluid surface in the storage tanks, dipping and mixing tanks, in order to prevent a siphon effect that allows the preservative solution to flow backwards [244, Norden 2014].

Technical description
When water comes from the public water system or groundwater, installations are equipped with a non-return valve in order to prevent wood preservative solution from being sucked back into the water mains system [243, EOS 2016].

In cases where non-return valves are not permitted (e.g. by local water authorities), the risk of a filling pipe back-siphoning can be eliminated by having the discharge point of the filling pipe positioned high enough above the height of the maximum level of liquid which the receiving tank might receive. Such a device is required to have a siphon break in the water supply to the mixing tanks to prevent wood preservative solution from being sucked back into the water mains system as a result of a fall in the water supply pressure.

Achieved environmental benefits
Prevention of emissions to water.

Technical considerations relevant to applicability
Applicable to all three preservative types.

Driving force for implementation
Reduction of environmental risks.

Example plants
Plants UK-1, UK-4, SE-2, SE-3, FR-1 and FI-1 in [236, TWG 2017].

Reference literature
[236, TWG 2017] [243, EOS 2016] [244, Norden 2014]

15.4.4.5 Prevention of overflows during pumping

Description
Techniques to prevent overflows during pumping include ensuring that:

- the pumping operation is supervised;
- for larger quantities, bulk storage tanks are fitted with acoustic and/or optical high-level alarms, with shut-off systems if necessary.

Technical description
A device or system can be fitted to prevent the overfilling of the mixing tanks or storage tanks and of the bund. Such a system could also include a device for presetting the water volume when preparing the fresh treatment solution or when adjusting treatment solution strengths. This minimises the risk of an overflow, even if a filling height shut-off system is installed in the tank.

Security devices are in place in order to avoid overfilling. Very often, automatic devices exist for the mixing tank for its filling with the required quantities of water and wood preservative. Tanks are fixed and fitted with a gauge. Tanks are located in a masonry (or similar) pit, and have filling limiter. Reserves of absorbents are located close by in order to absorb limited possible leaks [243, EOS 2016].

Achieved environmental benefits

- Prevention of emissions to soil, water and groundwater.
- Reduction of fugitive emissions from solvent spillages.

Technical considerations relevant to applicability
Applicable to all preservative types.

Economics
Staff time in supervising pumping operation and cost of acoustic/optical high-level alarm systems.

Driving force for implementation
Reduction of environmental risks.

Example plants
Widely used, reported by the majority of the plants in the data collection.

Reference literature
[236, TWG 2017] [243, EOS 2016]

15.4.4.6 Heating of above-ground storage tanks for creosote

Description
Below a certain temperature, creosote crystallises and blocks the pipes; heating is provided if the outside temperature is too low. The tanks are always heated, at least in northern Europe.

Achieved environmental benefits
Improved resource efficiency and reduction of environmental risks associated with the storage of creosote.

Technical considerations relevant to applicability
Applicable to creosote plants.

Driving force for implementation
Improved operating conditions.

Example plants
Plants PL-1, UK-1, FR-1 and DE-9 in [236, TWG 2017].

Reference literature
[236, TWG 2017]

15.4.4.7 Techniques to reduce evaporation losses due to heating up of stored chemicals

Description
When exposure to sunlight may lead to evaporation of solvents and creosote stored in above-ground storage tanks, tanks are covered by a roof or coated with light-coloured paint to reduce the heating up of stored solvents and creosote.

Technical description
The tank colour influences the amount of thermal or light radiation absorbed by above-ground tanks and, therefore, the temperature of the liquid and vapour contents inside. This measure is applicable for all types of aboveground tanks where exposure to sunlight may lead to evaporation of solvents and creosote stored. The impact of the tank colour is limited if the tank is already fitted with a floating roof [44, COM 2006].

Achieved environmental benefits
Reduction of diffuse emissions.

Technical considerations relevant to applicability
Applicable to plants using solvent-based preservatives or creosote.

Driving force for implementation
Reduction of environmental risks.

Example plants
Plant PL-1 in [236, TWG 2017].

Reference literature
[44, COM 2006] [236, TWG 2017]

15.4.4.8 Lining of (existing) underground storage tanks with impermeable foil and equipping them with a leachate warning system

Description
See Section 15.4.3.6.

Example plants
Plants SE-3, FR-1, FI-1 and DE-8 in [236, TWG 2017].

Reference literature
[236, TWG 2017]

15.4.4.9 Closed storage containers

Description
Use of closed storage containers for treatment chemicals.

Achieved environmental benefits
Reduction/capture of diffuse emissions.

Technical considerations relevant to applicability
Generally applicable.

15.4.4.10 Mixing of preservation solution in closed system

Description
Preservation solution is mixed in a closed system (pipeworks and circulation system) to prevent diffuse emissions of treatment chemicals.

Technical description
Wood preservatives may be supplied to the treatment site in a concentrated or a ready-for-use form. The ready-for-use form is delivered directly to the storage tank and drawn to and from the treatment vessel. Concentrate products may be supplied in IBCs and their contents withdrawn from the containers using a discharge system. Alternatively, the concentrated product may be discharged from a bulk container into a concentrate storage tank. All these product transfers take place in a closed pipework and circulation system.

Achieved environmental benefits
Reduction/capture of diffuse emissions.

Technical considerations relevant to applicability
Applicable to all three preservative types.

Driving force for implementation
Reduction of environmental risks.

Example plants
Plants DK-2, PL-1, UK-1, UK-4, SE-2, SE-3, FR-3, FR-4, FI-1, DE-9, DE-8, IT-1, IT-2, DE-7 and FR-5 in [236, TWG 2017].

Reference literature
[236, TWG 2017]

15.4.4.11 Exhaust gas capture and air abatement system for releases during inspection or cleaning of storage tanks

Description
Treatment in a thermal oxidiser or equivalent emission control measures for exhaust gases released during inspection or cleaning of the storage tanks.

Systems for capturing exhaust gases when inspecting/cleaning storage tanks are may not be very common. Measures for safe work inside the tanks differ for creosote plants and plants using water-based preservatives.

Achieved environmental benefits
Reduction/capture of diffuse emissions.

Technical considerations relevant to applicability
Applicable to plants using solvent-based preservatives or creosote.

Driving force for implementation
Reduction of environmental risks.

Example plants
Plants UK-1, SE-3 and DE-5 in [236, TWG 2017].

Reference literature
[236, TWG 2017]

15.4.5 Preparation/conditioning of wood

15.4.5.1 Measurement and adjustment of wood moisture before treatment

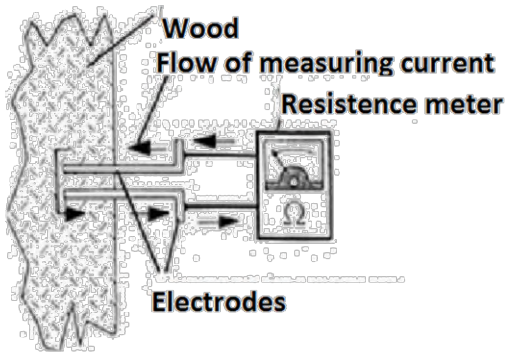
Description
Wood moisture is measured prior to treatment (e.g. by measuring the electric resistance or by weighing) and adjusted if needed (e.g. by further seasoning of the wood) in order to optimise the impregnation process and ensure the required product quality [243, EOS 2016].

Technical description
Several impregnation processes requires a certain level of wood moisture, in order to achieve the optimum result of the impregnation. Measuring the wood moisture before impregnation and - if needed - adjustment of the wood moisture ensure the required quality of the impregnated wood. Wood with a suboptimal moisture content is brought to the optimal wood moisture level before treatment (e.g. by extending seasoning (air drying) or by active drying (kiln drying)). Thus the need for repeated impregnation is avoided.

Determining the moisture content (‘impregnating maturity’) can be done by:

a) electric resistance measurement (manual or automated);
b) weighing procedures.

a) Electric resistance measurement
The electric resistance of wood increases with decreasing moisture. The electrical resistance is measured and transformed into a moisture value. The basic principle of electric wood moisture measurement is shown in Figure 15.26.



Source: [231, Germany 2013]

Figure 15.26: Basic principle of electric resistance wood moisture measurement

The measurement is either done manually, using a handset for electric resistance measurement (see Figure 15.27 below), or performed automatically [231, Germany 2013].

Source: [231, Germany 2013]

Figure 15.27: Manual wood moisture measurement

Automatic electric resistance measurement is supported by a computer and the measured values can be digitally recorded and documented.

An example of an automatic measurement procedure (applied in pole production) is given below [231, Germany 2013]:

- Issuing table for the automatic separation of the load and feeding of individual logs in the measuring system.
- Electrodes penetrate about 5-6 cm (sapwood heartwood boundary) into the raw wood (in the case of poles, the measurement area is usually at the soil-air boundary, as approximately a sixth of the pole is dug into the ground).
- Four transducers/sensors are used for detecting moisture nests (which arise in particular from the storage of wood).
- If the measurement of humidity is not optimal, the measurement is repeated at the points 30 cm above and below the first measuring point. If the moisture content is not correct after the second measurement, the raw wood must be dried further.

- When the optimal moisture content is reached, each pole is allocated with a number and conveyed to the treatment vessel where impregnation is carried out.

b) Weighing procedures

No information provided.

Achieved environmental benefits

The wood moisture measurement will ensure the required quality of impregnated wood and contributes to a reduction in the use of the required resources such as wood preservatives, wood and energy (by avoiding repeated impregnation, increasing the durability of the products and reducing/preventing early failure) [231, Germany 2013].

Environmental performance and operational data

- According to operators - simple, robust and reliable technology.
- Significant reduction in the rate of return (Plant DE-2 (in [231, Germany 2013]) indicated that the return rate was reduced from 30 % to 15 %), thus optimising storage utilisation.

Technical considerations relevant to applicability

Measurement and adjustment of the wood moisture prior to the treatment is only applicable if wood with a specific moisture content is needed.

Determination of moisture content by electric resistance measurement is applicable to wood with a moisture between 7 % and 30 % [231, Germany 2013].

Economics

Manual measurement of resistance

No information provided, but the costs are generally regarded to be low.

Automatic measurement of resistance

- Investment costs of Plant DE-3: approximately EUR 300 000-400 000 (payback period approximately 10 years).
- Operating costs of Plant DE-3: electrodes: 1 pin = EUR 4 (pin consumption approximately 350-400 pieces/year).
- Estimated staff costs of Plant DE-3: thousand EUR 70-80/year (1.5 employees).
- Prevention of failures and associated warranty can be very expensive (EUR 250-500 for a new pole and approximately EUR 1 000 for the replacement of the pole; training and installation costs) [231, Germany 2013].

Driving force for implementation

- Higher quality of products.
- Exact wood moisture determination is of crucial importance in the application of non-creeping wood preservatives [231, Germany 2013].

Example plants

Handsets for raw wood moisture determination are in use Europe-wide, and reported by the majority of the plants in the data collection [236, TWG 2017].

More specifically, automatic resistance measurement is used in Plant DE-3 and manual resistance measurement (handset) is used in Plants DE-1 and DE-2 in [231, Germany 2013].

Reference literature

[231, Germany 2013] [236, TWG 2017] [243, EOS 2016]

15.4.5.2 Removal of debris prior to treatment

Description
Debris (e.g. sawdust, woodchips) is removed from the surface of the wood/wood products before treatment (e.g. by blowing air through the batch of wood to be treated).

Technical description
Different methods are available to remove debris from the surface of the wood items; one way is ‘purging’. Blowing air through the batch of wood to be treated removes sawdust and other ‘impurities’.

Achieved environmental benefits
Reduced need for retreatment, reduced consumption of chemicals and reduced generation of waste (e.g. amount of sludge in the treatment vessel).

Driving force for implementation
Increased yield, improved operating conditions.

Example plants
Plants PL-1, UK-1, UK-2, UK-3, UK-4, SE-3, FR-4, FI-1, DE-8, DE-9, IT-2 and FR-5 in [236, TWG 2017].

Reference literature
[236, TWG 2017]

15.4.5.3 Removal of plastic wrap from wood packs prior to treatment

Description
Plastic wrappings are removed from wood packs to avoid wood preservatives being trapped in the plastic and being emitted after treatment (e.g. as drips) or generating hazardous waste (i.e. contaminated plastic waste).

Technical description
Packs of timber are invariably transported protected in plastic-based sheeting to protect the timber and prevent it taking up moisture during its time from preparation to the end-use application. Such plastic sheets may trap wood preservative solution in folds in the plastic which may be released from the treated pack when it is moved. The plastic is also contaminated with wood preservative and needs to be handled as hazardous waste [243, EOS 2016].

Achieved environmental benefits
No trapping of treatment solution, thus prevention of spills/soil contamination.

Technical considerations relevant to applicability
Only applicable to wood/wood products that are delivered to the WPC plant in wrapping. Poles, for example, may be delivered without any wrapping [Plant IT-1 in [236, TWG 2017]].

Driving force for implementation
Reduction of environmental risks.

Example plants
Plants DK-2, PL-1, UK-1, UK-2, UK-3, UK-4, SE-3 and FI-1 in [236, TWG 2017].

Reference literature
[236, TWG 2017] [243, EOS 2016]

15.4.5.4 Optimisation of wood charge

Description

The way wood or wood items are bundled/piled or loaded into the treatment vessel has an impact on the quality of the treated wood, but also on the emissions from the process. The basic principles of optimised wood loads are free access, free drainage and non-trapping of preservative solution. This is achieved by:

a) separation of wood in packs by spacers;
b) sloping of wood packs in traditional horizontal treatment vessels;
c) using tilting pressure treatment vessels;
d) optimised positioning of shaped wood pieces;
e) securing wood packs;
f) maximisation of the wood load.

The charging equipment (used to remove the treated wood from the treatment vessel) is designed in such a way that prevents the carry-over of treatment chemicals.

Technical description

Several techniques can be applied to optimise the preparation of the wood charge (i.e. how the wood is charged into the treatment vessel). The main aim is to allow free movement of preservative solution through the wood items to ensure impregnation quality, but at the same time these measures allow for optimum draining of preservative solution after treatment, thus reducing consumption and dragout of preservatives, and the risk of emission to the environment. The following measures are applied:

a) Separation of wood in packs by spacers

Timbers that are being presented for treatment in packs usually have spacers (stickers). They are placed at regular intervals in the pack to facilitate the flow of treatment chemicals through the pack and also help in the draining and recovery of excess treatment chemicals after treatment. However, in some cases (e.g. for cladding), spacers cannot be used as they would cause marks on the surface of the timber [243, EOS 2016].

b) Sloping of wood packs in traditional horizontal treatment vessels

Wood packs are inclined in the treatment vessel to facilitate the flow of treatment chemicals and the draining after treatment.

In dipping, treatment a hydraulic cylinders system is used during the dripping phase.

c) Use of tilting pressure treatment vessels

Some larger autoclave plants with a large wood throughput alternatively use tilting vessels. These allow for the whole vessel to be inclined after treatment; excess treatment chemicals drain easily and can be recovered from the bottom of the vessel.

d) Optimised positioning of shaped wood pieces

Shaped wood pieces are positioned so as to prevent trapping of treatment chemicals.

e) Securing wood packs

The wood packs are secured inside the treatment vessel in order to limit the movement of wood pieces which could change the structure of the pack and reduce the impregnation efficiency. There are a number of options being used depending on the packs/commodities being treated:

1. Pack straps or chains to hold timbers to the bogie. This gives greatest flexibility and allows for uneven packs and small packs to be put on top of other packs, etc. The majority of plants work in this way.

2. Side arms on the bogie allow the timbers to move during treatment but then return to the bogie when the vessel empties. They are used infrequently but work well where the pack size is close to that of the vessel. Timber bearers are placed on top of the packs to stop the packs hitting the top of the vessel.

3. Hydraulic clamping of the timbers within the vessel. This can be applied with or without a bogie depending on the timber handling system design. It works best where packs are all of similar dimensions. When there are big differences in pack heights, additional spacer sections are placed on top of small packs to level out the charge and ensure clamps hold the packs [242, EWPM/WEI 2016].

f) Maximisation of the wood load
The wood load in the treatment vessel is maximised to ensure the best ratio between the wood to be treated and the treatment chemicals.

Achieved environmental benefits
Reduced consumption of preservatives, energy etc. due to less retreatment, and reduced waste generation and reduced emissions of preservative solution.

Technical considerations relevant to applicability
Use of tilting pressure treatment vessels may be considered a technique applicable to new plants or major plant upgrades.

Economics
Due to the higher investment costs of tilting vessels, a large volume of wood/wood throughput is required for amortisation.

Driving force for implementation
Increased yield, improved operating conditions.

Example plants
Widely applied, reported by majority of the plants in the data collection.

Reference literature
[236, TWG 2017] [242, EWPM/WEI 2016] [243, EOS 2016]

15.4.6 Preservative application process / Non-pressure processes

15.4.6.1 Enclosure for spraying and spray tunnels (with gas extraction and emission abatement system)

Description
Spraying processes are enclosed and overspray is collected and reused in the preparation of wood preservation solution to prevent emissions of aerosols from wood and wood products preservation using water-based treatment chemicals.

Achieved environmental benefits
Reduction of emissions to air.

Cross-media effects
Energy consumption for extraction and treatment.

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation
Workplace health and safety.

Reference literature
[212, TWG 2018]

15.4.6.2 Enclosure for bath processes: dipping and immersion (with gas extraction and emission abatement system)

Description
Enclosing the process wherever possible so that air can be extracted and treated by an abatement equipment, thermal oxidation or adsorption with solvent recovery.

Technical description
Emissions to air from bath processes (dipping, immersion) can be reduced by enclosing the process and extracting and treating the gaseous emissions. Different technical solutions are possible:

- Having a lid on the tank when immersing the wood/wood product in solvent-based preservative and having an extraction system with vapour treatment [247, Belgium 2014].
- Exhaust gas capture for hot-cold bath (creosote) treatment (see Section 15.4.13.2).

Achieved environmental benefits
- Reduction/capture of diffuse emissions.
- Reduction of emissions to air, especially VOCs and PAHs.

Cross-media effects
Energy consumption for extraction and treatment.

Driving force for implementation
Workplace health and safety.

Reference literature
[247, Belgium 2014]

15.4.6.3 Single-walled treatment vessels with sufficiently large and wood-preservative-resistant containment, fender and automatic leak detection device

Description
When single-walled treatment vessels are used, sufficiently large and treatment-chemicals-resistant containment, fender and automatic leak detection device are employed.

Achieved environmental benefits
Reduction of emissions to soil and groundwater related to spills, drips and accidental releases of treatment chemicals.

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation
Reduction of environmental risks.

Example plants
Plants UK-4, FI-1, DE-8 and FR-5 in [236, TWG 2017].

Reference literature
[236, TWG 2017]

15.4.6.4 Double-walled treatment vessels with automatic leak detection device

Description
Use of double-walled treatment vessels with automatic leak detection devices.

Technical description
Double-walled treatment vessels are used in which the second layer works as an alternative to containment. Automatic leak detection devices are used to alert the operator in the event of unpredicted leakage, rupture or failure of vessels.

Achieved environmental benefits
Reduction of emissions to soil and groundwater related to spills, drips and accidental releases of treatment chemicals.

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation
Reduction of environmental risks.

Example plants
Plants DK-2, FR-3, DE-7 and DE-8 in [236, TWG 2017].

Reference literature
[236, TWG 2017]

15.4.6.5 Sufficient dripping time after treatment (dripping into treatment vessel)

Description
Sufficient dripping time is provided after treatment to allow surplus treatment solution on treated wood to drip into the treatment vessel or to flow back through a dripping pad to the treatment vessel (see also Section 15.4.8.5).

Technical description
After treatment with preservatives, the treated wood is held for a minimum time over the treatment vessel to allow surplus treatment solution to drip into the treatment vessel or the wood is held over a dripping pad which slopes towards the treatment vessels and allows the drips to flow to the dipping vessels, thus avoiding the release of preservatives from the tanks or vessels.

Source: [231, Germany 2013]

Figure 15.28:Example of a drip pad with dripping treatment solution flowing back into the treatment vessel

Achieved environmental benefits

- Prevention of soil and groundwater contamination.
- Reduction of treatment chemicals consumption.

Technical considerations relevant to applicability

Generally applicable.

Driving force for implementation

Reduction of environmental risks.

Example plants

Plants UK-4, SE-3, FR-3, FR-5, FI-1, DE-7 and DE-8 in [236, TWG 2017].

Reference literature

[236, TWG 2017]

15.4.7 Preservative application process / Pressure processes

15.4.7.1 Precautionary design features for pressure treatment vessels (autoclaves)

Description

Precautionary design features for pressure treatment vessels (autoclaves) comprise the following techniques:

a) Process controls to prevent operation unless the treatment vessel door is locked and sealed.

b) Process controls to prevent the treatment vessel from opening while it is pressurised and/or filled with preservative solution.
c) Catch-lock for the treatment vessel door.
d) Use and maintenance of safety relief valves.

Technical description

a) The treatment vessel door is locked and sealed once the treatment vessel is loaded and before treatment takes place. Process controls are in place that prevent the operation of the treatment vessel unless the door is locked and sealed.

b) Process controls display the pressure and whether liquid is present in the treatment vessel. They prevent the opening of the treatment vessel while it is still pressurised and/or filled.

c) The door of the treatment vessel is equipped with a catch-lock to prevent the release of liquids in the event that the treatment vessel door needs to be opened in an emergency situation (e.g. door seal is broken). The catch-lock permits the door to be partially opened to release the pressure while retaining liquids.

d) Treatment vessels are fitted with safety relief valves to protect the vessels from excessive pressure. The valves' discharge is directed to a tank of sufficient capacity. Safety relief valves are regularly inspected (e.g. once every 6 months) for signs of corrosion, contamination or incorrect fitting and are cleaned and/or repaired as required.

Achieved environmental benefits

Reduction of emissions to soil and groundwater related to spills, drips and accidental releases of treatment chemicals.

Technical considerations relevant to applicability

Generally applicable.

Driving force for implementation

Reduction of environmental risks.

Example plants

Widely applied, reported by the majority of the plants in the data collection.

Reference literature

[236, TWG 2017]

15.4.7.2 Control of emissions to air from the vacuum pump exhaust

Description

Air extracted from pressure treatment vessels (i.e. the vacuum pump outlet) is treated (e.g. in a vapour-liquid separator).

Technical description

Example plant: DE-1 (mixed: WB and C plant) in [231, Germany 2013]

Vacuum pumps are used to create the vacuum in the treatment vessel. In order to prevent aerosols from entering the environment, the extracted air from the water-based treatment vessels is directed to a settling tank (5 m^3) which contains the cooling water of the vacuum pump.

The use of liquid separators on the discharge side of vacuum pumps to avoid the release of preservatives via aerosols was also reported as a technique, but no information was provided [248, Austria 2014].

Achieved environmental benefits
Reduction of emissions to air / aerosols.

Technical considerations relevant to applicability
Applicable to all preservative types.

Example plants
Plant DE-1 in [231, Germany 2013].

Reference literature
[231, Germany 2013] [248, Austria 2014]

15.4.7.3 Reduction of emissions to air when opening the treatment vessel

Description
Sufficient time for dripping and condensation is allowed between the depressurisation period and the opening of the treatment vessel.

Technical description
To prevent or reduce aerosol formation and emissions to air, pressure processes can be operated with a drip-off and/or condensation phase at the end of the impregnation process before the treatment vessel is opened to remove the treated wood [230, VDI 2014].

Achieved environmental benefits
Reduction of emissions to air / aerosols.

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation
Workplace health and safety.

Example plants
Widely applied, reported by the majority of the plants in the data collection.

Reference literature
[230, VDI 2014] [236, TWG 2017]

15.4.7.4 Application of a final vacuum to remove excess treatment chemicals from the surface of treated wood

Description
To avoid dripping, a final vacuum is applied in the treatment vessel before opening it to remove excess treatment chemicals from the surface of the treated wood.

Technical description

The last phase of the pressure process is the final vacuum stage, which is after emptying the treatment chemicals and before opening the treatment vessel. In this phase, surplus treatment chemicals are removed and dripping is reduced to minimum.

Achieved environmental benefits
Reduction of emissions to air.

Technical considerations relevant to applicability
Application of a final vacuum may not be necessary if the removal of excess treatment chemicals from the surface of treated wood is ensured by the application of an appropriate initial vacuum (e.g. less than 50 mbar).

Driving force for implementation
Workplace health and safety.

Example plants
Widely applied, reported by the majority of the plants in the data collection.

Reference literature
[IT comment #104 in [212, TWG 2018]] [236, TWG 2017]

15.4.8 Post-treatment conditioning and interim storage

15.4.8.1 Roofing with roof guttering

Description
A roof covering the areas where treatment chemicals are stored or handled (i.e. treatment chemicals storage area, treatment, post-treatment and interim storage areas, pipes and ductwork for treatment chemicals, creosote (re)conditioning facilities) which protects freshly treated wood against weather/rainfall. Rainwater is stopped from entering the impregnation installation and leaching of treatment chemicals is prevented.

Technical description
Example plant: DE-2 in [231, Germany 2013]
The extraction rail area as well as the transport area to the storage areas for fresh impregnated wood (storage under the roof for at least 2 days, often longer) are covered and protected from the sides against the wind and rain (a new roof is under construction: roof, rafters/purlin roof structure with profiled sheeting with partial insulation and roof covering made of PVC). The relevant area of the roof is approximately 2 500 m^2.

Example plant: DE-4 in [231, Germany 2013]
Roofing in the area of the troughs and the drip area is for protection against rain and wind-driven rain and there is additional equipment for prevention of surface water accession.
The gradient of the adjacent transportation areas is directed away from the building so that surface water cannot access the impregnation area.

The roofing in the fixing area serves as protection against rain and wind-driven rain and washing out of non-fixed wood preservatives.

Storage under the roof depends on the product properties as well as the geometry of the impregnated wood. Besides, the fixing time depends on the wood preservatives applied and the weather conditions. In spring to autumn, the fixing time is approximately 24 hours. For the winter months, no representative data are available. The roof in the area of troughs and the drip area is approximately 150-200 m^2 (equivalent to the roof in the area of the troughs including the drip area without fixing area and storage for impregnating agents). The roof of the fixing area measures about 200 m^2.

Source: [231, Germany 2013]

Figure 15.29: Example of a roof cover in the area of the troughs (Plant DE-4)

Achieved environmental benefits

Example plant: DE-2 in [231, Germany 2013]

After the impregnation, the treated wood is exclusively transported and stored under the roof for at least 2 days until the complete fixation (after 48 hours) of the self-fixating wood preservative. This ensures that the wood preservatives cannot be washed out by the rain prior to full fixation.

Example plant: DE-4 in [231, Germany 2013]

The wood is dry-stored after impregnation until the complete fixation in the fixing area. This ensures that the wood preservatives cannot be washed out by the rain prior to full fixation.

Environmental performance and operational data

Example plant: DE-2 in [231, Germany 2013]

Washing out of non-fixed wood preservatives is prevented.

Example plant: DE-4 in [231, Germany 2013]

Through the existing drain and subsequent storage in the fixing area (covered), it is ensured that the fixation is completed and the leaching of non-fixed wood preservative is reduced to a minimum.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable to both existing and new installations [231, Germany 2013].

Economics

Example plant: DE-2 in [231, Germany 2013]

- Investment costs: approximately EUR 40/m^2 of roof surface.
- Operating and maintenance costs are negligible.

Example plant: DE-4 in [231, Germany 2013]

- Investment costs: no specifications as the impregnation area is situated in the hall.
- Operating and maintenance costs are negligible.

Driving force for implementation

Example plant: DE-2 in [231, Germany 2013]

- Quality assurance (prevents the leaching of wood preservatives by precipitation).
- Protects the process cycle from storm water (otherwise too much precipitation water would enter via the inlet chute of the storage into the drip tray).

Example plants
DE-2 and DE-4 in [231, Germany 2013].

Reference literature
[230, VDI 2014] [231, Germany 2013]

15.4.8.2 Weather protection for the storage of treated wood

Description
Permanent weather protection (e.g. roofing, tarpaulins) is used for the storage of treated wood in the event that it is required in the BPR authorisation for the wood preservative used for the treatment.

Technical description
After the freshly treated wood is deemed dry by the drip test, the wood packs are removed from the contained/bunded and roofed area. In a certain period following the treatment, the active ingredients of the wood preservatives have to react with the wood constituents to be fixed in the wood. During that period, the risk of leaching of treatment chemicals by precipitation has to be minimised to ensure the efficacy of the preservation as well as to prevent emissions to soil and groundwater. For this purpose, treated wood is stored under permanent weather protection (e.g. roofing, tarpaulins).

Example plant: IT-1 in [236, TWG 2017]
Freshly treated wood is stored under a roofed area, for at least 2 hours after treatment, with drip collection. When the wood is deemed dry (drip-free), it is handled and stored in covered stacks, under tarpaulins, for at least 24 hours until the wood preservatives are completely fixed.

Achieved environmental benefits
Increased efficacy of the preservation and prevention of soil and groundwater contamination.

Technical considerations relevant to applicability
Cranes and frames are needed to place tarpaulins on wood.

Driving force for implementation
Reduction of environmental risks.

Example plants
Plant IT-1 in [236, TWG 2017]

Reference literature
[DE comment #410 / IT comments #109, 108 & 110 in [212, TWG 2018]] [236, TWG 2017]

15.4.8.3 Fixation by steam (autoclave) or warm air (climate chamber) after preservation treatment

Description
For wood treated with non-fixating preservatives, steam fixation may be applied. The wood is put in a closed treatment vessel (without pressurisation) and ‘rinsed’ with steam. Fans are used

to circulate the steam in the treatment vessel until the desired fixation is achieved [231, Germany 2013].

Achieved environmental benefits
Minimisation of leaching of non-fixating preservatives.

Example plants
Plants FI-1 and SE-2 in [236, TWG 2017]

Reference literature
[231, Germany 2013] [236, TWG 2017]

15.4.8.4 Avoidance of contact of freshly treated wood with the floor

Description
Avoidance of contact of freshly treated wood with the ground, and sufficient ventilation at ground level, which accelerates drying.

Technical description

Example plant: IT-1 in [236, TWG 2017]
Treated wood is stored in stacks, sustained by big poles and concrete blocks, to separate wood from the floor.

Achieved environmental benefits
Prevention of soil and groundwater contamination.

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation
Reduction of environmental risks.

Example plants
Widely applied, reported by the majority of the plants in the data collection.

Reference literature
[IT comment #112 in [212, TWG 2018]] [236, TWG 2017]

15.4.8.5 Removal of treated wood from the contained/bunded area only after it is deemed dry by the drip test

Description
To allow the surplus treatment chemicals to drip back into the treatment vessel, treated wood/wood packs are held above the treatment vessel or over a dripping pad for a sufficient time after the treatment and before transfer to the post-treatment drying area.

Then, before leaving the post-treatment drying area, treated wood/wood packs are, for example, lifted by mechanical means and suspended for a minimum of 5 minutes. If no dripping of treatment solution occurs, the wood is deemed to be dry.

Technical description
Following treatment, wood/wood packs will continue to drip preservative solution until they are deemed to be dry. This dripping is not related to chemical fixation within the treated wood but

relates to excess preservative which has not been drawn back into the process during the vacuum stage.

To be defined as dry, a pack shall, for example, be lifted by mechanical means and shall be suspended e.g., for a minimum of 5 minutes. The pack should not form drips or drip treatment solution during this period. Wood packs remain in the post-treatment drying area until the packs are deemed to be dry [235, UK DEFRA 2013].

Achieved environmental benefits
Prevention of soil and groundwater contamination.

Environmental performance and operational data
Drying times are affected by plant specificities such as location, seasonality and meteorology, which can vary on a daily basis. The drip test ensures that the wood packs are removed from the contained/bunded area only once they are deemed dry. It also gives a recordable confirmation of the packs' status.

Technical considerations relevant to applicability
A drip test is conducted as a part of the transportation process. Treated wood/wood packs are lifted by mechanical means and held to complete the drip test. Failed wood/wood packs are repositioned to allow further drying in the contained/bunded area.

Driving force for implementation
Prevention of the transfer of treatment chemicals from the contained/bunded area to ground which is unsealed.

Example plants
Plants UK-4, FI-1, DE-7, DE-8 and FR-5 in [236, TWG 2017].

Reference literature
[235, UK DEFRA 2013][UK comment #168 in [212, TWG 2018]] [236, TWG 2017]

15.4.9 Waste minimisation, management and on-site treatment

15.4.9.1 Recirculation of collected drips and spills of treatment chemicals

Description
Drips and spills of preservatives/treatment chemicals collected from containments/bunds, drip trays or impermeable floors are recirculated to the treatment chemicals' system.

Technical description
After removal from the treatment vessel, wood packs are stored in the contained/bunded area to allow sufficient dripping time. Drips are collected in containments/bunds or drip trays. Liquids are directed to the treatment chemicals' system by vacuum pump (see Section 15.4.3.5). Ideally, the liquids are filtered to remove undesirable materials (e.g. wood-based particles).

Achieved environmental benefits
Reduction of waste and waste water generation, prevention or reduction of emissions to soil and groundwater, reduction of treatment chemicals consumption

Technical considerations relevant to applicability
Applicability may be limited where the collected liquid volume is low which limits the flow.

In the case of creosote or light organic solvent-based wood preservatives, it is not possible to recirculate water contaminated with preservative back into the product and such liquids have to be collected and disposed of according to hazardous waste legislation.

Economics
Reduced treatment chemicals costs.

Driving force for implementation
Containment of drips from wood packs during post-treatment conditioning and interim storage.

Example plants
Plants DE-6, DE-7, DE-9, DE-8, DK-1, FI-1, FR-5, FR-3, FR-4, IT-2, IT-1, PL-1, SE-2, SE-3, UK-2, UK-3 and UK-4 in [236, TWG 2017]

Reference literature
[236, TWG 2017] [UK comment #166 in [212, TWG 2018]]

15.4.9.2 Bulk delivery of treatment chemicals

Description
Delivery of treatment chemicals in tanks to reduce the amount of packaging.

Technical description
Bulk delivery of frequently used treatment chemicals reduces the amount of packaging needed for the delivery operations.

Achieved environmental benefits
Reduced quantity of waste sent for disposal.

Technical considerations relevant to applicability
Generally applicable.

Example plants

Plants PL-1, UK-1, UK-2, UK-3, UK-4, IT-1, SE-2, SE-3, FR-1, FI-1, DE-5 and IT-2 in [236, TWG 2017].

Reference literature

[236, TWG 2017]

15.4.9.3 Use of reusable containers

Description

Reusable containers used for treatment chemicals (e.g. IBCs) are returned to the supplier for reuse.

Achieved environmental benefits

Reduced quantity of waste sent for disposal.

Technical considerations relevant to applicability

Generally applicable.

15.4.9.4 Separation of hazardous and non-hazardous waste at source and separate storage

Description

Waste is stored in suitable containers or on sealed surfaces and hazardous waste is kept separately in a designated weather-protected and contained/bunded area.

Technical description

All waste streams generated within plant are stored in suitable containers or on sealed surfaces. Hazardous wastes (e.g. waste contaminated with wood preservatives) are stored separately in a weather-protected and contained/bunded area.

Achieved environmental benefits

Prevention of soil and groundwater contamination.

Technical considerations relevant to applicability

Generally applicable.

Driving force for implementation

Reduction of the environmental risks related to waste management

Example plants

Plants DE-5, DE-9, DE-8, DK-1, FI-1, FR-5, FR-1, IT-2, IT-1, PL-1, SE-3, UK-1, UK-2, UK-3 and UK-4 in [236, TWG 2017].

Reference literature

[236, TWG 2017]

15.4.9.5 Reuse, recycling and recovery of wastes

Description

Wastes produced before and after impregnation (wood wastes) can be used for energy or material recovery by sending them to an authorised plant.

Technical description
Wood wastes (even impregnated) are sent to an authorised plant for energy or material recovery.

Achieved environmental benefits
Optimisation of waste management and reduction of waste sent to final disposal.

Example plants
Plants DK-1, DK-2, FI-1, FR-1, IT-2, IT-1, PL-1, SE-3, UK-1, UK-3 and UK-4 in [236, TWG 2017].

Reference literature
[IT comment #91 in [212, TWG 2018]] [236, TWG 2017]

15.4.9.6 Recovery and reuse of waxes and oils

Description
When waxes or oils are used for impregnation, surplus waxes or oils from the impregnation process are recovered and reused.

Achieved environmental benefits
Reduction of waste generation and reduction of wax or oil consumption.

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation
Increased resource efficiency.

Example plants
Plant IT-2 in [236, TWG 2017].

Reference literature
[236, TWG 2017]

15.4.9.7 Collection of preservative-treated wood waste for proper recovery or disposal as hazardous waste

Description
Treated wood waste is collected and sent for energy recovery (see Section 15.4.9.5) or disposed of as hazardous waste.

Example plants
Plants DE-5, DE-9, DE-8, DK-1, FI-1, FR-5, FR-1, IT-1, PL-1, SE-2, SE-3, UK-1, UK-2, UK-3 and UK-4 in [236, TWG 2017].

Reference literature
[236, TWG 2017]

15.4.9.8 Collection of preservative residues and sludges for proper disposal as hazardous waste

Description
Drips and spills of treatment chemicals collected from the areas where treatment chemicals are stored or handled flow across the sealed surface within the contained/bunded and roofed

working area to be collected in a sump prior to being recycled to the treatment system. The sludge formed in the base of the sump due to grits and wood fibres picked up by treatment chemicals is periodically removed and disposed of as hazardous waste.

Technical description
Waste sludge deposited in the treatment chemicals' sump is removed by physical means and placed in containment, such as drums, which is then be sealed and stored prior to proper disposal as hazardous waste.

Achieved environmental benefits
Prevents the release of treatment chemicals outside the contained/bunded working area.

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation
Sludge is deposited in the preservative collection sump and this limits the capacity of the sump. High sludge volumes increase the risk of transfer into the treatment system and the associated operational issues that can arise.

Example plants
Plants DE-6, DE-5, DE-8, FI-1, FR-5, FR-1, IT-2, IT-1, PL-1, SE-2, SE-3, UK-1, UK-2, UK-3 and UK-4 in [236, TWG 2017].

Reference literature
[UK comment #167 in [212, TWG 2018]] [236, TWG 2017]

15.4.10 Water / Waste water management

15.4.10.1 Separation of clean, uncontaminated rainwater or surface run-off water

Description
Clean, uncontaminated rain and surface run-off water are kept separated from areas where treatment chemicals are stored or handled, from areas where freshly treated wood is stored and from contaminated water by the use of drainage channels, outer kerb bunds, roofing with guttering and permanent weather protection.

Technical description
Keeping clean, uncontaminated rainwater or surface run-off water out of contact with preservatives and/or preservative-contaminated areas of the plant is achieved by channelling or diverting it away from the plant or any equipment. This is achieved by using at least the following techniques:

a) Drainage channel:
A drainage channel around the whole plant stops rain and surface run-off water from entering plant areas and thus from being polluted.

b) Outer kerb bund:
An elevated rim around the whole plant or parts of the plant stops rain and surface run-off water from entering plant areas and thus from being polluted.

c) Roofing with roof guttering:
A roof protects areas where treatment chemicals are stored or handled (i.e. treatment chemicals storage area, treatment, post-treatment conditioning and interim storage areas, pipes and ductwork for treatment chemicals, creosote (re)conditioning facilities) from

rainwater. The run-off water from the roofs is collected by roof guttering and channelled away from potential sources of contamination.

d) Weather protection (e.g. roofing, tarpaulins) for the storage of treated wood in the event that it is required in the BPR authorisation for the wood preservative used for the treatment.

Achieved environmental benefits
Reduced emissions to water.

Technical considerations relevant to applicability
For existing plants, the applicability of drainage channels and an outer kerb bund may be restricted by the size of the plant area.

Driving force for implementation
In the event of heavy rainfall, the excess amount of collected potentially contaminated rain and/or surface run-off water would lead to handling challenges in relation to treatment or disposal.

Example plants
Plants applying BAT candidates [236, TWG 2017]:

- Outer kerb bund: UK-1, UK-2, UK-3, SE-2, SE-3, DE-9 and IT-2.
- Roofed treatment area: reported by the majority of the plants in the data collection.

Reference literature
[236, TWG 2017]

15.4.10.2 Regular inspection, emptying and cleaning of oil separators, canals and sumps

Description
An inspection and maintenance programme can be put in place to prevent pollution by minimising leaks from subsurface pipework, sumps, canals and oil separators present in the installation.

Achieved environmental benefits
Prevention of emissions to surface water, groundwater and soil.

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation
Reduction of environmental risks.

Example plants
Plants DE-6, DE-5, DE-9, DE-8, FR-5, FR-1, IT-2, PL-1, SE-2 and UK-1 in [236, TWG 2017].

Reference literature
[236, TWG 2017]

15.4.10.3 Collection of potentially contaminated rain and/or surface run-off water

Description
Surface run-off water from areas that are potentially contaminated with treatment chemicals is collected separately. Collected waste water is discharged only after appropriate measures are taken (e.g. monitor (see Section 15.4.12), treat (see Section 15.4.10.6), use (see Section 15.4.10.4)).

Achieved environmental benefits
Reduced emissions to water.

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation
Environmental legislation.

Example plants
Plants DE-6, DE-5, DE-9, PL-1, UK-1, IT-2, FR-1, FR-2, FR-5 and SE-2 in [236, TWG 2017]

Reference literature
[236, TWG 2017]

15.4.10.4 Use of potentially contaminated surface run-off water

Description
After its collection, potentially contaminated surface run-off water is used for the preparation of water-based wood preservative solutions.

Achieved environmental benefits
Reduced emissions to water.

Technical considerations relevant to applicability
Only applicable to plants using water-based treatment chemicals. Applicability may be restricted by the quality requirements for its intended use.

Driving force for implementation
Reduced water consumption.

Example plants
Plants DE-6, DE-5, DE-9, PL-1, UK-1, IT-2, FR-1, FR-2, FR-5 and SE-2 in [236, TWG 2017]

Reference literature
[236, TWG 2017]

15.4.10.5 Reuse of cleaning water

Description
Water used to wash equipment and containers is recovered and reused in the preparation of water-based wood preservative solutions.

Technical description
Equipment and containers that contain residues of treatment chemicals are rinsed and cleaned. For the cleaning of treatment equipment, efficient cleaning methods (e.g. rotary spray nozzle

heads or similar means) are used to reduce the volume of cleaning water [235, UK DEFRA 2013]. Cleaning water is recovered and reused in the preparation of water-based wood preservative solutions.

Achieved environmental benefits

- Reduced volume of cleaning water.
- Reduced emissions to water.

Technical considerations relevant to applicability
Only applicable to plants using water-based treatment chemicals.

Driving force for implementation
Reduced water consumption.

Reference literature
[235, UK DEFRA 2013]

15.4.10.6 Treatment of waste water/collected potentially contaminated rainwater and surface run-off

Description
Where contamination in the collected surface run-off water and/or cleaning water is detected or can be expected, and where the use of the water is not feasible, the waste water is treated in an adequate WWTP (on or off site).

Technical description
See the CWW BREF [31, COM 2016] for more information on waste water treatment.

Example plant: UK-1 (mixed: WB and C plant) in [236, TWG 2017]
The water from the whole site is collected and treated prior to discharge. The waste water treatment plant takes the effluent to a holding tank and then treats it through a number of process stages to ensure it is suitable to be discharged from the site to the town drain which in turn feeds the South Forty-Foot Drain. There are no discharges to the public sewer [Plant UK-1 in [236, TWG 2017]].

Achieved environmental benefits
Reduced emissions to water.

Environmental performance and operational data
The example plant provided the data on emissions to water from their on-site waste water treatment plant as presented in Table 15.21. Measurements are made for compliance monitoring. No contextual information was submitted with regard to the measurements (e.g. frequency, monitoring standards/methods, and uncertainty of measurements).

Table 15.21: Emissions to water reported for 2016 by a mixed WPC plant (water-based and creosote treatment on site)

Measured parameter	Waste water flow (m^3/h)	Biocides (mg/l)	Cu (mg/l)	Cr (mg/l)	TOC [solvents] (mg/l)	PAHs (mg/l)	Benzo[a] pyrene (mg/l)
Average value (of samples taken during the monitoring exercise)	NI	NI	0.017	< 0.002	NI	0.059	< 0.01
Duration of monitoring exercise (h)	NI	NI	4	4	NI	4	4
Number of samples/measurements per monitoring exercise	NI	NI	20	20	NI	20	20
NB: NI: No information provided. *Source:* [Plant UK-1 in [236, TWG 2017]]							

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation
Environmental legislation.

Example plants
Plants DE-8, FR-1, IT-2 and UK-1 in [236, TWG 2017]

Reference literature
[236, TWG 2017]

15.4.10.7 Disposal of waste water, collected potentially contaminated rainwater and surface run-off as hazardous waste

Description
Where contamination in the collected surface run-off water and/or cleaning water is detected or can be expected, and where the treatment or use of the water is not feasible, the collected surface run-off water and/or cleaning water is disposed of as hazardous waste.

Achieved environmental benefits
Reduced emissions to water.

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation
Environmental legislation.

Example plants
Plant PL-1 in [236, TWG 2017]

Reference literature
[236, TWG 2017]

15.4.10.8 Collection and treatment of condensates from depressurisation of treatment vessel and vacuum periods and from creosote reconditioning

Description

Condensates are collected, allowed to settle and treated in an activated carbon or sand filter. The treated water is either reused (closed circuit) or discharged into the public sewer system. Alternatively, the collected condensates may be disposed of as hazardous waste [230, VDI 2014] [231, Germany 2013] [DE comment #381 in [212, TWG 2018]].

Technical description

In pressure treatment plants using impregnating oils (creosote), waste water streams are generated in the form of condensates (e.g. from droplet separators) during depressurisation of the treatment vessel and during the vacuum periods. These condensates are collected, allowed to settle and treated in an activated carbon or sand filter. The treated water is either reused (closed circuit) or discharged into the public sewer system [230, VDI 2014] [231, Germany 2013].

Treated waste water can be recirculated if water-soluble salt concentrates or emulsions are used on site. If waste water treatment is carried out on site, it consists of a storage tank, flotation and chemical treatment/precipitation.

Process condensates occurring during the ‘creosote conditioning phase’ prior to the treatment process can be collected and treated the same way as condensates from the vacuum/depressurisation phase of autoclaves.

Designs may vary, but control techniques usually include closed-loop and secure systems with a condensate return system within the installation boundary. Condensate/water may be boiled and vapour recovered and disposed of via high-temperature (> 850 °C) or vapour scrubbing systems [243, EOS 2016].

Waste gas from waste water treatment is cleaned, e.g. with activated carbon. For this purpose, waste gas from waste water treatment can be combined with waste gas from creosote processing and both streams can be treated together.

Achieved environmental benefits

Reduced emissions to water.

Technical considerations relevant to applicability

Generally applicable.

Driving force for implementation

Environmental legislation.

Example plants

Plants DE-5, DE-8, FR-1, PL-1, UK-1 (collecting from depressurisation of treatment vessel and vacuum periods) in [236, TWG 2017].

Reference literature

[230, VDI 2014] [231, Germany 2013] [243, EOS 2016] [236, TWG 2017] [DE comment #381 in [212, TWG 2018]]

15.4.11 Energy management and efficiency

15.4.11.1 Heat recovery from waste gases of thermal oxidation

Description
Waste heat from thermal oxidisers is used by means of heat exchangers to preheat the water for steam generation.

Technical description
See the ENE BREF [109, COM 2009] for more information on heat recovery.

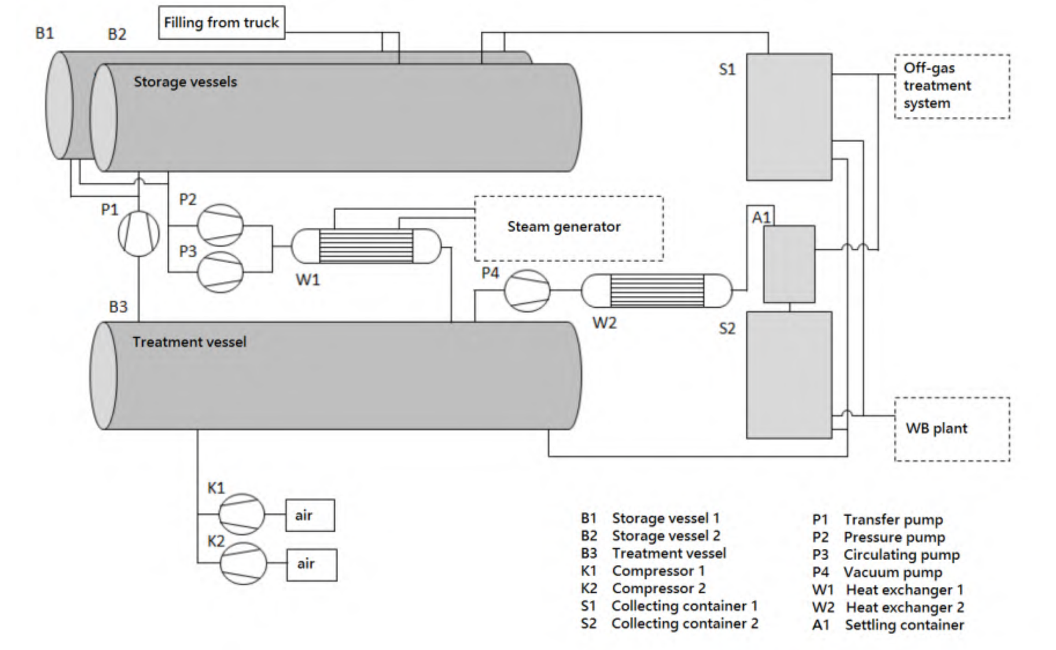
Example plant: DE-1 (mixed: WB and C plant) in [231, Germany 2013]
For the layout and more technical details of Plant DE-1, Figure 15.30 shows the schematic of the creosote treatment.

Achieved environmental benefits
Reduction of energy consumption.

Environmental performance and operational data
Example plant: DE-1 (mixed: WB and C plant) in [231, Germany 2013]
Approximately 98 % of the company's natural gas (1 440 000 kWh/year) is used for steam generation. The steam generator has a capacity of 9.2 t/h. The actual steam generation is about 3.25 t/h. The temperature of the feed water is increased to 80 °C by means of a heat exchanger of the thermal off-gas treatment system and a pressure of 9 bar in the steam generator is reached with a 3.0 kW feed pump. The fan on the burner has a power of 7.0 kW and the circulating pump for distributing the steam of 1.09 kW.

Condensates are collected, treated and returned to the system by means of a condensate pump (0.55 kW).

The steam is used for heating of the creosote and for the steam fixation in the fixing system. The air emission values of the steam generator were once measured (but this is no longer required by the authority).



Source: [231, Germany 2013]

Figure 15.30: Schematic of Plant DE-1

Driving force for implementation
Reduction of energy costs.

Example plants
Plant DE-1 in [231, Germany 2013].

Reference literature
[109, COM 2009], [231, Germany 2013]

15.4.11.2 Variable pump control

Description
After reaching the required working pressure, the treatment system is switched to a pump with reduced power and energy consumption in pressure processes (autoclaves).

Technical description
A pressure pump with relatively high power is used for building the desired working pressure in the treatment vessel. After reaching the working pressure, the system is switched to a more energy-efficient pressure pump with lower power.

Achieved environmental benefits
Reduction of energy consumption.

Environmental performance and operational data
The operator estimates a reduction in energy consumption of 25 % (6 000 kWh/yr/pump).
Cross-media effects
None.

Technical considerations relevant to applicability
Applicability may be limited in the case of oscillating pressure processes.

Economics
Investment costs: approximately EUR 5 000 (payback period at an average price of electricity for industrial customers in Germany in 2011 (EUR 0.113/kWh): approximately 7 years).

Driving force for implementation
Reduction of energy consumption (cost savings).

Example plants
Plants DE-1 in [231, Germany 2013] and PL-1, UK-3, UK-4, IT-1, SE-2, SE-3, FR-4, FI-1, DE-5, DE-6, DE-8 and DE-9 in [236, TWG 2017].

Reference literature
[231, Germany 2013] [DE comment #409 in [212, TWG 2018]] [236, TWG 2017]

15.4.12 Monitoring

15.4.12.1 Monitoring of waste water and surface run-off water

Description
Waste water and surface run-off water that is not reused in the treatment process is analysed for content of pertinent pollutants, i.e. substances depending on the preservative type and biocides used in the treatment, e.g. solvents, specific active substances, metals.

Technical description

One MS provided information that it is a regulatory obligation to monitor the waste water at least annually if certain flow thresholds are exceeded (15 m^3/h, 300 m^3/d or 7 500 m^3/yr). However, none of the plants from this MS took part in the data collection; therefore no further details on the monitoring are available [247, Belgium 2014].

The monitoring of emissions is carried out in accordance with EN standards or, if EN standards are not available, in accordance with ISO, national or other international standards which ensure the provision of data of an equivalent scientific quality.

Achieved environmental benefits

Control of emissions to water, maintenance of proper operation of the waste water treatment plant and detection of accidental releases.

Environmental performance and operational data

The information available with regard to monitoring of waste water and surface run-off water (based on the plants that took part in the data collection) is summarised in Table 15.22 below.

Table 15.22: Information on monitoring of waste water and surface run-off

Plant	Plant type	Monitoring frequency	Parameters monitored
UK-1	Mixed: WB+C	Compliance monitoring Periodic	Cu, Cr, PAHs, benzo(a)pyrene
SE-1	Water-based (WB)	Twice per year	Cu, Cr, As, PAHs, benzo(a)pyrene, HOI (oil)
DE-5	Creosote (C)	Compliance monitoring Periodic	Cu, Cr, PAHs, benzo(a)pyrene, HOI (oil), least volatile lipophilic substances, phenol index, COD
DE-6	Water-based (WB)	Four times per year	Cu

Source: [236, TWG 2017]

Cross-media effects

Some equipment, ancillary materials and energy are required for carrying out monitoring.

Technical considerations relevant to applicability

Generally applicable.

Economics

The costs associated with monitoring of waste water and surface run-off water relate to personnel and equipment used for sampling and measurement.

Driving force for implementation

Environmental legislation.

Example plants

Plants DE-6, DE-5, IT-2, IT-1, SE-2, SE-1, SE-3, UK-1 and FR-2 in [236, TWG 2017].

Reference literature

[236, TWG 2017] [247, Belgium 2014]

15.4.12.2 Monitoring of soil

Description

Regular monitoring of emissions to soil.

Technical description

Of the plants that took part in the data collection exercise in 2017, five plants confirmed that soil pollution is monitored regularly (PL-1, UK-1, UK-2, UK-3 and UK-4) with monitoring frequencies comprising 'as required', every 5 years or every 10 years.

Example plant: PL-1 in [236, TWG 2017]

Soil monitoring is carried out every 5 years and the content of metals, Cu, Cr, benzo[a]pyrene, styrene, toluene, xylene, aromatic hydrocarbons, mineral oil, phenol, naphthalene and total PAHs in the soil is determined (in mg/kg). The plant has identified historic soil and ground water pollution on site (baseline study in 2015).

Achieved environmental benefits

Control of emissions to soil and detection of accidental releases.

Environmental performance and operational data

The information available with regard to monitoring of soil (based on the plants that took part in the data collection) is summarised in Table 15.23 below.

Table 15.23: Information on monitoring of soil contamination

Plant	Plant type	Monitoring frequency	Parameters monitored (unit)
PL-1	Mixed: WB+C	Every 5 years	Metals, Cu, Cr, benzo[a]pyrene, styrene, toluene, xylene, aromatic hydrocarbons, mineral oil, phenol, naphthalene, total PAHs
UK-1	Mixed: WB+C	As required	NI
UK-2	Water-based (WB)	Every 10 years	Biocides (mg/kg)
UK-3	Water-based (WB)	Every 10 years	Biocides (mg/kg)
UK-4	Water-based (WB)	Every 10 years	Cu, nitrate, 2-aminoethanol (monitored to show variation in concentrations)

Source: [236, TWG 2017]

Cross-media effects

Some equipment, ancillary materials and energy are required for carrying out monitoring.

Technical considerations relevant to applicability

Generally applicable.

Economics

The costs associated with monitoring of emissions to soil relate to personnel and equipment used for sampling and measurement.

Driving force for implementation

Environmental legislation.

Example plants

Plants DE-5, DE-9, FI-1, FR-5, FR-1, FR-3, FR-4, PL-1, SE-2, UK-1, UK-2, UK-3 and UK-4 in [236, TWG 2017].

Reference literature
[236, TWG 2017]

15.4.12.3 Monitoring of groundwater quality

Description
Regular monitoring of groundwater quality.

Technical description
Of the plants that took part in the data collection exercise in 2017, 14 plants confirmed that groundwater quality is monitored regularly with monitoring frequencies comprising twice a year to every 5 years. No information was submitted on sampling or measurement standards used in groundwater monitoring. Three plants reported they have piezometers installed to control potential emissions to soil and groundwater

Piezometers are used to measure the level of groundwater at the sampling point. The number and location of piezometers that need to be installed are determined based on the plant specificities with the aim of following the direction of the movements of complex aquifers (e.g. one upstream and two downstream piezometers) [EPF comment #42 in [212, TWG 2018]].

The monitoring of emissions is carried out in accordance with EN standards or, if EN standards are not available, in accordance with ISO, national or other international standards which ensure the provision of data of an equivalent scientific quality.

Achieved environmental benefits
Control of groundwater quality and detection of accidental releases.

Environmental performance and operational data
The information available with regard to monitoring of groundwater quality (based on the plants that took part in the data collection) is summarised in Table 15.24 below.

Table 15.24: Information on monitoring of groundwater

Plant	Plant type	Monitoring frequency	Parameters (unit)
DK-1	Water-based (WB)	Yearly	Cu, Cr, As, B (µg/l)
UK-2	Water-based (WB)	NI	Azoles, pyrethroids
UK-3	Water-based (WB)	Every 2 years	Biocides (µg/l), COD
UK-4	Water-based (WB)	Every 5 years	Cu, nitrate, 2-aminoethanol (monitored to show variations)
SE-2	Water-based (WB)	Twice per year	As, Cu, Cr
SE-1	Mixed: WB+C	Twice per year	Cu, Cr, PAHs, benzo[a]pyrene, HOI (oil)
FR-3	Water-based (WB)	Twice per year	Propiconazole (%)
FR-4	Water-based (WB)	Twice per year	Tebuconazole propiconazole, permethrine, cypermethrin, Cu (µg)
FR-1	Creosote (C)	Twice per year	PAHs, benzo[a]pyrene (µg/l)
FI-1	Water-based (WB)	Every 3 years	As, Cu, Cr
DE-9	Mixed: WB+C	Yearly (in future every 2 years)	PAHs (µM/l) naphthalene, BTEX (sum of benzene, toluene, ethylbenzene and xylene), phenol, sulphate, nitrate, Fe (sulphate, nitrate and Fe only to prove that degradation is in progress)
DE-6	Water-based (WB)	Twice per year	Cu
FR-5	Water-based (WB)	Twice per year	NI
FR-2	Mixed: WB+C	Twice per year	As, Cr, Cu, Hg
Source: [236, TWG 2017]			

Cross-media effects
Some equipment, ancillary materials and energy are required for carrying out monitoring.

Technical considerations relevant to applicability
Generally applicable.

Economics
The costs associated with monitoring of groundwater quality relate to personnel and equipment used for sampling and measurement.

Driving force for implementation
Environmental legislation.

Example plants
Plants DE-5, DE-9, FI-1, FR-5, FR-1, FR-3, FR-4, PL-1, SE-2, UK-1, UK-3, UK-4 in [236, TWG 2017].

Reference literature
[236, TWG 2017]

15.4.12.4 Monitoring of potential receiving surface waters in the vicinity of WPC plants

Description
Regular monitoring of potential receiving surface waters in the vicinity of WPC plants.

Technical description
Of the plants that took part in the data collection, three have potential receiving surface waters in the vicinity of the WPC plant; two reported that the surface water bodies are regularly monitored. At Plant UK-1, the water is checked on an *ad hoc* basis by the competent authority; at Plant SE-1, monitoring is done twice a year (no information is available as to who carries out the monitoring).

Achieved environmental benefits
Control of emissions to potential receiving surface waters in the vicinity of WPC plants.

Cross-media effects
Some equipment, ancillary materials and energy are required for carrying out monitoring.

Economics
The costs associated with monitoring relate to personnel and equipment used for sampling and measurement.

Driving force for implementation
Reduction of environmental risks.

Example plants
Plants SE-2 (no information submitted in questionnaire), SE-1 and UK-1 in [236, TWG 2017].

Reference literature
[236, TWG 2017]

15.4.12.5 Monitoring of emissions in waste gases

Description
Regular monitoring of emissions in waste gases.

Technical description
Monitoring of the relevant parameters can be accomplished by online measurements (which facilitate rapid intervention and control) or analytical results derived from air samples. Parameters to be monitored and the frequency of monitoring depend on the characteristics of the type of processes and material used and the abatement techniques applied within the WPC plant.

Of the plants that took part in the data collection exercise in 2017, six plants confirmed that emissions to air are monitored regularly (SE-1, UK-1, DE-9, FR-1, PL-1 and DE-5) with monitoring frequencies comprising yearly or every 3 years.

In addition, TVOC emissions to air can be monitored continuously to ensure the correct functioning of the off-gas treatment system (e.g. for an activated carbon filter to determine the loading of the material at an early stage based on the abatement efficiency of the system). However, for the plants that took part in the WPC data collection, no information was submitted in this regard.

The monitoring of emissions is carried out in accordance with EN standards or, if EN standards are not available, ISO, national or other international standards which ensure the provision of data of an equivalent scientific quality.

Achieved environmental benefits
Control of emissions in waste gases, maintenance of proper operation of the off-gas treatment system and detection of accidental releases.

Environmental performance and operational data
The information available with regard to monitoring of emissions in waste gases (based on the plants that took part in the data collection) is summarised in Table 15.25 below.

Table 15.25: Information on monitoring applied for emissions in waste gases

Plant	Plant type	Purpose	Parameters monitored (units)
SE-1	Mixed: WB+C	Compliance monitoring NO_X / CO: continuous Every 3 years	TVOC (mg C/Nm^3) PAHs (mg/Nm^3) PCDD/PCDF (TCSS-ekv I-TEQ) (mg/h) NO_X, CO (mg/Nm^3) O_2 (%)
UK-1	Mixed: WB+C	Compliance monitoring Yearly	PAHs (including naphthalene) (mg/Nm^3) Total VOCs (mg/Nm^3)
DE-9	Mixed: WB+C	Compliance monitoring Every 3 years	Waste gas flow (Nm^3/h) TVOC (mg C/Nm^3) NO_X, CO (mg/Nm^3) O_2 (%)
FR-1	Creosote (C)	Compliance monitoring Yearly	Waste gas flow (Nm^3/h) TVOC (mg C/Nm^3) PAHs (mg/Nm^3) Naphthalene (mg/Nm^3) Benzene (mg/Nm^3)
PL-1	Mixed: WB+C	Compliance monitoring Yearly	TVOC (mg C/Nm^3)
DE-5	Creosote (C)	Compliance monitoring Every 3 years	Benzene (mg/Nm^3) Benzo(a)pyrene (mg/m^3) Phenols (mg/m^3)

Source: [236, TWG 2017]

Cross-media effects
Some equipment, ancillary materials and energy are required for carrying out monitoring.

Technical considerations relevant to applicability
Generally applicable.

Economics
The costs associated with monitoring of emissions in waste gases relate to personnel and equipment used for sampling and measurement.

Driving force for implementation
Environmental legislation.

Example plants
Plants DE-9, DE-5, FR-1, PL-1 and UK-1 in [236, TWG 2017].

Reference literature
[236, TWG 2017]

15.4.13 Off-gas extraction and treatment

15.4.13.1 Vapour emission control for creosote (re)conditioning area

Description
Enclosure of the creosote (re)conditioning area with off-gas extraction and treatment by activated carbon or a thermal oxidiser.

Vapour emissions from this process are connected to the condensate collection system [243, EOS 2016].

Achieved environmental benefits
Reduction of emissions to air.

Driving force for implementation
Workplace health and safety.

Example plants
Plants DE-5, FR-1 and UK-1 in [236, TWG 2017].

Reference literature
[236, TWG 2017] [243, EOS 2016]

15.4.13.2 Exhaust gas capture for hot-cold bath creosote treatment

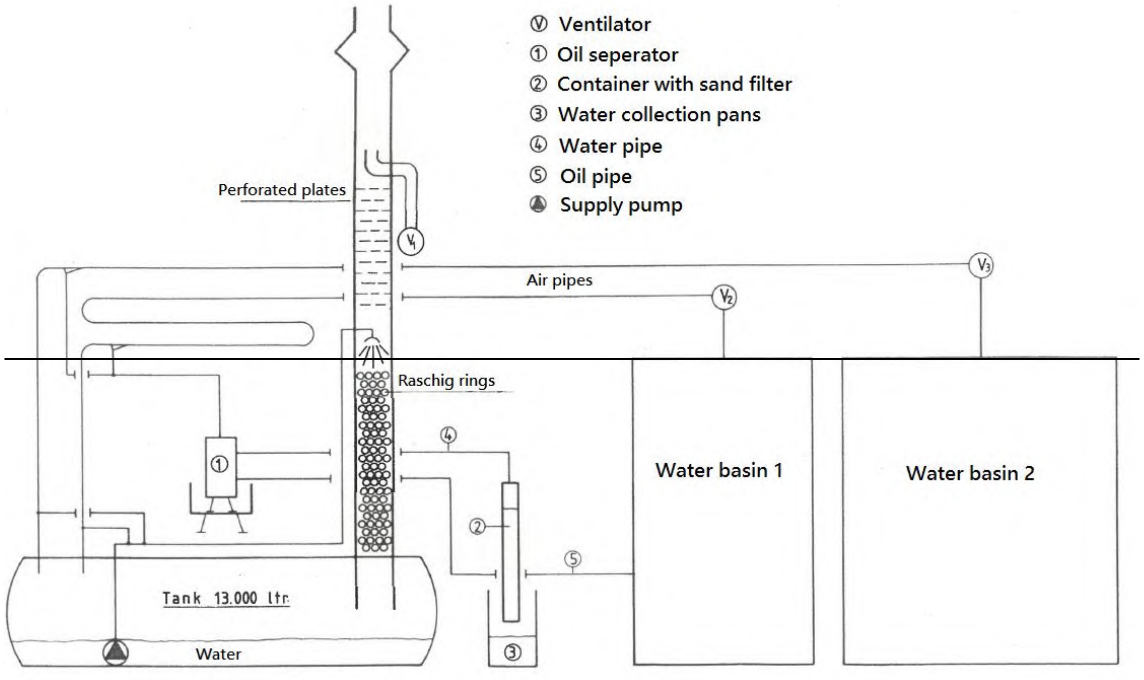
Description
An enclosure with doors that are opened for loading/unloading is installed covering the impregnation trough and captures emissions during the whole treatment process: impregnation, lifting of the charge and cooling.

Emissions are extracted until the timber has cooled to ambient temperature. The off-gases are directed to an air pollution control device, e.g. an exhaust gas scrubber or activated carbon filter.

Technical description

During the impregnation process and cooling stage, the hot-cold bath treatment tank is closed by a moveable top cover and waste gas is collected from the closed tank for further treatment (e.g. scrubber) [231, Germany 2013].

The extracted emissions are abated by a scrubber (see Figure 15.31).



Source: [Plant DE-8 in [236, TWG 2017]]

Figure 15.31:Schematic of the emission abatement system (scrubber) installed at a hot-cold bath creosote treatment plant

Achieved environmental benefits

- Reduction/capture of diffuse emissions.
- Reduction of emissions to air, especially VOCs and PAHs.

Driving force for implementation

Workplace health and safety.

Example plants

Plant DE-8 in [236, TWG 2017].

Reference literature

[231, Germany 2013] [236, TWG 2017]

15.4.13.3 Enclosure of emitting equipment or processes and extraction of off-gases

Description

Enclosure of emitting equipment or processes (e.g. storage and impregnation tanks, depressurisation, creosote reconditioning) of plants using creosote and/or solvent-based treatment chemicals and extraction of off-gases followed by treatment.

Technical description
During the impregnation process using creosote and/or solvent-based treatment chemicals, air is displaced from the impregnation, preheating and storage vessels. This air is contaminated and has to be collected and treated with an off-gas treatment technique.

To reduce fugitive emissions, the area around the opening of the impregnation vessels can also be covered by an enclosure (building). During and after the opening of the vessels, the extracted air is collected at the top of the enclosure and treated in an off-gas treatment system. If the opening of the vessels is enclosed, there must be a possibility to open the vessels from the outside of the enclosure, because of occupational health and safety reasons. Furthermore, enclosure (building) of the working area with slight sub-atmospheric (negative) pressure (off-gas sent to abatement system) can reduce fugitive air emissions.

Example plant: DE-1 (mixed: WB and C plant) in [231, Germany 2013]
The air, which is displaced from the treatment vessel or is pumped out by the vacuum pump P4 (18.5 kW), is cooled by a heat exchanger W2 and collected in a settling container A1. The gas phase is passed from the settling tank to the thermal off-gas treatment system. The existing liquid phase consisting of water and tar oil is intermediately stored in a collecting container S2. The aqueous phase can be reused in the preparation of water-based wood preservative solutions (i.e. in the production line of the Korasit CK). The tar oil is sucked back into the system by means of a vacuum in the treatment vessel (see also Figure 15.25).

Achieved environmental benefits
Reduction/capture of diffuse emissions.

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation
Workplace health and safety.

Example plants
All plants using the off-gas treatment techniques in Sections 15.4.13.4 to 15.4.13.8.

Reference literature
[231, Germany 2013] [236, TWG 2017]

15.4.13.4 Thermal oxidation

Description
Oxidation of VOCs by heating off-gases with air or oxygen to above their auto-ignition point in a combustion chamber and maintaining a high temperature long enough to complete the combustion of VOCs to carbon dioxide and water. Exhaust heat can be recovered by means of heat exchangers.

Technical description
Process gas from the coal-tar oil impregnation tanks is fed to a thermal oxidiser. Organic components in the process gas are oxidised with natural gas at a temperature of 750 °C. Exhaust heat can be recovered by means of heat exchangers.

Exhaust gases generated from the tanks of the creosote-impregnating installation are fed into the thermal oxidation (see VDI 2442 [260, VDI 2014]). Organic components in the exhaust gas are burnt. The thermal oxidiser performs the process of oxidation of flammable gases and aromatic substances in the exhaust gas where the mixture of air or oxygen with pollutants is heated with natural gas in a combustion chamber long enough to be above the auto-ignition point in order to reach almost complete combustion to CO_2 and water [231, Germany 2013].

Example plant: DE-1 (mixed: WB and C plant) in [231, Germany 2013]

The thermal oxidation works with natural gas at a temperature of 750 °C. The hot exhaust gas is used to preheat the combustion air, as well as to heat water to 80 °C to produce steam for the steam generator. The thermal oxidiser is only in operation when the process gas is displaced or extracted by suction from the tanks of the creosote production line. For this purpose, the system is heated to 750 °C for 15 minutes. The process gas is blown into the system for 15 minutes. In another 15 minutes, the temperature is controlled and reduced stepwise, to avoid excessively rapid cooling. The supply pipe for process gas to be oxidised is equipped with a fire safety device.

The ventilation for the burner has a capacity of 0.76 kW and the exhaust fan has a capacity of 7.5 kW. Accumulated hot water from the heat exchanger of the thermal oxidation is returned to the steam cycle system by a condenser pump (0.46 kW) and heated to 80 °C in the thermal treatment. The exhaust gas of the thermal oxidation is inspected at regular intervals (measurement according to § 28 BIMSchG).

Achieved environmental benefits

Reduction of emissions to air (VOCs, PAHs and odour).

Environmental performance and operational data

The values in Table 15.26 come from a typical measurement protocol (normal operating conditions, indicative for the thermal oxidation, mass concentration, related to dry exhaust gas, standard conditions, 273 K, 101.3 kPA, no reference oxygen level set, measurement accuracy: ± 5 %) [231, Germany 2013].

Table 15.26: Reported emission values after thermal oxidation in the creosote (coal tar oil) impregnation installation plant DE 1

Parameter	Half-hour average values	Limit values (operating permit)	Sampling point	Measurement procedure
CO	49 mg/m^3	100 mg/m^3	The sampling point is located directly in front of the fan in the exhaust duct (1)	In accordance with VDI 2459, Part 6
NO_X	104 mg/m^3	200 mg/m^3		In accordance with VDI 2456, Part 9
Total C	14 mg/m^3	50 mg/m^3		VDI 3481, Part 1 and EN 12619
Benzo[a]pyrene	< 0.002 mg/m^3	0.1 mg/m^3		Sampling in accordance with DIN EN 1948 and analysis according to VDI 3873, Part 1

(1) The sampling point is not the recommendation of VDI 2066 Part 1. For practical reasons, inlet and outlet conditions are not respected. The results obtained are representative in the sense of No 5.3.2.2 TA Luft of 24.07.2002. A plausibility check is given in the measurement protocol.

Source: [231, Germany 2013]

The total exhaust gas volume amounts to 500 000 m^3 per year. On the basis of specified concentrations, this corresponds to annual pollutant loads of 24.5 kg/year of CO, 52 kg/year of NO_X, 7 kg/year of total carbon and less than 0.001 kg/year of benzo[a]pyrene. Emissions occur discontinuously as the thermal off-gas treatment is only operated temporarily. The annual pollutant loads are in the range of the hourly values of the Technical Instructions on Air Quality Control (TA Luft) for benzo[a]pyrene and oxides of nitrogen (see point 4.6.1.1 TA Luft; for oxides of nitrogen 20 kg/h; 0.0025 kg/h for benzo(a)pyrene) [231, Germany 2013].

The natural gas consumption is 1 440 000 kWh/year for thermal off-gas treatment and associated steam generation (used as the heat supply for the impregnation processes in the system).

The treatment performance of the thermal oxidiser is approximately 500 000 m^3/year [231, Germany 2013].

Table 15.27: Reported emission levels for creosote pressure treatment plants equipped with thermal oxidisers

Parameter	Achieved emission level					
	Waste gas flow (Nm^3/h)	**TVOC** (mg C/Nm^3)	**PAHs** (mg/Nm^3)	**PCDD** (mg/Nm^3)	**NO$_X$** (mg/Nm^3)	**CO** (mg/Nm^3)
Plant: DE-9 (measurement in 2016)						
Average value	**1 723**	**3.3**	-	-	**35**	**158**
Duration of monitoring exercise (h)	1.5	1.5	-	-	1.5	1.5
Number of samples	3	3	-	-	3	3
Monitoring standard/method	ISO 10780 and VDI 2066 Bl. 1	EN 12619:2013	-	-	DIN 33962	EN 15058:2006
Uncertainty of a single measurement	-	2.3g/m^3 EN 12619 and VDI 3481 Bl4	-	-	0.002 g/m^3 DIN 33962	0.007 g/m^3
Plant: SE-1 (measurement in 2014, for NO$_X$/CO additionally in 2016 and 2015)						
Average value	**10700**	**1**	**1**	**0**	**686 (2014)** 522 (2015) 459 (2016)	**464 (2014)** 312 (2015) 353 (2016)
Duration of monitoring exercise (h)	24	24	24	24	8 776	8 776
Number of samples	1	1	1	1	Continuous	Continuous
Monitoring standard/method	-	-	-	-	-	-
Uncertainty of a single measurement (%)	5	5	7	6	-	-
Uncertainty subtracted from the reported values?	Yes	Yes	Yes	Yes	-	-

Source: [Plants DE-9 and SE-1 in [236, TWG 2017]]

Cross-media effects

Energy use for the thermal oxidiser (CO$_2$ emissions; use of natural gas) [231, Germany 2013].

Technical considerations relevant to applicability

Generally applicable.

Economics

- Investment costs: no information provided.
- Operating costs: cost for an unspecified share of 1 440 000 kWh/year of natural gas.

- Personnel costs for the operation, maintenance and technical certification. Specific costs are not available [231, Germany 2013].

Driving force for implementation
Environmental legislation.

Example plants
Plants DE 1 in [231, Germany 2013] and DE-9 and SE-1 in [236, TWG 2017].

Reference literature
See also Section 17.10.5.2.
[31, COM 2016] [231, Germany 2013] [236, TWG 2017]

15.4.13.5 Sending off-gases to a combustion plant

Description
Part or all of the off-gases are sent as combustion air and supplementary fuel to a combustion plant (including CHP plants) used for steam and/or electricity production.

Technical description
Example Plant: UK-1 (Combustion in clean waste wood biomass boiler) in [236, TWG 2017]:
The installation incorporates a wood-fired boiler which burns untreated offcuts and process wastes. However, as part of site improvement plans, this is to be replaced with a new energy-efficient 2 MW biomass boiler within the first year of this permit being issued. This similarly burns clean wood waste only arising from the installation. It is to provide power and heat and in addition is designed to take emissions from the creosote impregnation processes and thermally treat them in the secondary combustion chamber of the appliance, significantly reducing potential odour emissions and residual VOCs to the environment [Plant UK-1 in [236, TWG 2017]].

Achieved environmental benefits
Reduction of emissions to air (VOCs) from creosote treatment.

Environmental performance and operational data

Table 15.28: Reported emission levels for a creosote pressure treatment plant applying combustion in clean waste wood biomass boiler

Measured parameter	**Waste gas flow** (Nm^3/h)	**Total VOCs** (mg/Nm^3)	**PAHs (including naphthalene)** (mg/Nm^3)
Average value (of samples taken during the monitoring exercise)	NI	**176.1** (2016) **144.2** (2015) **258.1** (2014)	**11.1** (2016) **3.73** (2015) < **0.12** (2014)
Duration of monitoring exercise (h)	NI	**6**	**1.5**
Number of samples/measurements per monitoring exercise	NI	**2**	**2**
O_2 level (%)	NI	NI	NI
Monitoring standard/method	NI	NI	NI
Uncertainty of a single measurement (%)	NI	NI	NI
Uncertainty subtracted from the reported values?	NI	NI	NI
Abatement efficiency (%)	NI	NI	NI
How was the abatement efficiency defined?	NI	NI	NI

NB:
NI: No information provided.
Source: [Plant UK-1 in [236, TWG 2017]]

Technical considerations relevant to applicability

- Applicable to creosote and solvent-based treatment plants.
- Technique may not be applicable for off-gases containing substances referred to in IED Article 59(5) or its applicability may be restricted due to safety considerations.

Driving force for implementation
Environmental legislation.

Example plants
Plant UK-1 in [236, TWG 2017].

Reference literature
[236, TWG 2017]

15.4.13.6 Adsorption using activated carbon

Description
Organic compounds are adsorbed on the surface of activated carbon. Adsorbed compounds may be subsequently desorbed, e.g. with steam (often on site) for reuse or disposal and the adsorbent is reused.

Technical description
For a general description on adsorption techniques, see Section 17.10.6.2.

Achieved environmental benefits
Reduction of VOC emissions to air.

Environmental performance and operational data

The emission data provided for example creosote plant DE-5 for the WPC data collection in 2017 is summarised in Table 15.29.

Table 15.29: Reported emission levels for creosote pressure treatment plant equipped with adsorption

Measured parameter	**Waste gas flow** (Nm^3/h)	**TVOC** (mg C/Nm^3)	**CMR** (mg/Nm^3)	**Naphthalene** (mg/Nm^3)	**Benzene** (mg/Nm^3)	**Benzo(a) pyrene** (mg/m^3)	**Phenols** (mg/m^3)
Average value	**4 480**	**3.1**	**0.00034**	**< 1.91**	**< 0.06**	**0.000004**	**< 0.032**
Duration of monito-ring exercise (h)	4	4	4	4	4	4	4
Number of samples/ measurements per monitoring exercise	8	8	8	8	8	8	8
Additional information on measurements	-	Max. 6.9	Max. 0.0014	-	-	Max. 0.000005	Max. < 0.055
Monitoring standard/method	NI	EN 12619:2013	DIN EN 13649/ VDI 3874 sampling	DIN EN 13649 / VDI 3874 sampling	DIN EN 13649	VDI 3874 sampling	VDI 3874 sampling
Uncertainty of a single measure-ment (%)	10	-	-	-	-	-	-
Uncertainty subtracted from the reported values?	No	No	No	No	No	No	No

NB: Year of measurement 2015.
Source: 5 [Plant DE-5 in [236, TWG 2017]]

Technical considerations relevant to applicability

Generally applicable.

Driving force for implementation

Environmental legislation.

Example plants

Plant DE-5 in [236, TWG 2017].

Reference literature

[236, TWG 2017]

15.4.13.7 Absorption using a suitable liquid

Description

Use of a suitable liquid to remove pollutants from the off-gases by absorption, in particular soluble compounds.

Technical description

Wet scrubbing is a mass transfer between a soluble gas or dust and a solvent – often water – in contact with each other. A full description of the wet scrubbing process and the types of wet scrubbing equipment available is given in the CWW BREF [31, COM 2016].

Example plant: DE-8 in [236, TWG 2017]

The waste gas stream enters the wet scrubber at the bottom and flows upward through the scrubbing zone. To increase the surface, the wet scrubber is filled with Raschig rings (metal). Perforated plates are installed in the stack over the scrubbing zone to increase the water recirculation from the waste gas stream (moisture elimination). The washing water is collected/stored in a tank below the scrubber and reused in the scrubbing process.

Creosote and water partly condense in the pipe system. These condensates are collected in a special tank and treated as described in Section 15.4.10.8. A schematic for the abatement system including a wet scrubber is given in Figure 15.31.

Achieved environmental benefits

- Reduction of emissions to air, especially VOCs and PAHs.
- Reuse of scrubbing water.

Environmental performance and operational data

Table 15.30: Reported emission levels for a creosote plant with hot-cold bath treatment equipped with a scrubber

Parameter	**Achieved emission level**				
	Waste gas flow (Nm^3/h)	**TVOC** (mg C/Nm^3)	**PAHs** (mg/Nm^3)	**Naphthalene** (mg/Nm^3)	**Benzo(a) pyrene**
Year of measurement: 2006					
Average value (of samples taken during the monitoring exercise)	1260	NI	0.198 (¹)	NI	< LoD (LoD: 0.05 µg/m^3)
Duration of monitoring exercise (h)	NI	NI	NI	NI	NI
Number of samples/measurements per monitoring exercise	NI	NI	2	NI	2
Abatement efficiency (%)	NI	NI	NI	NI	NI
Year of measurement: 1997					
Average value (of samples taken during the monitoring exercise)	NI	3.9*	1.38	1.21	< LoD (LoD: 0.002 mg/m^3)
Duration of monitoring exercise (h)	NI	0.5	0.5	0.5	0.5
Number of samples/measurements per monitoring exercise	NI	1	1	1	1
Abatement efficiency (%)	NI	98.7**	97.9**	97.9**	NI

(¹) Individual PAH values of the samples taken during the monitoring exercise: 0.192 mg/Nm^3 and 0.204 mg/Nm^3.
* Calculated, 1- and 2-methylnaphthalene included.
** Simultaneous measurements of raw and clean gas.
NI: No information provided.
Source: [Plant DE-8 in [236, TWG 2017]]

Cross-media effects

In example plant DE-8, the amount of collected waste water from condensates is $2m^3$ per year which can be used in a water-based treatment plant for the preparation of treatment solution.

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation
Environmental legislation.

Example plants
Plant DE-8 in [236, TWG 2017].

Reference literature
[236, TWG 2017]

15.4.13.8 Condensation

Description
A technique for removing organic compounds by reducing the temperature below their dew points so that the vapours liquefy. Depending on the operating temperature range required, different refrigerants are used, e.g. cooling water, chilled water (temperature typically around 5 °C), ammonia or propane.

Condensation is used in combination with another abatement technique.

Technical description
For further information, see the CWW BREF [31, COM 2016].

Example plant: FR-1 in [236, TWG 2017]
A condenser is placed between the autoclaves and the vacuum pump. It condenses the creosote vapours by the cooling down process, and collects them in order to achieve creosote vapour with less VOC gas. This equipment is made with two separated circuits, one for the creosote gas and the other for the cooling water which cools the creosote gas with a contact surface through the network of pipes. The refrigeration unit is installed in order to maintain cooling water with a maximum temperature of 15 °C [EPF comment #31 in [212, TWG 2018]].

Achieved environmental benefits
- Reduction of VOC emissions.
- Collected solvents may be reused or recycled.

Environmental performance and operational data
Example plant: FR-1 in [236, TWG 2017]
Average emission values in the range of 49.7 mg C/Nm^3 to 154.9 mg C/Nm^3 were reported for two emission points (autoclaves).

Cross-media effects
Energy consumption.

Technical considerations relevant to applicability
Applicability may be restricted where the energy demand for recovery is excessive due to the low VOC content.

Economics
See the CWW BREF [31, COM 2016].

Driving force for implementation
- Workplace health and safety.
- Pretreatment of off-gases prior to other another abatement technique.

Example plants
Plant FR-1 in [236, TWG 2017].

Reference literature
[EPF comment #31 in [212, TWG 2018]] [31, COM 2016] [236, TWG 2017]

15.4.14 Noise

Description
Implementation of operational and maintenance techniques for the reduction of noise emissions.

Technical description
Noise emissions can be reduced by the implementation of the techniques given below:

a) installation of noise walls and utilisation/optimisation of the noise-absorbing effect of buildings;
b) enclosure or partial enclosure of noisy operations;
c) use of low-noise vehicle transport systems;
d) noise reduction measures for fans used in kiln drying;
e) noise management measures (e.g. improved inspection and maintenance of equipment, closing of doors and windows).

Achieved environmental benefits
Reduction of noise levels.

Technical considerations relevant to applicability
The applicability is restricted to cases where a noise nuisance at sensitive receptors is expected and/or has been substantiated.

Driving force for implementation
Environmental legislation. Reduced complaints in the vicinity of the plant.

Example plants
Plants applying BAT candidates:

a) DE-7 and DE-8;
b) PL-1, UK-1, UK-4, FI-1, DE-7, DE-8 and DE-9;
c) PL-1 and DE-9;
d) no information provided;
e) PL-1, UK-1, SE-2, FI-1, DE-5, DE-7 and DE-8 in [236, TWG 2017].

Reference literature
[236, TWG 2017]

16 ADDITIONAL SECTORS

This section contains information for the two following STS sectors not covered by the data collection exercise: manufacture of mirrors and manufacture of coated abrasives.

16.1 MANUFACTURE OF MIRRORS

[25, GEPVP et al. 2004] [184, AGC GLASS EUROPE 2017]

16.1.1 General information on the manufacture of mirrors

The main production of mirrors is usually carried out by large multinational corporations in plants with capacities of more than 2 million m^2/yr (data from 2004). The major facilities are situated in Germany, France, Spain, Italy, Belgium, Poland, the United Kingdom, Luxembourg and the Czech Republic. There are also some small producers.

Based on data from 2004, the total demand for mirrors in Europe is estimated as 40 million m^2/yr. This leads to an annual consumption range of solvents of approximately 2 000-3 600 tonnes. The general applications of mirrors in Europe are:

- mirrors for bathrooms;
- mirrors for furniture;
- architectural uses, e.g. wall covering;
- automotive applications.

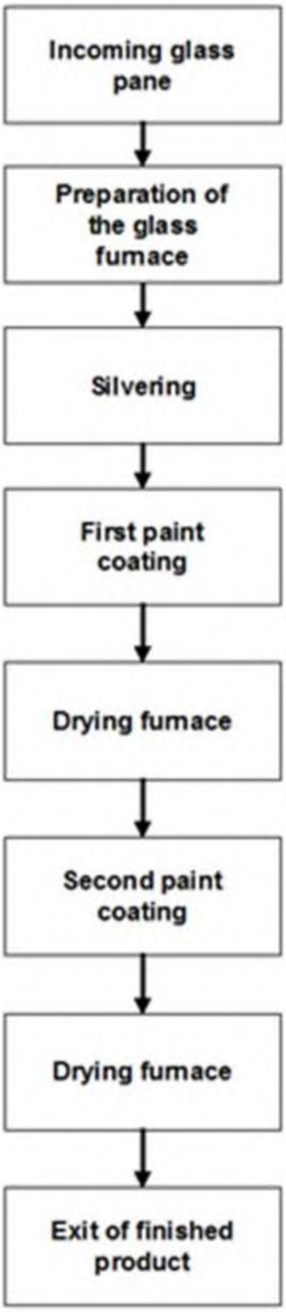
The specific organic solvent consumption, i.e. hourly, of each installation is dependent on the surface of the mirrors produced. The largest lines can produce mirrors of 6 m by 3.2 m, i.e. 19 m^2. As mirror production is a continuous process, the speed of the line also affects the hourly consumption rates. Thus, some lines exceed the annual and hourly consumption threshold, whilst others only exceed the annual threshold.

It is estimated that the number of lines that exist in Europe are between 15 and 20 (data from 2004). Normally, the number of employees occupied in a mirror line is low, though most lines are part of a large manufacturing company.

16.1.2 Applied processes and techniques in the manufacture of mirrors

The production line is designed as a continuous process. The glass sheet lies on a large conveyor that leads the mirror through the different steps of manufacturing. Conveyors are up to 3.5 m wide and more than 150 m long to allow the manufacturing of large mirrors. Typically, mirrors consist of one glass pane covered by a reflective metallic layer which is protected by one or more paint coatings. After the paint coating, the mirror passes through the drying furnace.

Figure 16.1 summarises the different steps in the manufacture of mirrors. These are described in detail in the following sections.



Source: [25, GEPVP et al. 2004]

Figure 16.1: Flow chart of the manufacture of mirrors

16.1.2.1 Incoming glass pane

Glass is usually fed to the mirror factory by lorries. The glass is then stocked on stillages and unloaded onto the mirror line using vacuum lifting devices.

16.1.2.2 Preparation of the glass surface

The preparation of the glass surface consists of a light polishing step using a water-based abrasive slurry containing cerium oxides. No solvent is used at this stage. The resulting waste water is treated and the sludge recovered for recycling or disposal.

16.1.2.3 Silvering

The reflective metallic layer is generally made of silver, which is sensitive to corrosion and therefore protected by the paint layer which follows. A description of the silvering process and control of emissions of silver, tin, and palladium can be found in the STM BREF [23, COM 2006]. Currently, most producers use the tin process instead of the copper process for fixing the silver layer. No solvent is used at this stage. Aluminium is also used for the reflective metallic layer.

16.1.2.4 Paint coating

The glass is passed through a laminar curtain of paint, which falls continuously from a trough-type assembly. The excess coating material is continuously reused, but extra solvent is added to ensure proper application viscosity. The paint used is solvent-based and contains 30-40 wt-% solvent. The paint consumption ranges from 150 g/m^2 to 200 g/m^2. The total thickness of the dried paint coating(s) is in the range of 40 µm to 70 µm.

16.1.2.5 Drying

After the paint coating, the mirror is taken to the drying furnace where the solvent is evaporated and the paint dried, allowing its polymerisation. Drying is promoted by heating the product by infrared radiation with or without convection heat.

16.1.2.6 Exit of the finished product

At the end of the line, the mirror is unloaded using vacuum lifting devices and stacked on stillages.

16.1.3 Current consumption and emission levels in the manufacture of mirrors

As only a small number of plants above the IED capacity threshold were identified, it was decided not to collect data via questionnaires. The following sections are the same as in the original STS BREF (2007).

16.1.3.1 Mass balances

No information provided.

16.1.3.2 Consumption

16.1.3.2.1 Materials

The total solvent consumed amounts to 50-90 g/m^2, depending on the type of product manufactured. Also, some solvent is used for cleaning. The solvent used is xylene.

The greatest proportion of the solvent is used to adjust the paint viscosity and applied onto the product. A small amount is used for cleaning purposes, i.e. < 10 %. When this solvent is not contaminated, it is added to the solvent used to adjust the paint viscosity.

Normally, it is expected that 100 % of the glass used as input is transformed into mirror. Only accidental losses of glass may occur (e.g. due to quality problems). In most instances, the rejected glass/mirror is recycled.

16.1.3.2.2 Water

The water consumption is in the range of 15 l/m^2 to 30 l/m^2.

16.1.3.2.3 Energy

No information provided.

16.1.3.3 Emissions

16.1.3.3.1 Emissions to air

The solvent content in the clean gas can be reduced to < 50 mg C/Nm^3 when applying abatement equipment. Lower values can be achieved in new installations. In existing installations, due to the wear of the mobile parts (e.g. valves), the emission levels increase. The nature of the solvents used can also have an impact on the reduction level that can be achieved. Table 16.1 shows air emission values measured at three different installations.

Table 16.1: Air emission values from three different mirror lines

Line	**TVOC (mg C/Nm^3)**	**CO (mg/Nm^3)**	**NO_X (mg/Nm^3)**
1	57 (range 20–100)	65	43
2	16	120	< 25
3	55	98	41
Source: [25, GEPVP et al. 2004]			

In a good practice plant, all areas where solvents are used are enclosed and the air containing the solvent is extracted. A total of 97.4 % of the solvent is treated and destroyed. The rest, i.e. 2.6 %, is released to the air because it is at a concentration too low to be treated.

16.1.3.3.2 Emissions to water

Because there is no contact between the water and the solvent anywhere in the process, solvent is not present in the waste water.

Water is used for the surface preparation and the application of the tin (or copper) and silver layer (see the STM BREF [23, COM 2006]). Thus, water treatment is needed to remove contaminants and to ensure the recycling of the silver. Conventional techniques are used; for example, when copper is used instead of tin, ion exchange and ammonia stripping can be used to remove the copper from the waste water. Table 16.2 shows water emission values after treatment.

Table 16.2: Water emission values after treatment

Compound	Value (mg/l)
NH_3	100
Ag	0.5
Cu	4
Ce	5
Source: [25, GEPVP et al. 2004]	

16.1.3.3.3 Waste generation

The waste containing solvents consists mainly of wipes from cleaning and spent solvent containing some coating. Its management and disposal is dictated by its composition and specific measures may be needed due to its solvent content. When it does not contain any contaminants that can alter the quality of the final product, the spent solvent is reused to adjust the paint viscosity. Reusable or recyclable paint containers are commonly used in mirror production.

16.1.4 Techniques to consider in the determination of BAT for the manufacture of mirrors

In Chapter17, techniques are discussed which might also be applicable to mirror manufacturing. In Table 16.3, the general techniques relevant for mirror manufacturing that are described in Chapter 16 are shown. These techniques are not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 17.1.

Table 16.3: Reference to techniques generally applicable to the sector

Technique	Section number
Environmental management techniques	17.1
Storage and handling of raw materials	17.2
Monitoring	17.3
Water use and waste water generation	17.4
Energy management and energy efficiency	17.5
Raw material management (including substitution)	17.6
Coating processes and equipment	17.7
Drying and/or curing techniques	17.8
Cleaning techniques	17.9
Off-gas extraction and treatment	17.10
Waste water treatment techniques	17.11
Waste management techniques	17.12
Odour emissions	17.13

16.1.4.1 Replacement of conventional solvent-based paints (substitution)

16.1.4.1.1 High-solids paints

For a general description, see Section 17.7.2.1. The mirror industry is already using this type of paint. The solvent content in the paint is between 30 wt-% and 40 wt-%.

16.1.4.2 Paint application techniques and equipment

16.1.4.2.1 Curtain coating

Description

For a general description, see Section 17.7.3.4. The glass is passed through a laminar curtain of paint continuously falling from a trough-type assembly. This allows the manufacture of large-dimension mirrors while ensuring the required quality of the layers. The excess coating material is permanently reused, but extra solvent is added to ensure proper application viscosity.

The paint used is solvent-based and contains 30-40 % solvent. Its consumption ranges from 150 g/m^2 to 200 g/m^2. In the past, paint contained high quantities of lead (up to 15 %). Today, new developments in mirror manufacturing allow the industry to use a low-lead-content paint (< 0.5 %). No chromate is used in this type of paint.

Technical considerations relevant to applicability

This technique is widely used in plants for the manufacturing of large mirrors.

Reference literature

[25, GEPVP et al. 2004]

16.1.4.3 Drying/curing

The following techniques are applied:

- infrared radiation curing (see Section 17.8.5.1);
- combined convection and IR radiation drying/curing (thermal reactor) (see Section 17.8.4);
- ultraviolet (UV) curing (see Section 17.8.5.4).

16.1.4.4 Off-gas treatment

Description

The areas where the paint is mixed and applied onto the mirror are enclosed and equipped with an air extraction system (see Section 17.10.2) routing the solvent emissions to the off-gas treatment equipment. Currently, any of the oxidation techniques described in Section 17.10.5 can be applied.

Technical considerations relevant to applicability

Given the amount of solvent per cubic metre in the flue-gas, many mirror manufacturers use regenerative thermal oxidisers (see Sections 17.10.5.4 and 17.10.5.5). As the solvent is mainly xylene, a low burning temperature (750-800 °C) may be applied. Only low levels of NO_X are formed. Regenerative thermal oxidisers are particularly suited to plants working continuously, i.e. 24 hours a day, 7 days a week. For plants working for example only 8 hours a day and 5 days a week, this technique might be not suitable, as the temperature of the installation must be maintained during the non-working hours. In this case, other oxidising techniques might be more suitable.

Reference literature

[25, GEPVP et al. 2004]

16.2 MANUFACTURE OF COATED ABRASIVES

[4, Germany 2002] [38, TWG 2004] [78, TWG 2005] [150, FEPA/VDS 2016]

16.2.1 General information on the abrasives industry

16.2.1.1 Areas of application

Grinding is one of the oldest production processes. A principal characteristic of grinding is the effect of numerous, non-orientated cutting materials in the workpiece. Contemporary abrasive materials are synthetic corundum or silicon carbide or cubic boron nitride (CBN) or diamond.

A large variety of workpiece materials can be processed such as ferrous and non-ferrous metals, glass, ceramics, natural stone, concrete, plastics and wood. The field of application of grinding is wide and includes activities such as rough grinding of cast iron or high-accuracy grinding of tubular needles for medical purposes. Numerous products in tool manufacturing, construction of vehicles, aircraft, power plants or furniture only obtain their finish and high-quality surface through grinding.

16.2.1.2 General information

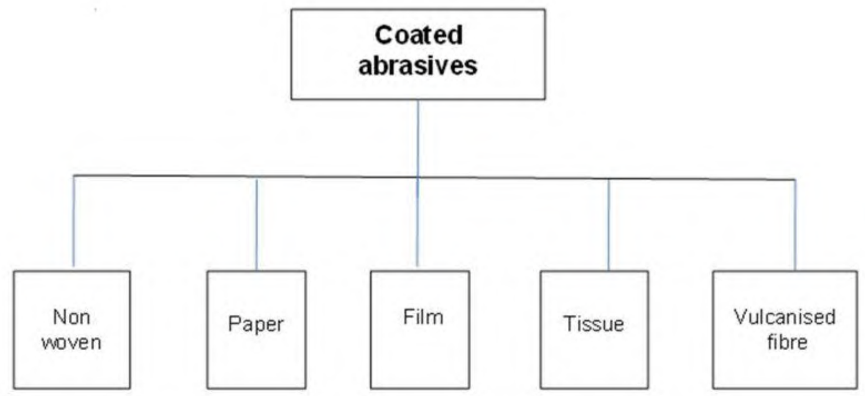
It is estimated that in Europe there are more than 200 companies producing all kinds of abrasives (not only coated abrasives). With a turnover estimated at EUR 3.5 billion and 20 000 jobs in the EU, the abrasives industry is of major importance for the European Union [150, FEPA/VDS 2016].

It has to be taken into consideration that no installation has been identified that exceeds the criteria (consumption capacity threshold) set in Annex I, point 6.7 of the IED. The following information is based on the information provided for the preparation of the STS BREF published in 2007 and updated with available data. No reference installations are available.

16.2.1.3 Characterisation of the product ‘abrasive’ and its quality demands

Basically, the production of abrasives can be distinguished between bonded abrasives, superabrasives, coated abrasives and loose abrasives, which do not have any solid linkage to a backing (e.g. polishing pastes). For this document, only the manufacture of coated abrasives is relevant.

Figure 16.2 shows a simplified overview of the different types of coated abrasives.



Source: [4, Germany 2002] updated by [150, FEPA/VDS 2016]

Figure 16.2: Overview of different types of coated abrasives

Organic solvents are partially used in the fabrication of bonded and loose abrasives. It can be assumed that European installations do not represent an activity in the sense of the IED Annex I, point 6.7. Consequently, production processes related to these activities are not mentioned in the following paragraphs.

The activity of manufacturing coated abrasives may be subject to the IED. However, in the EU no installation for the manufacturing of coated abrasives has been identified which exceeds the threshold limits set in the Directive, Annex I, point 6.7.

Coated abrasives are a basic material for many grinding machines with elements such as blades, stripes, page discs or assembled from those elements (e.g. peel shims, fan grinding wheels, belts). According to the purpose of use and basic material, a large number of bonding systems can be differentiated.

Non-woven abrasives occupy a special position between coated abrasives and bonded abrasives as they can be both used as an abrasive body as well as an abrasive element. They consist of polyamide fibres, e.g. to which the grinding material is fixed via bonding material. The production processes are comparable to the production of coated abrasives.

Coated abrasives are composed of:

- backing, e.g. paper, finished fabric, vulcanised fibre, film;
- bonding material, e.g. glue systems, phenolic resin, epoxy resin, polyurethane, urea resin;
- abrasive grain, e.g. flint, silicon carbide, corundum, zirconia alumina, seldom used: diamond and CBN (cubic boron nitride).

16.2.1.3.1 Backing

The term ‘coated abrasives’ refers to the importance of the backing. According to the purpose of end-use and the strain of a flexible abrasive, the backing has to show specific properties. For hand grinding or sanding, special flexibility and high buckling resistance are both required. For high-performance grinding with abrasive belts, abrasive discs and cylindrical sleeves, excellent mechanical properties such as swell resistance, tenacity, resistance against abrasion or alternating stress are required.

To meet all these requirements, the following groups of backing materials are particularly used:

- paper;
- film;
- fabric;
- combination of paper and fabric;
- vulcanised fibre.

Table 16.4 shows an example of a classification of the backing materials used.

Table 16.4: Selected backing materials for coated abrasives

Backing material	Weight class equipped (g/m^2)
A-paper	≤ 85
B-paper	86-110
C-paper	111-135
D-paper	136-220
E-paper	221-270
F-paper	271-350
G-paper	351-500
H-paper	> 500
A-paper water resistant	≤ 115
C-paper water resistant	> 115
Heavy cotton/X-weight	370-400
Film	100-200
Flexible cotton/J-tissue	270-290
High flexible cotton/J-flex-tissue	200-220
Heavy polyester/X-tissue	475-505
Very heavy polyester/Y-tissue	630-665
Source: [4, Germany 2002] updated by [150, FEPA/VDS 2016]	

Paper

The papers used in the production of coated abrasives consist of extremely firm and tenacious fibres. They are processed in different qualities, weights, sizes and widths according to their use. They can be distinguished between:

- flexible;
- single-layer paper with a homogeneous tensile strength in any direction of straining;
- heavy, multilayer cylinder paper which has an especially high stability in any direction of rolling (long direction).

All types of backings (A to F shown in Table 16.4) are adjusted to dry grinding. A- and C-papers with water-resistant preservation (latex or varnish) are appropriate for wet grinding.

Abrasives on A-, B-, and C-papers are used in offhand grinding and for hand-operated grinding machines (e.g. a grinding pencil). D- and E-papers are necessary as backings for stationery/fixed grinding machines up to the highest demand.

Film

For the production of coated abrasives, films are used which consist of highly tear-resistant plastic. Depending on the intended application, films of different quality, weight, strength and width are processed. Film-based abrasives are mainly used for dry grinding.

Textile backing

Textile backing is used for coated abrasives that are processed into wide bands or used in belt, surface and plunge grinding. They consist of fabric as a result of the high strain they are exposed to. These 'technical fabrics' are made of raw cotton (woven or stitch-bonded). They can be distinguished between heavy X-tissue and light J-tissue. This differentiation is made due to the thread layer, which means the number of fibres used as the warp and weft. Heavy X-tissue has a comparatively low thread count, compared to the light J-tissue.

Before being treated with abrasive grains, the tissue has to be subjected to a special treatment. The raw tissue is first downsized and dyed and afterwards shrunk to its final density. The fabric is finished on its thrust face with adhesives, synthetic resins/plastics or similar substances and finally flattened.

Vulcanised fibre
Numerous industrial manufacturing processes require special high-performance abrasives with a high wear resistance. In this case, vulcanised fibre is used as backing material. Vulcanised fibre is a very hard, multilayer fibre material. In the course of its fabrication, numerous non-woven-paper-like webs are connected through flattening with a contact adhesive. Vulcanised fibre can be manufactured in every thickness. In the abrasive industry, the vulcanised fibre thicknesses of 0.8 mm, 0.6 mm and 0.4 mm are the most important. The thicker material is used for high wear resistance and the thinner material for greater flexibility. Abrasives applied mechanically to vulcanised fibre backing have an extremely high resistance to stress. They are applied in almost all industrial branches, e.g. in automotive, machines, ship or apparatus engineering.

16.2.1.3.2 Bonding material

The efficiency of coated abrasives depends, to a large extent, on the bond (grain adhesion) of the abrasive grain. Consequently, bonding materials play an important role. In order to achieve a good adhesion of the grain and other required properties, the bonding materials are successively applied in several layers.

The following bonding materials are the most important:

- hide glue (also known as animal glue or protein glue);
- synthetic resin;
- varnish.

Depending on the bonding agents used, the following types of bonding systems are differentiated:

- Glue bond (solvent-free). The bond consists of hide glue and the backing of paper or fabric. These coated abrasives are used for lower shear forces or if the durability of the material is not important (e.g. for the treatment of lubricating materials).
- Partially synthetic resin bond (resin over glue, solvent-free). The abrasive bond system consists of a hide glue make coat and a size coat of synthetic resin. Abrasive papers or fabrics can be used universally, especially for medium grinding operations. Due to the elastic make coat of hide glue and the resistant size coat of synthetic resins, the qualities are very suitable for the surfacing of formed workpieces.
- Synthetic resin bond (solvent-free where possible). Abrasives for high stock removal capacity are bonded with synthetic resins. The abrasive grains are bound exceptionally well to fix to the backing by the comparatively strong resin bond. They are resistant to very high cutting forces. High performance rates can be obtained.
- Varnish, waterproof bond (solvent-based). Numerous workpieces and specific application methods require water-based cooling or rinsing agents. Therefore, the aforementioned methods cannot be used because either the bonding material or the finishing will be dissolved by the cooling agent. In these cases, totally waterproof tissue qualities are required. Special synthetic resins are used as bonding materials. Such waterproof

abrasives are applied for the wet grinding of steel, glass, ceramics, natural or artificial stone and plastics. For example, when grinding primers, fillers and clear or pigmented lacquers, often clogging or dusty grinding residues result. These load or glaze the abrasive. Therefore, it is necessary to work with waterproof abrasive papers in wet grinding. These papers have a flexible paper backing, which is impregnated with latex or lacquer to make them water-resistant. The make- and size coats are made with special resins and lacquers. Waterproof abrasive papers are not only water-resistant but also resistant against loading and glazing.

16.2.1.3.3 Abrasive grain

For the production of coated abrasives, different types of inert abrasive grains are used. The primary materials used are fused aluminium oxide, silicon carbide and alumina zirconia.

- Aluminium oxide:
    - corundum;
    - semi-special fused alumina;
    - special fused alumina rose;
    - special fused alumina red;
    - special fused alumina white;
    - ceramic corundum;
    - zircon corundum.
- Silicon carbide (SiC):
    - black SiC;
    - green SiC.

There is a wide range of products based on chemistry, particle size, grain shape and special treatments. For abrasives, particle size is especially carefully controlled in accordance with European Standards (FEPA), American Standards (ANSI) and Japanese Standards (JIS).

Table 16.5 shows the use of solvents attributed to the different products.

Table 16.5: Use of solvents in manufacturing of attributed to products

Base	Product	Formed part	Application	Bonding material systems	Solvent
A-paper	Dry grinding paper	Sheets, rolls	Lacquer and wood grinding (paint)	Hide glue, synthetic resin bond	No
B-paper	Dry grinding paper	Sheets, rolls	Lacquer and wood grinding (paint)	Hide glue, synthetic resin bond	No
C-paper	Dry grinding paper	Sheets, rolls, belts	Lacquer, wood and metal grinding (machine)	Partial or complete synthetic resin bond	No
D-paper	Dry grinding paper	Sheets, rolls, belts	Lacquer, wood and metal grinding (machine)	Partial or complete synthetic resin bond	No
E-paper	Dry grinding paper	Sheets, rolls, belts	Lacquer, wood and metal grinding (machine)	Partial or complete synthetic resin bond	No
F-paper	Dry grinding paper	Sheets, rolls, belts	Lacquer, wood and metal grinding (machine)	Partial or complete synthetic resin bond	No
A-paper waterproof	Wet grinding paper	Sheets	Common grinding of lacquer (hand)	Synthetic resin bond	Yes
C-paper waterproof	Wet grinding paper	Sheets, belts	Common grinding of lacquer (hand) Machine grinding	Synthetic resin bond	Yes
Film	Dry grinding film	Discs with velcro backing	Grinding of putty, base coats, filler and topcoats	Synthetic resin bond	Partially
X-tissue cotton	Dry grinding; wet grinding	Sheets, rolls, belts	Grinding of metal, glass, wood (machines)	Synthetic resin bond	Partially
J-tissue cotton	Dry grinding	Sheets, rolls, belts	Grinding of metal, glass, wood (machine)	Synthetic resin bond	Partially
J-flex-tissue	Dry grinding	Sheets, rolls, belts	Grinding of metal, glass, wood (machine)	Synthetic resin bond	Partially
X-tissue polyester	Dry grinding; wet grinding	Sheets, rolls, belts	Grinding of metal, glass, wood (machine)	Synthetic resin bond	Partially
Y-tissue polyester	Dry grinding; wet grinding	Sheets, rolls, belts	Grinding of metal, glass, wood (machine)	Synthetic resin bond	Partially

Source: [4, Germany 2002] updated by [150, FEPA/VDS 2016]

16.2.1.4 Quality requirements

The most important quality criterion is the retention of the standardised grain size. Toughness, hardness, low dust content, no components of quartz or fibrous parts, and the grain structure are also important. Quality requirements that arise from customers are:

- range of flexibility;
- non-allergenic properties for hand-operated wet grinding;
- the amount of grains applied to the abrasive for very fine grains.

Due to these requirements, the use of organic solvents is currently necessary in the case of abrasives for wet grinding.

16.2.2 Applied processes and techniques in coated abrasives manufacturing

16.2.2.1 Process overview

Coated abrasives are produced in the following way:

- coating of a backing with bonding materials;
- electrostatic or mechanical grain coating as specified in Section 16.2.2.2.3;
- pre-drying;
- repeated coating with bonding materials;
- drying;
- rolling up into large rolls (jumbo rolls);
- topcoating (optional).

Differences in the procedures include the type of drying ovens (festoon dryer or tensionless dryer), the application procedure and the off-gas treatment (biological treatment, thermal combustion or no treatment).

Solvent coatings are more frequently used in the production of jumbo rolls than self-adhesive products or endless abrasive belts.

Conventional solvent-based bonding systems are still state of the art for coated abrasives used in wet grinding processes e.g. in the automotive industry. To achieve the required waterproof qualities, a constant wetting of surfaces with bonding material and a uniform drying, and the use of solvents are essential (see also Table 16.5).

Wet grinding processes are indispensable in a broad area of high-technology applications to create surfaces with sufficient quality and smoothness. This demand in workpiece quality can only be achieved by high-quality abrasive papers, which in turn require the use of solvent-based bonding systems for different reasons which are given below.

Most important in fine grit applications (grit size 3 µm to 20 µm) and high-quality abrasive papers, low-viscosity bonding systems with a high solids content are required. The abrasive particles have to be fixed to the surface of the backing without fully covering the tips to guarantee a sufficient stock removal rate. The controlled uniform drying is another important factor in evaluating binding systems for waterproof abrasive products. Only if the film of the binding system combined with the abrasive particles is fully and evenly dried vertically and horizontally can a sufficient quality of the resulting abrasive product be achieved. Furthermore, in most cases the backings used in such applications exhibit a very unpolar surface because only film or highly pre-coated papers fulfil the demand for smoothness and surface quality. The wetting of such unpolar surfaces can only be achieved by solvent-based bonding systems, because other systems, mainly water-based ones, feature much greater contact angles. The use of these systems would result in wetting defects, leading to a weakened bonding of the abrasive particles to the surface, and therefore a diminished quality of the abrasive product.

Coated abrasives with constant quality are manufactured in production plants with high production levels. Such plants usually consist of the following units:

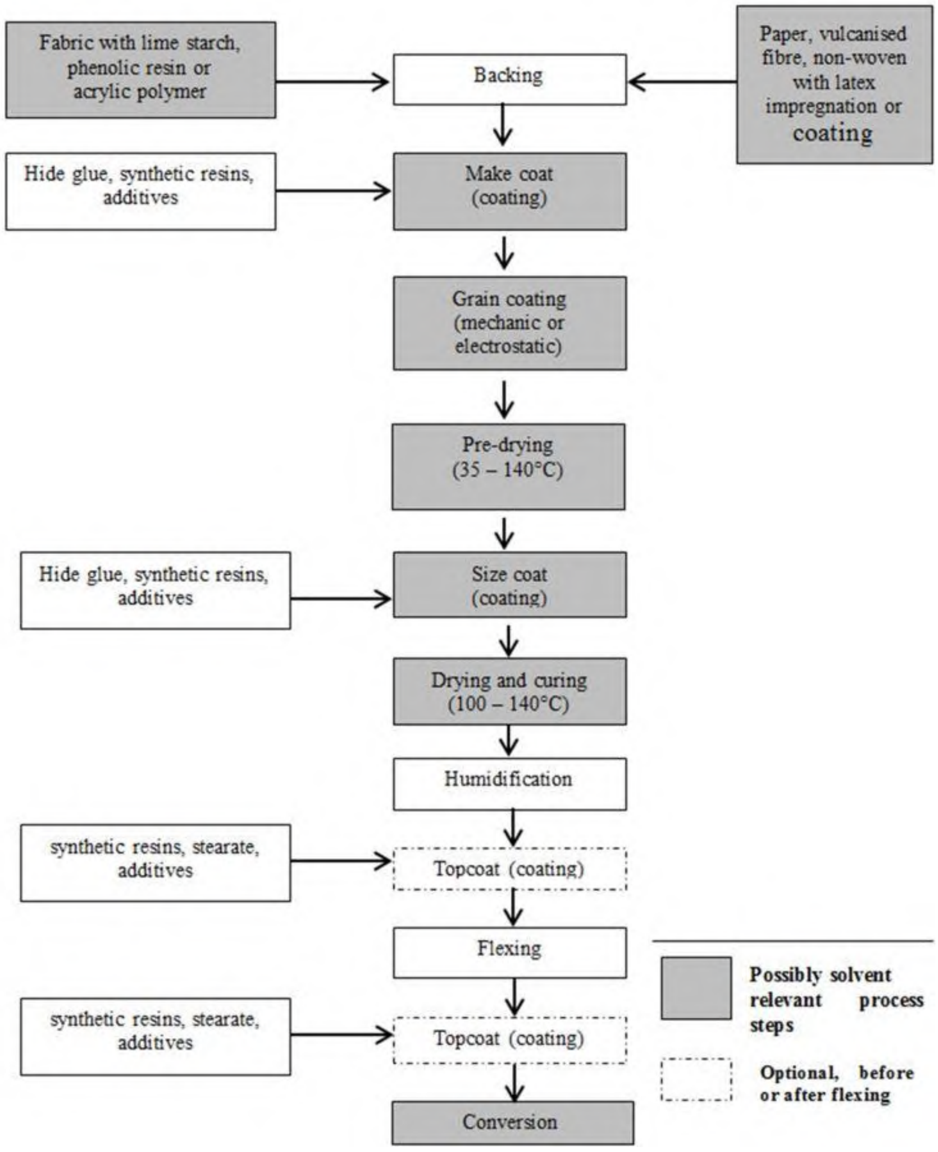
- base coat part (maker);
- pre-dryer;
- size coat part (sizer);
- dryer;
- spooler;
- topcoating (optional).

In the first step, the reverse side of the backing is printed in the 'maker' with the required information (e.g. brand and quality labels). Afterwards, the make coat is applied on the front side of the backing. Then it is coated with abrasive grains. In the second part of the plant – the pre-dryer – hot air dries or hardens the make coat. In the third production unit – the 'sizer' – the backing that is now coated with abrasive grains is furnished with a size coat. In the fourth unit, the hot-air-heated dryer can be found and the finished abrasive material runs through it for a specific time. After this procedure, the material leaves the plant dried and cured and is rolled up into large rolls (jumbo rolls). Optionally, an additional topcoat is applied as an additional layer before or after the flexing.

A multitude of electronic and thermal measuring units control the whole procedure and ascertain specific tolerance limits. Among other things, this refers to the grain coating of the backing.

16.2.2.2 Detailed process steps

Figure 16.3 shows an overview of a typical plant.



Source: [4, Germany 2002] updated by [150, FEPA/VDS 2016]

Figure 16.3: Schematic process flow for coated abrasives

16.2.2.2.1 Pretreatment of backings

The pretreatment is an optional process step in an abrasive production plant.

Paper

Depending on the further application of the paper, the pretreatment differs. For example, the backing for waterproof abrasive papers is impregnated with long chain alkyd resins. Latex dispersion sometimes used in combination with water-dilutable phenolic resins (for better heat resistance) may be a solvent-free alternative.

Fabrics

The following fabrics are used as backing:

- cotton;
- synthetic;
- mixed (cotton and synthetic).

The modification of the bonding material for the tissue depends on the requested (mechanical) flexibility of the product. Phenolic resins, caoutchouc (natural rubber) or dispersions of synthetics are the materials commonly used for this purpose.

Vulcanised fibre

Vulcanised fibre is not usually pretreated.

16.2.2.2.2 Coating of the backing with bonding materials

The backings are coated with the bonding material in a coating machine, e.g. by means of a spreader roll (application of the make coat).

Depending on the application profile of the abrasive, there are different bonding materials. In addition to natural products such as hide glue and starch or resins (e.g. epoxy, urea, alkyd and polyurethane resins), phenolic resins are mostly applied. The advantages of phenolic resins compared to other bonding materials are a better adherence, a lower sensitivity against humidity and a higher thermal resistance. Aqueous phenolic resins are often preferred to the slightly more flexible products with a solvent content because of their easier handling process.

The drying and hardening process is carried out in the festoon pre-dryer. The backing material runs in large loops over sticks through the various temperature zones of the dryer or hardener, which is heated with circulating hot air. Thus, a specific dwell time corresponding to the bonding material is guaranteed.

If necessary, the web is stretched at the end of the dryer. For the final imbedding and fixing (size coating), several binding layers may be applied.

The conclusive hardening of phenolic resins is carried out at temperatures up to a range of 100-140 °C, depending on the bonding and the abrasive grain. This procedure takes places in a drying channel (such as in pre-drying) or after spooling in the hardening oven.

16.2.2.2.3 Coating of the backing with grain

Electrostatic grain coating

The backing runs through an electrostatic field. The side with the make coat is positioned downwards. At the same time, the abrasive grain runs for a certain distance under the coated backing on a conveyor belt. When the abrasive grain enters the electrostatic field, it is charged and thus attracted by the backing above. It reaches the coated backing and trickles into the make coat. During this process, the grains are oriented with their sharp ends vertical to the backing. As a consequence, the abrasive obtains outstanding cutting characteristics.

Mechanical grain coating

Before electrostatic grain coating, coated abrasives were coated with ‘gravity grain coating’. This procedure is still in use in some special fields. The abrasive grain falls over a hopper and free falls onto the make-coat-coated backing. Most of the grain clings to the binding layer. The surplus grain falls into a collecting funnel when the direction of the backing web is changed. From there, the abrasive grain can be recycled and used again.

Other coatings

For special applications where fine grain sizes are needed, the abrasives are coated in a third procedure – the elutriating process. The grain, polish powder or filling material is directly added to the bonding material. In a sizer, the well mixed mass runs over reverse rolls and is applied to the backing material. The application of a make coat is not necessary here.

16.2.2.2.4 Flexing

After the spooler, the rolls of abrasive tissue, paper or fibre (jumbos) have to be further treated in order to guarantee the quality of the products depending on their further purpose. To this end, the rigid coating with grain and bonding materials is rendered flexible after hardening and conditioning. Depending on the kind of abrasive used, there are several particular methods for flexing. They can be differentiated between 90°-flexing and cross-flexing. For the 90°-flexing, the non-sprinkled side of the abrasive is drawn over a flexing roll.

The degree of flexing depends on the radius of the flexing roll. The flexing is realised according to the specific purpose and properties of each abrasive. When the layer of the bond material and the abrasive grain is broken due to very high flexing, this leads to reduced abrasive capacity of the product.

16.2.2.2.5 Topcoating of the product

[150, FEPA/VDS 2016]

Optionally, the rolls coming from the spooler or the flexing are coated with an additional topcoat layer. The topcoat mainly consists of synthetic resins, stearate and additives. With this topcoat, specific properties are achieved.

16.2.2.3 Installation components

The processes described are typically carried out in installations with the components listed in Table 16.6.

Table 16.6: Components of installation and differentiation

Unrolling	Unroll stands with a working width of 900-1 650 mm and a speed of 10-50 m/min are in use.
Printing	Usually two to three printing rolls are used.
Roll coating (alternative: spraying)	Realised through a two-printing roller with a ladle tank or alternatively with jet spraying.
Grain coating field (electrostatic or mechanic)	Use of a grain coating field with a plate capacitor (around 30 kV or more voltage) or grain coating hopper (hopper gate on the backing).
Dryer (loop dryer or tensionless dryer)	Temperature of 35-140 °C (in the loop dryer, the coated web runs through in loops; in the tensionless dryer, the web is transported flat without contact through the dryer).
Humidification	Usually at the end of the dryer in a vapour zone.
Spooling	Realised through a running lap winder.
End drying	Use of a small dryer, usually with the capacity for single jumbo rolls.
Exhaust air treatment	Application of dust separators and thermal or regenerative treatment at 700 °C (or higher) with or without energy recovery (depending on site-specific circumstances and energy or heat demand).
Water treatment	Biological water treatment plant or bioreactor.
Flexing	Flex machines consisting of unrolling, flexing rods (the web runs with the back side in a narrow angle over the flexing rod in order to make the product flexible), rolling up.
Conversion	Gluing of abrasive belts to overlapping endless belts is prepared in machines for cutting the belts into sections before gluing under pressure and heat in pressure units. PU glues containing solvent may be used. Cutting and punching devices produce sheets, discs and rolls.

Source: [4, Germany 2002] updated by [150, FEPA/VDS 2016]

System differentiations related to explosion protection

It is usually necessary to install explosion protection equipment around the application units and the open run of webs. The application units and the open run of webs are equipped with properly working suction units. Monitoring takes place by suitable measures appropriate to the site-specific conditions.

Where required, all electrical equipment is protected against explosions according to these guidelines. All loop driving devices are situated outside the loop zone. The loop zone is exclusively indirectly heated.

The maximum speed of the production line is controlled to guarantee a maximum level of 50 % of the LEL of the substance with the lowest flashpoint.

In order to achieve a sub-atmospheric (negative) pressure and to guarantee the 50 % LEL, the dryer is constantly driven with a certain exhaust air amount.

The off-gas streams are collected and led to the off-gas treatment installation. The air streams are monitored. The grain coating room is equipped with an extraction unit and monitored as well.

The coating machines along with the electrostatic grain coating installations are protected by fire-extinguishing systems.

The pre-dryer and the main dryer are completely protected by inner fire-extinguishing systems (dry ascending pipes).

16.2.3 Current consumption and emission levels in coated abrasives manufacturing

As no plants above the IED capacity threshold were identified, the STS TWG concluded not to collect data via questionnaires. The following sections are the same as in the original STS BREF (2007).

16.2.3.1 Mass balances

In Table 16.7, Table 16.8 and Table 16.9, the mass balances of three existing plants are shown.

Table 16.7 shows the mass balance of an abrasive production plant with a typical product mix of different binding types:

- hide glue (solvent-free);
- partial synthetic resin (solvent-free);
- synthetic resin (almost solvent-free).

The balance has been established using real values with specific values related to 10 kilotonnes of final product per year. The capacity of this plant corresponds approximately to this amount. The output values are half-hour mean values.

Table 16.7: Mass balance of abrasive manufacturing in Plant 1

Input		Output	
Raw materials (1)			
Paper/fabric	4 701 t/yr	Product	10 000 t/yr
Abrasive grain	3 214 t/yr	Waste for combustion	77 t/yr
Bonding material including phenols and other synthetic resins	2 436 t/yr	Waste for disposal	37 t/yr
		Hazardous waste	116 t/yr
Solvents (2)			
Water	827 t/yr	Water	827 t/yr
Organic solvents (3)	275 t/yr	Fugitive emissions of VOCs	38 t/yr
		TOC after thermal treatment	< 20 mg/m^3
		NO_X after thermal treatment	< 100 mg/m^3
		CO after thermal treatment	< 100 mg/m^3
		Relative oxygen of a thermal or regenerative treatment	18-21 %
Energy (kWh/yr)			
Electric current	3 007 243		
Gas	21 871 076		
Hot water	16 379 075		

NB:
(1) The input of raw material adds up to 10 351 t and the output only to 10 230 t (mass balance is not closed).
(2) Similarly with the organic solvent (input 1 102 t, output 865 t).
(3) Differences in the mass balances are due to the combustion of solvents and other additives in the off-gas treatment systems [4, Germany 2002] [78, TWG 2005].
Source: [38, TWG 2004]

Table 16.8 shows the mass balance of Plant 2, where only fabric is assembled by means of preservation. The manufactured fabric is used as backing for coated abrasives. Light and heavy cotton and also heavy polyester fabrics are impregnated. The values shown are exclusively values of the fabric impregnation. The mass balance has been established using real values with specific values related to 10 kilotonnes of final product per year. The capacity of this plant is about 5 kilotonnes of final product per year. The corresponding abrasive production is carried out in Plant 3, which is described in Table 16.9.

Table 16.8: Mass balance of the impregnation plant for the manufacturing of abrasives in Plant 2

Input		**Output**	
Raw materials (1)			
Raw fabric	8 101 t/yr	Impregnated fabric	10 000 t/yr
Corresponding to m^2/yr	24 261 025	Corresponding to m^2/yr	24 261 025
Phenolic resins	1 002 t/yr	Hazardous waste	185 t/yr
Lattices	2 104 t/yr	Waste for disposal	133 t/yr
Hide glue/starch	585 t/yr	Waste for further treatment	484 t/yr
Additives	670 t/yr	Paper waste	117 t/yr
Solvents (2)			
Organic solvents (3)	125 t/yr	Fugitive emissions of VOCs	12 t/yr
		TOC after thermal treatment	< 20 mg/m^3
		NO_X after thermal treatment	< 100 mg/m^3
		CO after thermal treatment	< 100 mg/m^3
		Dust	< 10 mg/m^3
		Relative oxygen of a thermal or regenerative treatment	18-21 %
Accessory agents			
Water (m^3/yr)	101 630	Waste water	
		Manufacturing	46 750 m^3/yr
		Cooling	8 794 m^3/yr
		Vapour	21 752 m^3/yr
		Sanitary	7 692 m^3/yr
		Cleaning	16 639 m^3/yr
Energy (kWh/yr)			
Energy	46 258 325		

NB:
(1) The input of raw material adds up to 12 462 t and the output only to 10 919 t (mass balance is not closed).
(2) The same with the organic solvent (input 125 t, output 12 t).
(3) Differences in the mass balances are due to the combustion of solvents and other additives in the off-gas treatment systems [4, Germany 2002] [78, TWG 2005].
Source: [38, TWG 2004]

Table 16.9 shows the mass balance of Plant 3, which is a production site for coated abrasives. It comprises several machines, however without pretreatment of the backings. The production includes hand grinding and dry grinding papers, waterproof paper and tissue abrasives, light and medium as well as heavy fabric qualities and abrasive non-woven products. The balance has been established using real values with specific values related to 5 000 000 m^2 of final product per year. The capacity of this plant is slightly above this amount. Output values are half-hour mean values.

Table 16.9: Mass balance of abrasive manufacturing in Plant 3

Input (1)		Output (1)	
Raw material			
Impregnated backing	5 000 000 m^2/yr	Product	5 000 000 m^2/yr
Abrasive grain	992 t/yr		
Solvents			
Organic solvents (2)	259 t/yr	Fugitive emissions of VOCs	30.1 t/yr
		TOC after thermal treatment	< 20 mg/m^3
		NO_X after thermal treatment	< 100 mg/m^3
		CO after thermal treatment	< 100 mg/m^3
		Dust	< 10 mg/m^3
		Relative oxygen of a thermal or regenerative treatment	18-21 %
Phenolic and other resins	520 t/yr		
Lattices	22.2 t/yr		
Accessory agents			
Water	32 063 m^3/yr		
Energy			
Gas and current	34 831 581 kWh/yr		

NB:
(1) The mass balance is not closed.
(2) Differences in the mass balances are due to the combustion of solvents and other additives in the off-gas treatment systems [4, Germany 2002] [78, TWG 2005].
Source: [38, TWG 2004]

16.2.3.2 Consumption

See Section 16.2.3.1 for the consumption of raw materials, solvents, water and energy.

16.2.3.3 Emissions

16.2.3.3.1 Emissions to air

Examples of emissions from three plants in Germany are given in Section 16.2.3.1.

After off-gas treatment, the emission levels achieved are lower than 20 mg C/m^3 for TVOC and lower than 100 mg $/m^3$ for both CO and NO_X. The maximum limits for phenol (20 mg/m^3) are also complied with.

16.2.3.3.2 Emissions to water

Waste water arises from the cleaning of machine parts, mainly containing phenol and fluoride. The following waste water treatments are normally carried out before discharge to a municipal waste water treatment plant:

- neutralisation;
- fluoride precipitation;
- filtration;
- biological treatment.

The techniques mentioned above are described in detail in the STM BREF [23, COM 2006] and in the CWW BREF [31, COM 2016].

The following emission levels or lower are achieved:

total phenol	75 mg/l;
VOCs in steam phenol:	20 mg/l;
fluoride:	40 mg/l;
sulphate:	200 mg/l;
iron:	1 mg/l;
aluminium:	1 mg/l;
zinc:	1 mg/l.

16.2.3.3.3 Waste

According to the product spectrum, waste arises during conversion in the form of cuttings (e.g. edges, punchings). In some cases, a proportion of these cuttings may be separated, recut and sold.

16.2.4 Techniques to consider in the determination of BAT for the manufacturing of coated abrasives

In Chapter 17, techniques are discussed which might also be applicable to the manufacturing of coated abrasives. In Table 16.10, the general techniques relevant for the manufacturing of coated abrasives are shown. These techniques are not repeated in this section, unless information specific for this industry was made available. A description of the type of information considered for each technique is given in Table 17.1.

Table 16.10: Reference to techniques generally applicable to the sector

Technique	Section number
Environmental management techniques	17.1
Storage and handling of raw materials	17.2
Monitoring	17.3
Water use and waste water generation	17.4
Energy management and energy efficiency	17.5
Raw material management (including substitution)	17.6
Coating processes and equipment	17.7
Drying and/or curing techniques	17.8
Cleaning techniques	17.9
Off-gas extraction and treatment	17.10
Waste water treatment techniques	17.11
Waste management techniques	17.12
Odour emissions	17.13

The EGTEI background document for the industrial application of adhesives (see Annex 21.3) gives some data on the costs and benefits at the European level of some techniques to reduce VOC emissions. However, the EGTEI approach necessarily has to limit its complexity, and only key techniques are given without consideration of the other BAT factors, such as cross-media effects, or of the technical characteristics of individual installations and products [83, EGTEI 2005].

16.2.4.1 Substitution of conventional solvent-based bonding materials

16.2.4.1.1 Solvent-free bonding materials

Description
Solvent-free bonding materials are hide glue and starch, and partial synthetic resins. In the case of fabrics, they can be used for specific product qualities. However, resins are usually applied, because they have a better adherence, a lower sensitivity against humidity and a higher thermal resistance. Water-based phenolic resins are often preferred to the slightly more flexible products with solvent content, because of their easier handling process.

The waterproof qualities required for abrasive paper can only be achieved by using solvent-based bonding materials.

Achieved environmental benefits
Solvent emissions are omitted.

Technical considerations relevant to applicability
Solvent-based bonding materials are necessary for the production of wet grinding abrasives. They are commonly applied for the production of dry grinding papers.

Reference literature
[4, Germany 2002] [38, TWG 2004]

16.2.4.2 Drying

16.2.4.2.1 Convection drying

For a general description, see Section 17.8.6. Loop or tensionless dryers are commonly applied at a temperature of 35-110 °C. In the loop dryer, the coated web runs through in loops. In the tensionless dryer, the web is transported flat and without contact through the dryer.
[4, Germany 2002]

16.2.4.3 Off-gas extraction and treatment

16.2.4.3.1 Increase of the internal solvent concentration

For a general description, see Section 17.10.3.2.

This is commonly applied to increase the solvent reduction efficiency of the off-gas treatment system. The maximum speed of the production line is controlled to guarantee a maximum level of 50 % of the LEL of the substance with the lowest flashpoint. To this end, the speed is electronically blocked. In order to achieve sub-atmospheric (negative) pressure and to guarantee the 50 % LEL, the dryer is constantly driven with a certain amount of exhaust air [4, Germany 2002].

16.2.4.3.2 Containment and collection of off-gases

For a general description, see Section 17.10.2.

Off-gases from the places where the web runs open, the units applying bonding material and the dryer are collected and routed to the off-gas treatment system. Fugitive solvent emissions are reduced to a range of 9.6-13.8 % of the solvent input.
[4, Germany 2002] [78, TWG 2005]

16.2.4.3.3 Dry filter systems

For a general description, see Section 17.10.4.4.

Several types of bag filters are applied. The emission values obtained depend on the dust characteristics, filter construction and the filter itself. A static dust concentration of < 10 mg/m^3 was reported as achievable (2002 data). For more information on dust emissions abatement techniques and achievable emission levels, see Section 17.10.4.
[4, Germany 2002]

16.2.4.3.4 Thermal oxidation

For a general description, see Section 17.10.5.2.

At exhaust air volumes of up to 66 000 Nm^3/h, installations achieve emission values of < 20 mg VOCs/m^3 (half-hour mean value) [4, Germany 2002].

16.2.4.3.5 Regenerative thermal oxidation

For a general description, see Sections 17.10.5.4 and 17.10.5.5.

This is commonly applied to treat off-gases from the dryers, the places where the web runs open and the units applying bonding material.

During production, the regenerative oxidiser can normally work autothermally (above 2-3 g/m^3 organic solvent in the waste gas). At exhaust air volumes of up to 66 000 Nm^3/h, the installations achieve emission values of < 20 mg C/m^3, < 100 mg CO/m^3 and 100 mg NO_X/m^3 (half-hour mean values). Phenol levels of < 20 mg/m^3 are achieved [4, Germany 2002].

16.2.4.3.6 Biological treatment

This technique is not applicable due to the specific conditions in the abrasive industry. Pilot installations have been tested. However, due to the high and changing concentrations of total C in the raw gas, this technology is not applicable in the abrasive industry from a technical or economic point of view.

Thermal oxidation and regenerative thermal oxidation are currently seen as BAT in the manufacture of coated abrasives.

17 TECHNIQUES TO CONSIDER IN THE DETERMINATION OF BAT APPLICABLE IN MORE THAN ONE STS SECTORS

This chapter 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 and that are applied to more than one sector (industry). The intention is to help the reader to easily find the general information for those techniques. Effort has been made to limit repetition of the information for those techniques which are also described in Sections X.4 (Techniques to be considered for each specific industry where X is the specific industry chapter). Techniques which are relevant for only one sector are mainly presented in the relevant X.4 sections only. 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 techniques. 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 the prevention or limiting of the environmental consequences of accidents and incidents, as well as site remediation. They also cover the prevention or reduction of 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 17.1 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 Directive.

This chapter and the Sections X.4 do not necessarily provide an exhaustive list of techniques that 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 17.1: Information breakdown for each technique described in Chapter 17 and in all the Sections 4 in each of the Chapters 2 to 16

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

17.1 Environmental management techniques

17.1.1 Environmental management system (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 17.1).

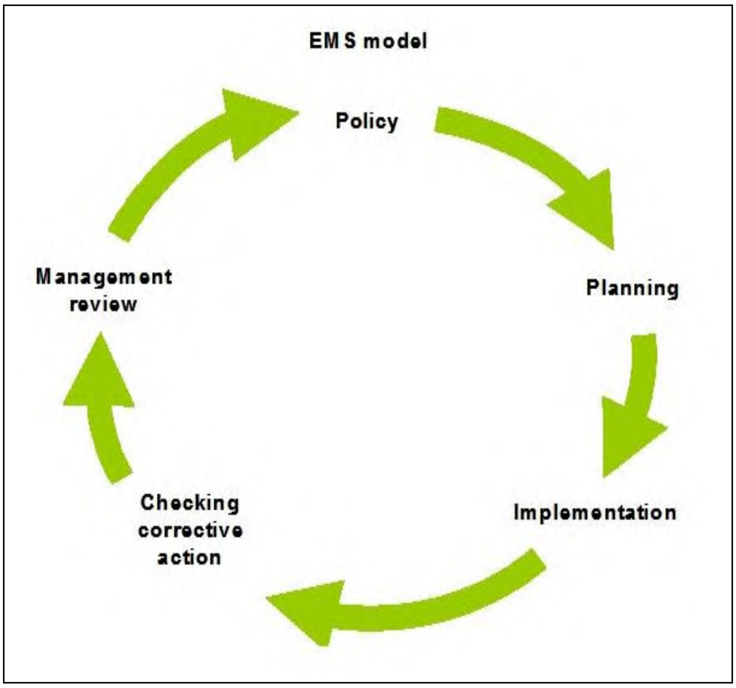


Figure 17.1: Continuous improvement in an EMS model

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, can give higher credibility to the EMS especially when subjected to a properly performed external verification. The European Union eco-management and audit scheme (EMAS) according to Regulation (EC) No 1221/2009 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 14001:2015 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 features:

i. commitment, leadership, and accountability of the management, including senior management, for the implementation of an effective EMS;
ii. an analysis that includes the determination of the organisation's context, the identification of the needs and expectations of interested parties, the identification of characteristics of the installation that are associated with possible risks for the environment (or human health) as well as of the applicable legal requirements relating to the environment;
iii. development of an environmental policy that includes the continuous improvement of the environmental performance of the installation;
iv. establishing objectives and performance indicators in relation to significant environmental aspects, including safeguarding compliance with applicable legal requirements;
v. planning, and implementing the necessary procedures and actions (including corrective and preventive actions where needed), to achieve the environmental objectives and avoid environmental risks;
vi. determination of structures, roles and responsibilities in relation to environmental aspects and objectives and provision of the financial and human resources needed;
vii. ensuring the necessary competence and awareness of staff whose work may affect the environmental performance of the installation (e.g. by providing information and training);
viii. internal and external communication;
ix. fostering employee involvement in good environmental management practices;
x. establishing and maintaining a management manual and written procedures to control activities with significant environmental impact as well as relevant records;
xi. effective operational planning and process control;
xii. implementation of appropriate maintenance programmes;
xiii. emergency preparedness and response protocols, including the prevention and/or mitigation of the adverse (environmental) impacts of emergency situations;
xiv. when (re)designing a (new) installation or a part thereof, consideration of its environmental impacts throughout its life, which includes construction, maintenance, operation and decommissioning;
xv. implementation of a monitoring and measurement programme; if necessary, information can be found in the Reference Report on Monitoring of Emissions to Air and Water from IED Installations;
xvi. application of sectoral benchmarking on a regular basis;
xvii. periodic independent (as far as practicable) internal auditing and periodic independent external auditing in order to assess the environmental performance and to determine whether or not the EMS conforms to planned arrangements and has been properly implemented and maintained;
xviii. evaluation of causes of nonconformities, implementation of corrective actions in response to nonconformities, review of the effectiveness of corrective actions, and determination of whether similar nonconformities exist or could potentially occur;

xix. periodic review, by senior management, of the EMS and its continuing suitability, adequacy and effectiveness;
xx. following and taking into account the development of cleaner techniques.

Specifically for surface treatment using organic solvents, BAT is also to incorporate the following features in the EMS:

i. Interaction with quality control and assurance as well as health and safety considerations.
ii. Planning to reduce the environmental footprint of an installation. In particular, this involves the following:
    - Assessing the overall environmental performance of the plant (see Section 17.1.2).
    - Taking into account cross-media considerations especially the maintenance of a proper balance between solvent emissions reduction and consumption of energy (see Section 17.5), water (see Section 17.4) and raw materials. It is essential that the operator understands what happens to the inputs (understanding the process), e.g. solvents, and how their consumption leads to emissions and therefore impacts. It is equally important, when controlling significant inputs and outputs, to maintain the correct balance between solvent emissions reduction and cross-media effects, such as energy, water and raw materials consumption. Only by considering and balancing the cross-media effects can the environmental footprint of the installation be reduced to best effect. Whilst the solvent balance (see Section 17.3.1) is important in these industries, all significant consumption and emissions should be managed in a coordinated manner for the short, medium and long term, in conjunction with financial planning and investment cycles, i.e. adopting short-term end-of-pipe solutions to solvents emissions may tie the operator to long-term higher energy consumption and resulting CO_2 releases, and postpone investment in more balanced, environmentally beneficial solutions. This will require consideration of the cross-media issues, and assistance with these and the costing and cost-benefits issues is given in the ECM REF [50, COM 2006].
    - Reducing VOC emissions from cleaning processes (see Section 17.9).
iii. The inclusion of:
    - a plan for the prevention and control of leaks and spillages (see Section 17.2.1);
    - a raw material evaluation system to use raw materials with low environmental impact and a plan to optimise the use of solvent in the process (see Section 17.6);
    - a solvent mass balance (see Section 17.3.1);
    - a maintenance programme to reduce the frequency and environmental consequences of OTNOC (see Section 17.2.6);
    - an energy efficiency plan (see Section 17.5.1);
    - a water management plan (see Section 17.4.1);
    - a waste management plan (see Section 17.12.1);
    - an odour management plan (see Section 17.13.1).

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.

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 level of detail and the degree of formalisation of the EMS will generally 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 accurately determine 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 [250, IAF 2010].

Driving force for implementation

Environmental management systems can provide a number of advantages, for example:

- 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.

Reference literature

[250, IAF 2010] [251, EU 2009] [252, COM 2010] [253, COM 2015] [254, CEN 2015]

17.1.2 Overall environmental performance

Description

Identification of the process areas/sections/steps that represent the greatest contribution to VOC emissions and energy consumption, and identification and implementation of actions to minimise VOC emissions and energy consumption and regularly update the situation.

Technical description

In order to improve the overall environmental performance, the following actions are considered important:

- identify the process areas/sections/steps that represent the greatest contribution to the VOC emissions and energy consumption and the greatest potential for improvement;
- identify and implement actions to minimise VOC emissions and energy consumption;
- regularly (at least once every year) update the situation and follow up the implementation of the identified actions.

Achieved environmental benefits

- Reduction of consumption of materials, energy and water.
- Reduction of emissions, principally of VOCs.

Environmental performance and operational data
Incremental improvements that maintain and improve the environmental performance of the installation.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
The staff time required.

Driving force for implementation
Potential cost savings in materials and production efficiency.

Example plants
Widely used; example plant: #146 in [155, TWG 2016].

Reference literature
[181, COM 2017]

17.1.3 Benchmarking of consumption and emissions and subsequent action

Description
Benchmarking is the systematic recording of inputs (raw materials, water and energy) and outputs (emissions to air and water, and as waste), and the regular comparisons of these with previous data for the installation, with its sector, national or regional benchmarks (see Section 17.1.1 (xvi)). When data are benchmarked in an installation, it is good practice to maintain a system to identify any actions required from the data gathered and bring these actions to a conclusion (see Section 17.1.1 (xv, v, xvii)), including:

- identifying a person or persons responsible for evaluating and taking action on the data;
- informing those responsible for plant performance, including alerting operators rapidly and effectively to variations from normal performance;
- other investigations to ascertain why performance has varied or is out of line with external benchmarks.

Achieved environmental benefits
Benchmarking assists individual installations to assess their environmental performance with other installations and assists in identifying techniques used by the best-performing installations. It can identify or assist in identifying unplanned or unobserved events, such as pipe or pump seal leakage, losses to soil and groundwater, etc.

Environmental performance and operational data
This technique provides benchmarks and assessments of operational environmental performance of installations and techniques. Data can be gathered and compared on different levels such as technique or activity (press, process tank, or process line), site, sector, regional or national where anti-trust regulations and practices allow. It can be made public while keeping individual site identities confidential. For example, the following can be benchmarked:

- Solvents consumed and emitted. Fugitive emissions, and therefore total emissions, can only be determined using a solvent balance (see Section 17.3.1). Appropriate issues for benchmarking can be identified when carrying out a solvent mass balance (see Annex 21.5).

- Water consumption.
- Energy consumption, e.g. for drying and abatement equipment.
- Raw materials consumption, e.g. inks, wipes, paper, in press set-up up to 10 % of the substrate can be wasted.
- Wastes generated.
- Significant pollutants emitted to water, air or soil/groundwater.

Technical considerations relevant to applicability
Appropriate benchmarking requires comparable data – a ‘like for like’ comparison, e.g. for surface treatment activities this would be best achieved on a surface area treated basis or other consumption or throughout basis that is meaningfully process-related. The detail of the benchmarking, including the issues to be benchmarked, will depend on the consumption.

Economics
Use of the data to optimise the plant environmental performance will usually achieve economic optimisation.

Driving force for implementation
Benchmarking is also commensurate with good economic performance. Benchmarking and optimising environmental performance (such as raw material, water and power inputs, as well as material losses) will achieve economic optimisation at the same time.

Reference literature
[23, COM 2006] [38, TWG 2004] [43, Envirowise 1998] [78, TWG 2005]

17.2 Storage and handling of raw materials

This section covers the areas, processes and activities of the STS installation that are not covered elsewhere, as they refer to issues that are common for most of the STS sectors. In particular, it covers the prevention of emissions to soil, groundwater and surface water, although the techniques are also relevant to the prevention of fugitive emissions to air resulting from the delivery/receipt of organic solvents and other chemicals to/at the STS plant up to their final preparation step prior to application. However, when considering the integrated operation and the complexity of an IED installation, overlaps and repetition with other sections are inevitable: these have been cross-referenced where found.

The design, construction and operation, also referred to 'good housekeeping' or 'good practice', plays an important role for the reduction of fugitive emissions and the occupational health. For many installations, simple, affordable good housekeeping measures are being effectively applied to minimise solvent consumption, improve efficiency, achieve a cleaner workplace and reduce costs. An overview with practical examples is clearly described in the relevant guideline [42, Envirowise 2003].

Measures to prevent spillages and leakages are described extensively elsewhere, such as generally in the EFS BREF [44, COM 2006] and in national guidance documents [42, Envirowise 2003] [69, RIZA 1999] [70, INRS 1998]. The following sections are therefore a brief summary of key issues for this sector, together with more specific information relevant to the scale and type of operations.

17.2.1 Preparation and implementation of a plan for the prevention and control of leaks and spillages

Description

Preparation and implementation of a plan for the prevention and control of potential leaks and spillage incidents/accidents.

Technical description

This includes but is not limited to:

- site incident plans for small and large spillages;
- identification of the roles and responsibilities of persons involved;
- ensuring staff are environmentally aware and trained to prevent/deal with spillage incidents (see Section 17.2.5.1);
- identification of areas at risk of spillage and/or leaks of hazardous materials and ranking them according to the risk; this includes any possible access to sewers, such as drains and inspection hatches;
- in identified areas, ensuring suitable containment systems are in place, e.g. impervious floors and containment barriers are in place and in good order;
- identification of suitable spillage containment and clean-up equipment and regularly ensuring it is available, in good working order and close to points where these incidents may occur;
- waste management guidelines for dealing with waste arising from spillage control;
- regular (at least once every year) inspections of storage and operational areas, testing and calibration of leak detection equipment and prompt repair of leaks from valves, glands, flanges, etc.; see also Section 17.2.6 for inspections and maintenance.

Achieved environmental benefits

This technique prevents or minimises the contamination of surface waters, groundwaters and soils, and assists in site decontamination on cessation of activities. It also reduces fugitive emissions from solvent spillages.

Environmental performance and operational data

Small spills are likely to happen more often and the sum effect of these if not detected and dealt with is significant increases of fugitive emissions to air, soil and groundwater.

Impacts of spills in risk areas can be minimised in advance, e.g. by:
- sealing drains and inspection hatches to sewers;
- ensuring areas where solvents are stored are bunded and sealed with impermeable barriers and floors;
- providing 'catch pits' where solvents are regularly used, e.g. cleaning areas.

Source: [180, COM 2017] Plant #133 in [155, TWG 2016]

Figure 17.2: Spill kit in place in transit area between store and production zones

Cross-media effects

No adverse implications.

Technical considerations relevant to applicability

Generally applicable. The scope (e.g. level of detail) of the plan will generally be related to the nature, scale and complexity of the installation, as well as to the type and quantity of materials used.

Economics

- Staff time for training and updating plans.

- Materials for spillage clean-up.

Driving force for implementation

- Reduced risks of liability from contamination.
- Reduced risks of associated accidents, e.g. preventing slippery floors, risk of fire.

Example plants
Widely used; example plant: #133 in [155, TWG 2016].

Reference literature
[180, COM 2017]

17.2.2 Storage techniques

17.2.2.1 Sealing or covering of containers and bunded storage area

Description
Storage of solvents, hazardous materials, waste solvents and waste cleaning materials in sealed or covered containers suitable for the associated risk and designed to minimise emissions. The containers' storage area is bunded and of adequate capacity.

Technical description
Care should be taken during storage and handling. For example, containers should be appropriately sized and enclosed (e.g. using lids), to reduce vapour losses, while allowing sufficient room for expansion of stored solvent. Delivery pipes should be earthed. Sources of heat and draught should also be avoided to reduce the potential for evaporation. Containers should be fire-retardant and have self-closing lids. Appropriate handling and use, and minimisation of waste should be promoted, e.g. automatic/strictly controlled dosing, the use of pre-impregnated wipes, etc. Where possible and practicable, solvent should be piped directly to the point of use, with appropriate recovery of any excess.

The storage area for containers is bunded and of adequate capacity in order to ensure that any accidental release will be kept inside the bund and can be collected easily.

Achieved environmental benefits

- Reduced VOC emissions to air.
- Prevention of soil and groundwater contamination.

Environmental performance and operational data
Many solvents expand and contract significantly with changing ambient temperatures. Sufficient space should be allowed for this in the storage vessel, according to the solvents used, e.g. containers should allow about 10 % redundant volume.

Technical considerations relevant to applicability
Generally applicable. Health and safety issues may determine whether and how the solvent container is covered.

Driving force for implementation
Workplace health and safety.

Example plants
Widely used throughout industry.

Reference literature
[23, COM 2006] [38, TWG 2004] [78, TWG 2005] [212, TWG 2018]

17.2.2.2 Minimisation of storage of hazardous materials in production areas

Description
Hazardous materials are present in production areas only in amounts that are necessary for production; larger quantities are stored separately.

Technical description
Materials containing solvents or other hazardous materials should be limited to the current production needs and next changeovers. Full or partly empty containers from previous production runs are removed to storage areas. Only cleaning materials for the current production and the next changeovers are in the production areas. Larger quantities of solvent-containing materials or other hazardous materials are stored separately and possibly combined with centralised transfer systems (see Section 17.2.4.2)

Achieved environmental benefits

- Reduced risk of accidental spillages by movements of staff, lifting equipment, etc.
- Assistance in accounting for solvent-containing materials for solvent mass balances (see Section 17.3.1).

Technical considerations relevant to applicability
Generally applicable.

Economics
Staff time in moving containers.

Driving force for implementation
Assists meeting health and safety objectives.

Example plants
Widely used.

Reference literature
[212, TWG 2018]

17.2.3 Techniques for pumping and handling liquids

17.2.3.1 Prevention of leaks and spillages during pumping

Description
Leaks and spillages are prevented by using pumps and seals suitable for solvents and which ensure proper tightness. This includes equipment such as canned motor pumps, magnetically coupled pumps, pumps with multiple mechanical seals and a quench or buffer system, pumps with multiple mechanical seals and seals dry to atmosphere, diaphragm pumps or bellow pumps.

Technical description
It is essential to ensure that pumps, pipework (especially temporary/flexible piping) and the associated equipment (e.g. receiving containers) are suitable for solvents which ensure proper tightness and are properly secured and maintained.

Only pumps suitable for solvents, i.e. flameproof and with solvent-resistant seals, should be used. Relevant additional information can be found in [213, Germany 2002].

Where possible, manual handling is avoided by pumping solvents and solvent-based materials through a piped system (e.g. ring main) to the point of use. The advantages include:

- reduced risk of spillage during transfer and decanting;
- better containment and lower risk of exposure to contaminants;
- ability to fit flow meters to allow accurate auditing.

Achieved environmental benefits
This technique prevents or minimises the contamination of surface waters, groundwaters and soils, and assists in site decontamination on cessation of activities. It also reduces fugitive emissions from solvent spillages.

Environmental performance and operational data
Training and good supervision are required to ensure that staff do not carry out pumping operations in haste and without due care.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Driving force for implementation

- Reduced risk of liability from contamination.
- Workplace health and safety objectives including reduced risk of associated accidents, e.g. preventing slippery floors, reducing risk of fire.

Example plants
Widely used.

Reference literature

[38, TWG 2004] [44, COM 2006] [7, Germany 2003] [78, TWG 2005] [212, TWG 2018] [213, Germany 2002]

17.2.3.2 Prevention of overflows during pumping

Description
Measures which ensure for example that:

- the pumping operation is supervised;
- for larger quantities, bulk storage tanks are fitted with acoustic and/or optical high-level alarms, with shut-off systems if necessary.

Achieved environmental benefits
This technique prevents or minimises the contamination of surface waters, groundwaters and soils, and assists in site decontamination on cessation of activities. It also reduces fugitive emissions from solvent spillages.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
Staff time in supervising the pumping operation, and the cost of acoustic/optical high-level alarm systems.

Driving force for implementation

- Reduced risk of liability from contamination.
- Workplace health and safety objectives including reduced risk of associated incidents, e.g. preventing slippery floors, reducing risk of fire.

Example plants
Widely used.

Reference literature
[212, TWG 2018]

17.2.3.3 Capture of VOC vapour during solvent-containing material delivery

Description
When delivering solvent-containing materials in bulk (e.g. loading or unloading of tanks), the vapour displaced from receiving tanks is captured, usually by back-venting.

Technical description
Pumped solvents or solvent-containing liquids will displace solvent vapours from receiving tanks. These can be captured and:

- vented back to the discharging tank (vapour recovery system, back-venting);
- adsorbed and recovered or destroyed;
- vented into an off-gas treatment system.

Back-venting (gas balancing system) is operated in such a way as to ensure that the flow of liquid organic substances can only take place when the gas balancing system is connected and operated in a way that the back-venting system and the facilities connected to it may not release gas to the atmosphere during the process, except for emissions released for safety reasons.

Achieved environmental benefits
Reduction of fugitive solvent emissions to air.

Environmental performance and operational data
Back-venting may only account for 0.01 % to 0.03 % of the amount of solvent passing through the tanks, and is only likely to be considered where it can achieve better benefits.

Technical considerations relevant to applicability
May not be applicable for solvents with low vapour pressure or due to cost considerations.

Example plants
Plants #149 (routing of vapour from ink tanks to the recovery system) and #151 (air extraction of tank breathing from mass storage tanks and its direction to the treatment system) in [155, TWG 2016].

Reference literature
[155, TWG 2016]

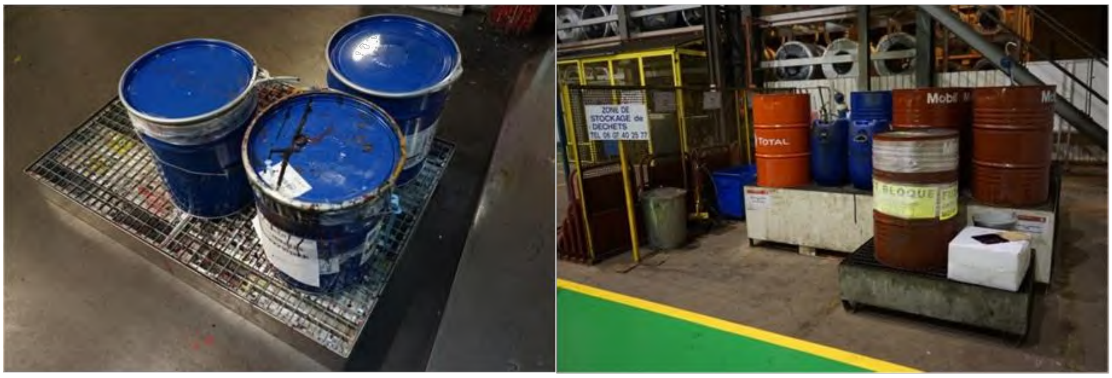
17.2.3.4 Containment for spills and rapid take-up when handling solvent-containing materials

Description

When handling solvent-containing materials in containers, possible spills are avoided by providing containment or rapid take-up, e.g. by using trolleys, pallets and/or stillages with built-in containment (e.g. 'catch pans') and/or rapid take-up by using absorbent materials.

Technical description

Examples of built-in containment are given in Figure 17.3.



Source: a) [180, COM 2017], Plant #133 in [155, TWG 2016];
b) [182, COM 2017], Plant #152 in [155, TWG 2016]

Figure 17.3: Built-in containment for moving and storing drums in production areas

Achieved environmental benefits

This technique prevents or minimises the contamination of surface waters, groundwaters and soils, and assists in site decontamination on cessation of activities. It also reduces fugitive emissions from solvent spillages.

Technical considerations relevant to applicability

Generally applicable.

Driving force for implementation

- Reduced risk of liability from contamination.
- Workplace health and safety objectives including reduced risk of associated accidents, e.g. preventing slippery floors, reducing risk of fire.

Example plants

Widely used; example plants: #133 and #152 in [155, TWG 2016].

Reference literature

[155, TWG 2016] [180, COM 2017] [182, COM 2017]

17.2.4 Minimisation of raw material consumption

See also Section 17.12 on waste minimisation and treatment.

17.2.4.1 Advanced mixing systems

Description
Computer-controlled mixing equipment to achieve the desired paint / coating / ink / adhesive.

Technical description
When using automated mixing systems, it is not strictly necessary to use standard colours to mix the required colour. Specific colours can be composed from non-standardised colours by computer-controlled equipment. This, however, requires very sophisticated software and exact knowledge of the non-standardised colours which are to be used for the mixing. For this purpose, these non-standardised colours need to be measured with a photo spectrometer and the result is introduced to the colour-computer.
For example, with an online mixing system for two-component products such as paints or adhesives, the exact amount needed will be dosed and mixed immediately before usage. The mixing unit is not a part of the paint or adhesive application tool. It is a stand-alone unit.
It is possible to obtain similar proportional benefits from using programmable scales or computerised Pantone colour-matching systems.

Achieved environmental benefits
Benefits include resource savings and a reduction in waste materials. During manual mixing, losses of 1 % or 2 % of solvents can occur. These can account for 15 % of the total VOC emissions. Automated mixing in enclosed machines reduces most of these emissions. Also, less cleaning agent is needed.

In printing, the amount of waste ink may be reduced by 75 % depending on the number of times that inks are mixed and the amounts involved. The automated technique permits a perfect dosage so that no colour correction is necessary, so therefore only the exact quantity of ink is prepared.

With an online mixing system for two-component products, waste reductions of 10-30 % can be achieved.

Environmental performance and operational data
This working method also makes it possible to use paints or inks that have been returned as an ingredient for new paints or inks (see Section 17.12.3). The return paints or inks are mixed according to the approximate colour, i.e. light greens, dark greens, light reds and dark reds. Once a certain quantity is achieved, the resulting colour is measured and the computer is programmed to use that colour whenever possible.

Cross-media effects
Automation requires energy.

Technical considerations relevant to applicability
Generally applicable.
Commonly applied in flexography and non-publication rotogravure printing for solvent-based inks, where more than 200 tonnes of press-ready ink per year are mixed.

Source: Amcor Flexibles Europe and Americas, HP Laminates, Ghent, BE, [180, COM 2017], Plant #133 in [155, TWG 2016]

Figure 17.4: Automatic mixing system in flexography plant

In the coil coating industry, automated colour mixing is routinely carried out in the paint-making factories, and the application is offered to the coil coating lines but it is not always appropriate. It depends on the colour and product mix. There are examples of coil coating lines using in-house computer-controlled colour-mixing schemes.

Online mixing systems for two-component products are applicable when produced using equipment dedicated to a single product line. There is no restriction in subsequent application techniques. In the Netherlands, companies are advised to apply this technique when over 2 000 litres of two-component paint needs to be mixed. For adhesives, relatively small amounts are mixed. It is commonly applied in wood and furniture painting. It is also applicable to the coating of trains, e.g. for applying the ground coat and primer/filler.

Economics

In printing, the investment cost depends on size and exact requirements, starting at approximately EUR 50 000 (2006 data). However, a saving will be incurred because less ink is used and less waste needs to be disposed of. Depending on the size of the operation, the savings may lead to a favourable payback time for the investment.

For online mixing systems for two-component products, investment costs are EUR 9 000-18 000 for a mechanically driven installation used for the mixing of base coat. The costs are EUR 27 000-37 000 for an electronically driven installation (2006 data). The payback time will normally be several years for companies coating small series. However, this depends on the amount of waste prevented, the price of the materials that are mixed and the costs for disposal.

Driving force for implementation

Resource savings and a reduction in waste generation.

Example plants

Plant #133 in [155, TWG 2016].

Reference literature
[1, INTERGRAF and EGF 1999] [5, DFIU et al. 2002] [7, Germany 2003] [27, VITO 2003] [38, TWG 2004] [155, TWG 2016] [180, COM 2017]

17.2.4.2 Centralised supply of VOC-containing materials (e.g. inks, coatings, adhesives, cleaning agents)

Description
Supply of VOC-containing materials (e.g. inks, coatings, adhesives, cleaning agents) to the application point by direct piping with ring lines, including system cleaning such as by pig cleaning or air flushing.

Technical description
VOC-containing materials (e.g. paints or inks, adhesives, cleaning agents, solvents for viscosity adjustment) are piped directly from the storage area to the application area (e.g. painting or inking units).

This method only fills as much material into the system as necessary for the processes. The excess material is pressed back from the (flexible) tube into the supply unit by an elastic separation module (pig cleaning) and is reused. The purged solvents can be recovered and reused.

Achieved environmental benefits

- Virtually closed systems with low VOC emissions and avoiding spillages during transfer and decanting.
- Lower use of cleaning agents, reduction of paint and solvent losses, decrease of the manual processes with the colour change.

Environmental performance and operational data
For better control, above-ground piping is installed, as underground pipes for solvents are a known source of serious soil and groundwater pollution.

Operating with pigging or air flushing optimises the benefits in terms of material savings and reducing VOC emissions.

The risk of staff exposure to contaminants is reduced.

The technique makes fitting of flow meters easier, to allow accurate auditing and more accurate calculation of the solvent mass balance.

There are fewer waste paints or inks, fewer containers and fewer materials to clean. For example, the achievable level of residues for heatset web offset printing plants is < 1 % of the purchased ink.
The system is effective if coupled with regular inspection and maintenance. Otherwise, solvent losses from pumps, valves and flanges may add up and become a significant source of VOC emissions.

Technical considerations relevant to applicability
May not be applicable in the case of frequent changes of inks / paints / coatings / adhesives or solvents.

Centralised supply is usually applied in large plants where large reusable paint or ink containers are used.

It is widely used in the automotive industry.

In printing, it is applicable to plants with sufficient ink consumption and is commonly applied in large heatset web offset printing plants. In publication rotogravure, this is a standard technique as only toluene is used and, therefore, direct supply is easy to apply. However, in flexography and non-publication rotogravure printing, the situation is more complex because of the many hundreds of different colours that are used since the viscosity control needs to be done with different solvents depending on the job in hand. Generally, ethanol (for flexography) or ethyl acetate or specific ethanol/ethyl acetate mixtures (for rotogravure), sometimes MEK (for adhesives and paints) and sometimes even other solvents are used.

It is commonly applied in the coating of wooden surfaces when large volumes of paint are used.

Pig cleaning systems are not applicable when the graduated flow return principle is applied (pipe system with different pipe diameters).

Economics
For new plants, this is a low-cost technique; however, retrofit may be very expensive.

The investment in piping and pumps is considerable. For example, for the printing industry, the minimum investment ranges from EUR 5 000 to EUR 24 000 (2006 data). Minimal savings are incurred through slightly cheaper ink and less disposal costs.

Driving force for implementation
Decreases the time that the painting or inking units are not running.

Example plants
Widely used.

Reference literature
[1, INTERGRAF and EGF 1999] [7, Germany 2003] [38, TWG 2004] [78, TWG 2005] [212, TWG 2018]

17.2.4.3 Supply of VOC-containing materials (e.g. inks, coatings, adhesives, cleaning agents) at the point of application using a closed system

Description
In the case of frequent changes of inks / paints / coatings /adhesives and solvents or for small-scale usage, supply of inks / paints / coatings / adhesives and solvents from small transport containers placed near the application area (spray booth, printing press, etc.) using a closed system.

Technical description
Inks / paints / coatings / adhesives and solvents are supplied to the process from small transport containers placed near the application area. A closed system is used to minimise emissions of VOCs and to avoid spillages.

Source: [182, COM 2017], Plant #152 in [155, TWG 2016]

Figure 17.5: Paint supply at coating head in coil coating

Environmental performance and operational data
Reduction of fugitive emissions and minimisation of risk of spills.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
Cost of supply system.

Example plants
Plants #152 and #166 in [155, TWG 2016].

Reference literature
[155, TWG 2016] [179, COM 2017] [182, COM 2017] [212, TWG 2018]

17.2.5 Automation of equipment

Description
Many operations in an installation may be automated such as spraying, roller coating and curtain coating, colour mixing, colour changing, piping delivery of solvents and solvent-based materials, and cleaning although manual painting is still applied for areas that are difficult to access or variably shaped parts.

Technical description

Many operations in an installation may be automated, depending on the activity and the industry. Examples are:

- robot application of coatings and/or sealants to internal and external surfaces for :
  - vehicles, see Section 2.4.4.2 and Section 2.2;
  - OMS and plastics, see Section 2.4.4.2 and Section 3.2;
- automated spray application using machines, see Section 2.4.4.1;
- automation of colour change, see Section 2.4.5.1 for automatic colour changers for vehicle coating and Section 2.2.3.2.3 for additional information on applied colour change techniques and associated material losses;
- printing, applicable to automatic mixing systems, see Section 17.2.4.1 (flexible packaging only);
- roller coating, see Section 17.7.3.1;
- curtain coating, see Section 17.7.3.4;
- piped delivery of solvents and solvent-based materials, see Section 17.2.2.

Achieved environmental benefits

See relevant sections.

Environmental performance and operational data

Depending on the technique: minimises overspray, optimises application and layer thickness (for painting), reduces dust and waste generation, increases material efficiency, reduces cleaning requirements, reduces waste solvent, etc.

In Table 17.2 and Table 17.3 examples for the introduction of robot spraying on a car coating line are presented.

Table 17.2: Example for the introduction of interior robot spraying on a car coating line

Upper medium class car, 500 units per day. Interior painting:		
Conversion from manual air spray to:	ESTA (electrostatic application)	From air-automated to ESTA robots
Paint saving:	138 000 l/yr 1.2 l/unit	60 950 l/yr 0.53 l/unit
Cost saving per year (2005 data): CPU (cost per unit) saving:	EUR 1 380 000/yr EUR 12	EUR 609 500/yr EUR 5.3
Payback time, paint costs only (ROI)	20 months	13 months
NB: 145 ml front door, 130 ml rear door, 255 ml engine compartment, 150 ml trunk. The paint costs EUR 10/l. No other baseline data are given. Transfer efficiency: air 25-35 %, ESTA interior: 55-65%, ESTA exterior 70-75 %, ESTA plastic parts painting: 55 %. Path length reduced by up to 60 %. Path speed reduced by up to 30 % (depending on parts' geometry). Painting time reduced by up to 40 % (depending on parts' geometry). Surface quality and corrosion protection higher due to wrap-around. Dust (paint overspray) and VOC emissions reduced due to higher transfer efficiency. *Source*: [110, Eurocar 2005] modified by [212, TWG 2018]		

Table 17.3: Example for the introduction of exterior robot spraying using metallic paints on a car coating line

Upper medium class car, 500 units per day. Metallic painting:	
Paint saving per year Per unit	41 641 l/yr 0.45 l/unit
Cost saving per year **(2005 data)** CPU (cost per unit) saving	EUR 416410/yr EUR 4.5
Amortisation (ROI)	10 months
NB: Unit painted surface 9.5 m^2. Base coat two-coat thickness 5 µm, solids content 15 %. The paint costs EUR 10/l. No other baseline data are given. *Source*: [110, Eurocar 2005] modified by [212, TWG 2018]	

Cross-media effects
See relevant sections.

Technical considerations relevant to applicability
See relevant sections.

Economics
See relevant sections. For savings in materials and time in vehicle painting, see example plant below.

Driving force for implementation
Increased quality and productivity.

Example plants
See relevant sections.
Aircraft parts: Airbus, Nantes, France; Airbus, Broughton, UK.
Vehicles: Seat Martorell, Spain; VW Pamplona, Spain, and VW, South Africa; Renault, Flins and Douai, France.

Reference literature
See relevant sections indicated in the Technical description above
[110, Eurocar 2005] [212, TWG 2018]

17.2.5.1 Soft purge in spraying

Description
Refilling the spray gun with new paint without intermediate rinsing.

Achieved environmental benefits
Reduction of rinsing solvent use.

Cross-media effects
Waste generation due to mixing of new and old paint.

Economics
Savings in cleaning solvents and cleaning/downtime.

Reference literature
[ACEA comment #28 in [212, TWG 2018]]

17.2.6 Emissions during OTNOC

Description

Identification of critical equipment: Equipment critical to the protection of the environment (critical equipment) is identified on the basis of a risk assessment. In principle, this concerns all equipment and systems handling VOCs (e.g. off-gas treatment system, leak detection system).

Inspection, maintenance and monitoring: A structured programme to maximise critical equipment availability and performance which includes standard operating procedures, preventive maintenance, regular and unplanned maintenance. OTNOC periods, duration, causes and, if possible, emissions during their occurrence are monitored.

Technical description

All equipment and systems handling VOCs need maintenance, both preventative and for breakdowns. Untreated emissions of flue-gases and of leaks of liquids can be minimised by:

- planned maintenance of larger repair and replacement tasks;
- regular maintenance checks.

The maintenance plan for the off-gas extraction and treatment equipment includes regular inspection, preventive and corrective actions to ensure that the off-gas extraction and treatment equipment operates according to its specifications and with optimal efficiency and minimises the occurrence, duration and impact of OTNOC. In order to prevent or minimise pollution from OTNOC, a minimum plant availability for the emission treatment plant may be defined (where applicable).

Achieved environmental benefits

Benefits include a reduction in overall emission loads. Generally, defects in off-gas oxidation equipment can give rise to VOC emissions equivalent to 0.4 % of the annual input per day (based on 250 working days/year).

Environmental performance and operational data

Defects in off-gas treatment can result in a significant increase of VOC emissions.).

Preventative measures to reduce OTNOC and unplanned emissions

A preventative maintenance system should be used, for example, to ensure that:

- maintenance requiring the switching off of emissions control equipment/systems (e.g. containment, extraction systems, off-gas treatment) is planned to take place when:
    - there are no emissions (e.g. shutdown periods) or when emissions levels are low;
    - during periods when emissions will have least impact, i.e. for VOC emissions, during periods of low sunlight levels, low probability of inversion layers, etc.; this is dependent on weather, time of year and local conditions;
- replacement of parts that require replacement on a regular basis is planned to take place before breakdowns are likely;
- parts that are essential to the normal running of emission control equipment are kept in stock, can be replaced or repaired rapidly with minimum downtime;
- routine and non-routine maintenance including maintenance of covers and pipe joints for solvent storage and delivery systems is carried out.

Regular maintenance checks

A maintenance schedule and record of all inspections and maintenance activities is kept:

- visually check for leaking seals, flanges, valves, welds, tanks and bunds;
- inspections by external experts where necessary;

- monitor key equipment for problems such as vibration, emission leaks and planning repairs (as above);
- test programmes, e.g. pressure-test pipelines and tanks, calibration of metering and monitoring equipment;
- check the tightness of nuts and bolts;
- check for wear and tear on machinery, valves and bunds, overheating bearings, etc.;
- recalibrate metering systems;
- ensure that extraction and abatement equipment is fully serviceable, and that:
  - dryers or ovens are not leaking;
  - ducting is not leaking;
  - bypasses are in good working order (i.e. not jammed).

Unplanned maintenance

Process operators and maintenance staff should identify and report leaks, broken equipment, fractured pipes, etc. to focus unscheduled maintenance.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

The staff time required.

Driving force for implementation

- Reduces downtime.
- Assists in maintaining product quality and throughput.
- Supports health and safety objectives.

Example plants

Widely applied in this sector.

Reference literature

[78, TWG 2005] [212, TWG 2018]

17.3 Monitoring

Information on monitoring is included within the Reference Document on Monitoring of Emissions to Air and Water from IED Installations (ROM) [266, COM 2018] which provides guidance on and procedures for:

- direct monitoring - methods and timing;
- consideration of total emissions including monitoring of fugitive and diffuse emissions, surrogate parameters and mass balances;
- how to deal with uncertainty.

17.3.1 Solvent mass balance

Description

The compilation, at least once every year, of the organic solvent inputs and outputs of the plant as defined in Part 7(2) of Annex VII to Directive 2010/75/EU.

Technical description

As part of understanding the environmental footprint/management plan of an installation, an operator needs to know:

- how a solvent is defined;
- how much solvent is used and where;
- how much solvent is emitted and where.

The outputs of organic solvents in the waste gas and as fugitive emissions are more difficult to determine than other emissions, such as in water. However, not all solvents emitted to water can be accurately measured, because for some no monitoring method is available. Emissions are determined by a mass balance, referred to as a solvent mass balance (SMB). A solvent mass balance is a tool to derive quantitative statements on the input and output of solvents. A solvent mass balance provides information for the solvent management plan which includes objectives, responsibilities, processes and control measures. Part 7 of Annex VII to the IED provides guidance on what is required in a solvent management plan. It includes the principles to be applied and a framework for a mass balance.

For consistency and clarity, the definitions for solvent inputs and outputs as stated in Part 7(2) of Annex VII to the IED are used:

Inputs of organic solvents (I):

- I1: The quantity of organic solvents or their quantity in mixtures purchased which are used as input into the process in the time frame over which the mass balance is being calculated.
- I2: The quantity of organic solvents or their quantity in mixtures recovered and reused as solvent input into the process. The recycled solvent is counted every time it is used to carry out the activity.

Outputs of organic solvents (O):

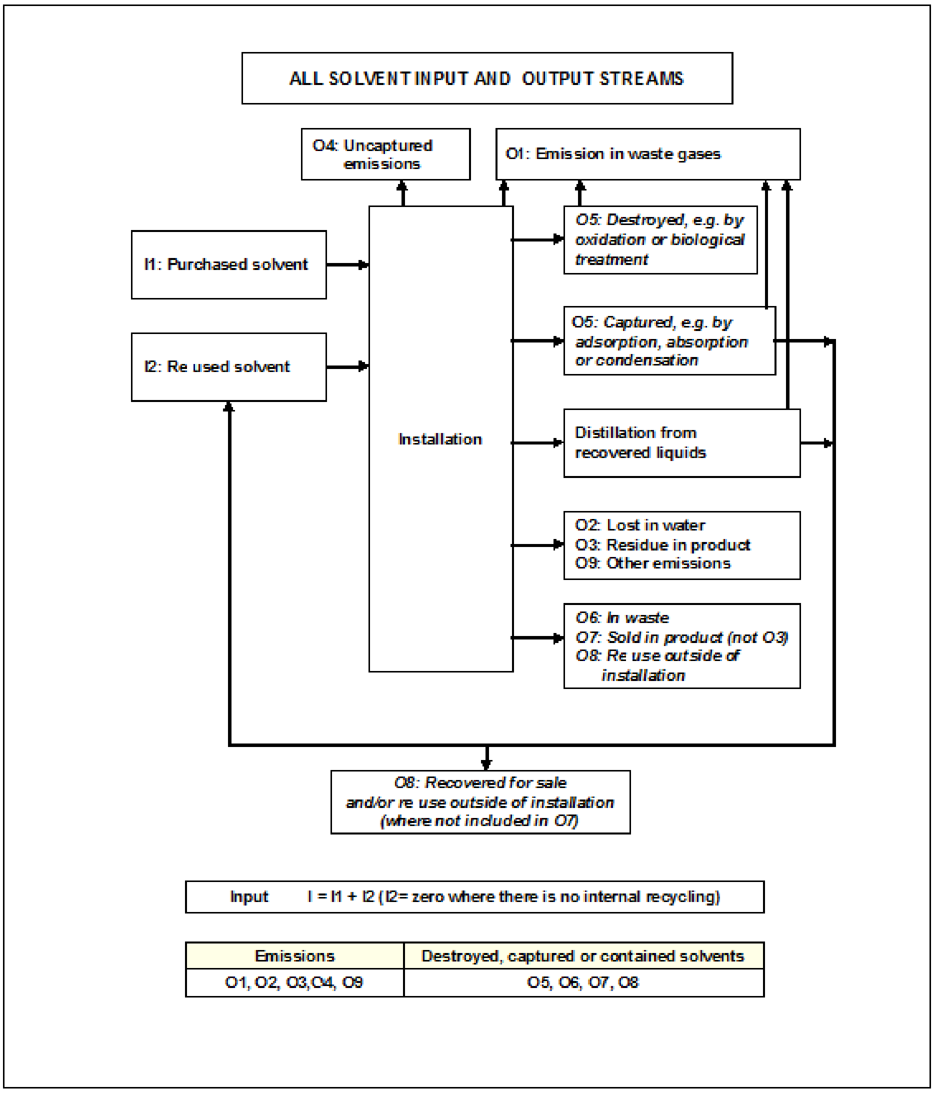
- O1: Emissions in waste gases.
- O2: Organic solvents lost in water, taking into account waste water treatment when calculating O5.
- O3: The quantity of organic solvents which remains as contamination or residue in products output from the process.

- O4: Uncaptured emissions of organic solvents into air. This includes the general ventilation of rooms, where air is released to the outside environment via windows, doors, vents and similar openings.
- O5: Organic solvents and/or organic compounds lost due to chemical or physical reactions (including those which are destroyed, by incineration or other waste gas or waste water treatments, or captured, as long as they are not counted under O6, O7 or O8).
- O6: Organic solvents contained in collected waste.
- O7: Organic solvents, or organic solvents contained in mixtures, which are sold or are intended to be sold as a commercially valuable product.
- O8: Organic solvents contained in mixtures recovered for reuse but not as input into the process, as long as not counted under O7.
- O9: Organic solvents released in other ways.

Figure 17.6 shows all of the usual input and output options for solvents.

The five most common cases (illustrated in Annex 21.5.1) are:

- no end-of-pipe abatement without internal solvent reuse;
- no end-of-pipe abatement with internal solvent reuse;
- solvent recovery and reuse (internally or externally);
- end-of-pipe abatement is used and the fugitive emissions (e.g. cleaning agents) are easily determined directly;
- end-of-pipe abatement is used and the fugitive emissions are not easily determined.



Input I = I1 + I2 (I2= zero where there is no internal recycling)

Emissions	Destroyed, captured or contained solvents
O1, O2, O3,O4, O9	O5, O6, O7, O8

Figure 17.6: All solvent inputs and outputs (using definitions from the IED)

The total emissions E = O1 + F (fugitive emissions).

The fugitive emissions (F) can be calculated (indirectly) as:

$$F = I1 - O1 - O5 - O6 - O7 - O8$$

(O7 is unlikely to apply to industries considered in this document.)

If the fugitive emissions (F) has to be explicitly determined (e.g. because of permit requirements), it can be determined by direct measurement of the inputs (I) and outputs (O) as:

$$F = O2 + O3 + O4 + O9$$

Deriving a mass balance usually involves a mix of direct measurement and estimation that will be derived for a specific situation (see Annexes 21.4 and 21.5). A technique used in several industries (e.g. for application in vehicle manufacturing industries, see Annex 21.5.1) is based on using the capture and destruction efficiency of the waste gas system using the following steps:

- measure the amount of solvent input (I = I1 + I2);
- measure the amount of emission in water and losses as waste, etc. (losses = O2, O3, O6, O7, O8, O9);

- measure or calculate the removal efficiency of the abatement technique;
- estimate the amount of solvent sent to abatement (I – losses);
- multiply the amount of solvent by the percentage efficiency of the abatement = waste gas emissions O1;
- fugitive emissions (as above): F = I1 - O1 - O5 - O6 - O7 - O8 or F = O2 + O3 + O4 + O9.

When applying the direct method for determination of fugitive emissions, it is not necessary to calculate O1 to calculate fugitive emissions. Additionally, O1 is needed when the total emissions are calculated.

Solvent balances whose function is to prove compliance with regulations or environmental permits are normally drawn up yearly. However, the balances may be prepared more frequently, e.g. monthly or quarterly, for the following reasons:

- Initially, operators will need to apply resources to set up a proper system of data collection and to draw up and check the solvent balances, e.g. one or two man- days per month will be required in large companies. Once a system has been established and key measurements have been identified, they could be easily monitored.
- Frequent solvent balances can be simpler than annual balances. For instance, they can be put into a spreadsheet and/or key indicators can be derived for regular checking, such as changes in stock that can be derived from administrative sources rather than by actual physical stocktaking.
- Deriving solvent balances is not always easy. The company needs to follow a learning curve. Solvent balances need to be derived a number of times before they can be expected to be correct.
- Frequent balances show trends giving an early warning if problems arise. Balancing will discover where emission limits are likely to be exceeded so that it is possible to correct the situation in time and still be in compliance when the solvent balance for the whole year is made.

In order to have an extra check on the correctness of the frequent balances, the annual balance should not be the mere sum of all these balances but should, as far as possible, be derived separately from original data. This annual balance can then be compared to the sum of the frequent balances to find any discrepancies.

Achieved environmental benefits

Solvent balances are essential to estimate fugitive emissions and therefore control them. Frequent balances indicate any irregular situation, reduce environmental risks and enable the reduction of solvent emissions.

Environmental performance and operational data

Emission figures should be comparable and it is important that throughout one industry the same definitions are applied, especially regarding what is classed as ‘solvent’ for the purposes of the mass balance. It is important to note that the IED not only defines a VOC by vapour pressure at standard conditions, but also includes any compound having a corresponding volatility under the particular conditions of use.

When deriving a mass balance, assumptions will usually be made about the efficient working of any off-gas extraction and treatment system. For example, the space ventilated is the same as the design (i.e. no unrecorded connections), equipment such as fans are operating at design efficiency, etc. Volumes of airflows can be large (e.g. in some cases, orders of magnitude of 10^6 m^3/h), so errors in these figures can cause large errors in calculating emissions emitted (see Annexes 21.4 and 21.5).

In order for the assumptions to be valid, the ventilation system must be inspected and maintained in good working order (see Annex 21.4 and Section 17.2.6). Examples of problems encountered are (see Annex 21.4):

- the extraction system was not constructed as designed or has been altered without the drawings being updated;
- automatic pressure controls, valves and dampers not working as designed;
- systems working in the wrong way, i.e. blowing instead of extracting, flow being in the wrong direction, etc.;
- fan motors, drive belts and/or pulleys may have been changed, giving different flow rates.

For the determination of volumetric flow, see the Reference literature below and Section 17.3.5.

The accuracy of the calculated source figures for a mass balance needs to be determined (see Annexes 21.4 and 21.5). Where the maximum error in any source has no effect on the objective of the mass balance, no further work is necessary to make the estimate more precise. However, if the inaccuracies are too large in order to meet the objective of the mass balance (e.g. verify compliance with the emission limit values), more information must be gathered to improve the level of accuracy, see Section 17.3.3. Guidance on how the accuracy of determination of fugitive emissions can be improved is given in Annex 21.4.

Cross-media effects
None.

Technical considerations relevant to applicability
This technique is applicable to all industries applying solvents and is used to calculate fugitive and total emissions.

Solvent balances may be inaccurate in complex situations, with large deviations where abatement techniques are used (see Environmental performance and operational data above).

Many countries and industrial organisations have developed guidance on how to derive a solvent mass balance and construct a solvent management plan. One includes a free spreadsheet to assist with the mass balance (in English).

The level of detail of the solvent mass balance will be proportionate to the nature, scale and complexity of the installation, and the range of environmental impacts it may have, as well as to the type and quantity of materials used.

Economics
Cost reduction by optimisation of solvent use.

Driving force for implementation
Better knowledge of solvent inputs and outputs and assessment of necessary actions.

Example plants
Widely used.

Reference literature

[1, INTERGRAF and EGF 1999] [38, TWG 2004] [78, TWG 2005] [130, ADEME 2006] [181, COM 2017] [212, TWG 2018], [266, COM 2018]

17.3.2 Implementation of a solvent tracking system

Description

The solvent tracking system controls both the used and unused quantities of solvents (e.g. by weighing unused quantities returned to storage from the application area).

Technical description

The factor I1 (quantity of solvents / solvent mixtures purchased which are used in the processes) is used in the mass balance exercise. In practice, it is difficult to establish the volume of paint used over a reference period, due to the difficulty of having the following:

- A perfect inventory in a business where thousands of drums are used, sometimes stored again and reused, and where hundreds of different paint references are the norm. In order to have as precise as possible a quantification of quantities used, and depending on the raw material distribution system (e.g. central automated distribution system or manual delivery using containers), various processes could be used like: computer-based registration of quantities delivered to the application, weighing of drums returning to storage after use, etc.
- Detailed knowledge of the precise solvent and solids content of the purchased materials. Usually material technical specifications (and/or safety data sheets) provide the dry content by weight as a range and there is no clear relation between dry content by volume and by weight. In addition, methodologies for the indirect estimation of the solvent content (as the difference in the dry content by weight) may suffer from the impact of removal of other volatile by-products of the chemical reactions that occur at such a high temperature and for such a long time. Various standard methods for the determination of non-volatile matter exist[43] but may not be followed in all cases.

Achieved environmental benefits

Enabling better control of fugitive and total VOC emissions by more accurate establishment of the solvent mass balance.

Cross-media effects

None identified.

Technical considerations relevant to applicability

Generally applicable, it is necessary for the SMB elaboration.

Economics

Personnel involved.

Example plants

Widely used.

Reference literature

[177, ECCA 2017] [212, TWG 2018]

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[43] e.g. ISO 3233-3:2015: Paints and varnishes. “Determination of the percentage volume of non-volatile matter - Part 3: Determination by calculation from the non-volatile-matter content determined in accordance with ISO 3251, the density of the coating material and the density of the solvent in the coating material” or EN 16074:2011: Paints and varnishes. “Determination of non-volatile matter content and spreading rate of coil coating materials”.

17.3.3 Full identification and quantification of the relevant solvent inputs and outputs

Description

This includes:

- identification and documentation of solvent inputs and outputs (e.g. emissions in waste gases, emissions from each fugitive emissions source, solvent output in waste);
- substantiated quantification of each relevant solvent input and output and recording of the methodology used (e.g. measurement, calculation using emission factors, estimation based on operational parameters);
- identification of the main sources of uncertainty of the quantification and implementation of corrective actions to reduce the uncertainty;
- regular update of solvent input and output data.

The characterisation and quantification of the relevant solvent inputs and outputs is done by a person/persons with sufficient expertise on compiling a solvent mass balance, depending on the complexity of the processes, sources of emissions, applied abatement techniques, and other conditions influencing the accuracy.

The analysis of the inaccuracies of the methodology used is followed by a judgment on whether these inaccuracies are acceptable, meaning they have no effect on the decision as to whether the installation complies with its emission limit values or not. If the inaccuracies are not acceptable, more information must be gathered to improve the level of accuracy (e.g. use of emission factors or direct measurement of fugitive emissions rather than subtraction of destroyed or captured emissions from the solvent input).

Technical description

The accuracy of the calculated source figures for a mass balance needs to be determined (see Annexes 21.4 and 21.5). Typical sources of inaccuracy include the following:

Estimation: Inaccuracy is often the result of making estimates instead of using measured values. For example, this could be the case with the solvent content of waste or the quantity of solvent recycled within the plant.

Measurement: Inaccuracy also occurs as the result of a single measurement, or a limited number of measurements, being extrapolated and used to determine the annual emissions or annual consumption. For example, this might be the case if the solvent concentration in stack emissions is used to calculate the annual emissions in waste gases.

Calculation: Inaccuracy also occurs if two numbers which are more or less equal and accurate in themselves are subtracted one from the other. The small difference between the two figures contains the sum of the possible errors in the original two numbers. The inaccuracy can be of the same order of magnitude as the result of the calculation.

Where the maximum error in any source has no effect on the objective of the mass balance, no further work is necessary to make the estimate more precise. However, if the inaccuracies are too large to meet the objective of the mass balance (e.g. verify compliance with the emission limit values), more information must be gathered to improve the level of accuracy. A quick way to assess if detailed analysis of emission sources is needed is to start with a worst-case approach, which estimates the highest possible level of fugitive emissions, considering the inaccuracies of measurements and estimations.

The choice of a suitable method is dependent on the type and size of the installation. There are different options to improve the quantification of fugitive emission sources, such as direct measurement. An example is to use a combination of passive samplers and flow characteristics of fugitive emission sources in the case of a closed workspace. Guidance on how the accuracy of determination of fugitive emissions can be improved is given in Annex 21.4.

Achieved environmental benefits
Accurate identification, characterisation and quantification of the relevant solvent inputs and outputs allow better determination and control of (fugitive) emissions. In this way, it enables the reduction of actual solvent emissions.

Cross-media effects
None identified.

Technical considerations relevant to applicability
This technique is generally applicable. The required level of detail of characterisation and quantification depends on the complexity of the installation and the ability to meet the objective of the mass balance (e.g. to verify compliance with emission limit values).

Economics
Costs are dependent on the level of sampling and analysis required. A good characterisation and quantification of solvent inputs and outputs can enable targeted, efficient abatement of emissions, reducing the risk of costs for over-dimensioning, inefficient resource use, etc.

Driving force for implementation
Better knowledge of emissions/outputs and assessment of necessary actions.

Example plants
Used at all STS plants in Europe; example of frequent SMB monitoring: Plant #146 in [155, TWG 2016].

Reference literature
[181, COM 2017] [212, TWG 2018] [155, TWG 2016]

17.3.4 Monitoring of changes that may influence the uncertainty of the solvent mass balance data

Description
Any change that could influence the uncertainty of the solvent mass balance data system is recorded, such as:

- malfunctions of the off-gas treatment system: date and period of time are recorded;
- changes that may influence air/gas flow rates, e.g. replacement of fans, drive pulleys, motors; the date and type of change are recorded.

Technical description
As an example, the off-gas treatment system performance can be monitored through pressure and temperature measurements at specific points, namely at the inlet off-gas and downstream waste gas stream. The results should be kept and controlled.

The monitoring system can send automatic alerts in case of any pressure and/or temperature out of tolerance level.

Achieved environmental benefits
Improved accuracy of solvent mass balance calculations.

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally applicable.

Economics
Involvement of personnel.

Example plants
Widely used.

Reference literature
[212, TWG 2018]

17.3.5 Monitoring of emissions in waste gases

Description
Regular monitoring of emissions in waste gases.

Technical description
Monitoring of the relevant parameters can be accomplished by online measurements (which facilitate rapid intervention and control) or analytical results derived from air samples. Parameters to be monitored and the frequency of monitoring depend on the characteristics of the type of processes and material used and the abatement techniques applied within the STS plant (see also the sector-specific sections on emissions). The monitoring of VOC emissions in waste gases contributes also to the elaboration of the solvent mass balance (determination of emission parameters O1 and O5).

The monitoring of emissions is carried out in accordance with EN standards or, if EN standards are not available, in accordance with ISO, national or other international standards which ensure the provision of data of an equivalent scientific quality.

Achieved environmental benefits
Benefits include control of emissions in waste gases, maintenance of proper operation of the off-gas treatment equipment and detection of unplanned releases. In addition, it contributes to the accuracy of the solvent mass balance figures.

Environmental performance and operational data
This information (where available) is detailed in this document for each type of activity in the dedicated chapters (Chapters 2 to 15).

Cross-media effects
Some equipment, ancillary materials and energy are required for carrying out monitoring.

Technical considerations related to applicability
Generally applicable to all STS plants where there are channelled emissions to air.

Economics
The costs associated with monitoring the waste gas relate to personnel and equipment used for sampling and measurement.

Driving force for implementation
Legislation on air pollution.

Example plants
See examples in Chapters 2 to 15.

Reference literature
[266, COM 2018]

17.3.6 Monitoring of emissions to water

Description
Regular monitoring of emissions to water.

Technical description
Monitoring of the relevant parameters can be accomplished by online measurements (that facilitate rapid intervention and control of the waste water treatment plant - WWTP) or analytical results derived from waste water samples. Parameters to be monitored and the frequency of monitoring depend on the activities which are connected to the WWTP and to the destination of the treated effluent (direct discharge or to further treatment in an industrial WWTP or a municipal WWTP).

Common parameters monitored are found in the relevant sector sections on emissions, and include: TSS, COD, TOC, Zn, Ni, Cr_{total}, Cr(VI), phenol index, AOX, fluoride and phosphates as P.

The monitoring of emissions is carried out in accordance with EN standards or, if EN standards are not available, in accordance with ISO, national or other international standards which ensure the provision of data of an equivalent scientific quality.

Achieved environmental benefits
Monitoring the waste water of a waste water treatment plant helps to maintain the proper operation of the waste water treatment plant, detects accidental releases and thus helps to prevent any possible adverse environmental effects by discharge of waste waters.

Environmental performance and operational data
This information (where available) is detailed in this document for each type of activity in the dedicated chapters (Chapters 2 to 15).

Cross-media effects
Some equipment, ancillary materials and energy are required for carrying out monitoring. The COD measurement relies on the use of very toxic compounds (i.e. mercury and chromate).

Technical considerations relevant to applicability
Generally applicable to all plants where there are emissions to water.

Economics
The costs associated with monitoring the effluent waste water relate to personnel and equipment used for sampling and measurement.

Driving force for implementation
Legislation on water pollution.

Example plants
See the relevant sections for emissions to water in Chapters 2 to 15.

Reference literature
[23, COM 2006], [31, COM 2016], [266, COM 2018]

17.4 Water use and waste water generation

More information on process descriptions used for water management can be found in the STM BREF [23, COM 2006].

17.4.1 Water management plan and water audits

Description
A water management plan and water audits are part of the environmental management system (EMS) and include:

- flow diagrams and a water mass balance of the plant;
- establishment of water efficiency objectives;
- implementation of water optimisation techniques (e.g. control of water usage, recycling, detection and repair of leaks).

Water audits are carried out at least annually to increase the reliability of controls and to ensure that the objectives of the water management plan are met.

Achieved environmental benefits
Reduction of water consumption and waste water discharge.

Cross-media effects
None reported.

Technical considerations relevant to applicability
The level of detail and nature of the water management plan and water audits will generally be related to the nature, scale and complexity of the plant. It may not be applicable if the STS activity is carried out within a larger installation, provided that the water management plan and the water audits of the larger installation sufficiently cover the STS activity.

Economics

- Staff time.
- Cost of any additional metering required.

Driving force for implementation
Cost reduction depending on pricing and availability of water.

Example plants
Plant #114 in [155, TWG 2016].

Reference literature
[155, TWG 2016]

17.4.2 Optimisation of water usage and discharge

Description
Water usage and discharge are optimised by managing the flow and water quality, e.g. of rinse and process waters. This may also assist the reuse and recycling of water.

Technical description
Water usage and discharge can be optimised to meet quality requirements such as by benchmarking, calculation, chemical or physico-chemical analysis (which can be online or manual). The water flow is then controlled by an authorised person using a variety of techniques such as using locking flow valves or monitoring key parameters, e.g. metering volumes temporarily or permanently. For example, for rinsing, the conductivity in the last water rinsing step is related to the maximum permitted load of contaminants which may influence further surface treatment processes. Monitoring the discharge from the rinses using conductivity measurements can reduce the amount of water used, because it helps to control the amount of make-up water required.

Determining the quality of various process waters provides information for the reuse and recycling of water, either directly or after relevant treatment.

Achieved environmental benefit
Water consumption and waste related to rinsing water will be reduced and the lifetime of further chemical treatment baths will be improved.

Waste water volumes will be reduced.

Cross-media effects
Reducing water usage could result in higher discharge concentrations, such as BOD and COD emissions and potential stress on the WWTP.

Environmental performance and operational data
The conductivity equipment and other online monitoring equipment need to be robust in handling and maintenance.

With regards to coil coating, the conductivity allowed for the last water rinsing step depends on the subsequent process, but is generally between 10 µS/cm and 100 µS/cm (at 20 °C). Measurement must be temperature-compensated.

Technical considerations relevant to applicability
It is considered a standard process where water-based techniques are used, e.g. water-based cleaning, treatment baths, coatings or wet scrubbers.

This technique is widely used in the coil coating industry and vehicle coating industry.

Economics
Low investment costs are involved for the conductivity equipment. Savings are achieved because there is a reduction of water consumption and waste generation.

Driving force for implementation
Economics and overall process stability.

Reference literature
[22, ECCA 2004] [23, COM 2006] [31, COM 2016]

17.4.3 Reverse cascade rinsing

Description
Multistage rinsing in which the water flows in the opposite direction to the workpieces/substrate. It allows a high degree of rinsing with a low water consumption.

This technique and associated techniques are described in the STM BREF [23, COM 2006].

Technical considerations relevant to applicability
Applicable where rinsing processes are used.

17.4.4 Reuse and /or recycling of water

Description
Water streams (e.g. spent rinse water, wet scrubber effluent) are reused and/or recycled, if necessary after treatment using techniques such as ion exchange or filtration. The degree of water reuse and/or recycling is limited by the water balance of the plant, the content of impurities and/or the characteristics of the water streams.

Savings in water consumption are achieved in conjunction with reduction of the amount of waste water to be treated, thus reducing the investment cost for waste water treatment, energy usage and chemicals. However, the cost of regeneration equipment and running costs needs to be considered. This technique and associated techniques required to achieve this are described in the STM BREF [23, COM 2006].

Technical considerations relevant to applicability
Generally applicable.

Closed-loop systems can be used in systems such as in cooling towers or heat exchangers that reduce the amount of water used in the line. In the event that cooling towers are used, special provisions should be taken for *legionella* control as cooling towers are considered one of the largest and most common sources of *legionella* disease outbreaks[44].

17.4.4.1 Recycling of wet/venturi scrubber water

Description
Effluent from wet/venturi scrubbers is treated on a continuous basis. Paint particles are coagulated and flocculated and the resulting paint sludge is removed continuously, allowing the water to be recycled.

Technical description
Due to the large flow rate, the coagulation of paint sludge from venturi scrubber effluents is usually performed on a continuous basis. Paint particles are coagulated using organic polymers followed by flocculation using iron salts and milk of lime (lime water) or bentonite. The coagulated paint sludge is removed continuously by sedimentation or flotation, allowing the water to be recycled in the scrubber system. The thin sludge is usually dewatered using decanter centrifuges and the thickened sludge disposed of as waste.

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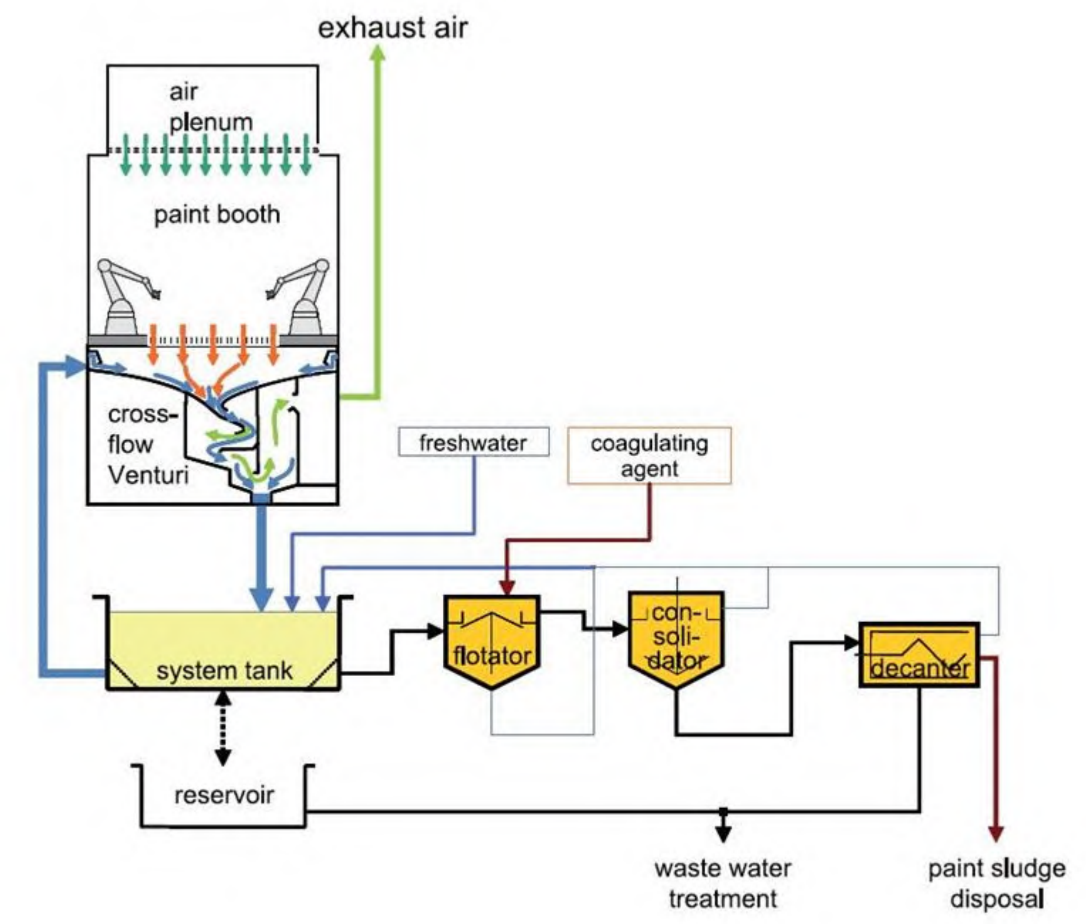
[44] García-Fulgueiras, Ana; Navarro, Carmen; Fenoll, Daniel; et al. (August 2003). ‘Legionnaires’ Disease Outbreak in Murcia, Spain’. Emerging Infectious Diseases. 9 (8): 915–921. DOI:10.3201/eid0908.030337. Retrieved June 16, 2017.



Source: [169, VDI 2013]

Figure 17.7: Simplified process flow chart of paint booth water recycling with paint sludge coagulation

Achieved environmental benefits

- Significant reduction in water usage.
- Waste is reduced by thickening the sludge.

Technical considerations relevant to applicability

Applicable to wet/venturi scrubber systems for paint overspray capture.

Driving force for implementation

Cost savings in water usage.

Example plants

Widely used. In particular, it is used in the vehicle coating industry and the coating of trains.

Reference literature

[169, VDI 2013]

17.4.4.2 Regeneration by ion exchange

Description
Ion exchange is the removal of undesired or hazardous ionic constituents of waste water and their replacement by H^+ and OH^- ions from an ion exchange resin. This technique and associated techniques required to achieve this are described in the STM BREF [23, COM 2006].

Technical considerations relevant to applicability
Applicable to ionic contaminants in water streams.

17.4.4.3 Magnetic separator

Description
Magnetic material is extracted from water using a magnetic force. See also Section 17.11.1.3.

17.4.4.4 Filtration (ultra and nanofiltration and reverse osmosis)

See Section 17.11.4.3.

17.5 Energy management and energy efficiency

17.5.1 Energy efficiency plan

Description
An energy efficiency plan is part of the Environmental Management System (EMS, see Section 17.1.1) and entails defining and calculating the specific energy consumption of the activity, setting key performance indicators on an annual basis (e.g. MWh/tonne of product) and planning the periodic improvement targets and related actions. The plan is adapted to the specificities of the plant in terms of process(es) carried out, materials, products, etc.

The energy efficiency plan gathers a set of organisational and technical measures aiming at using energy efficiently. It is part of the energy management system and closely connected to the environmental management system (EMS).

Technical description
Extensive information about energy efficiency can be found in the ENE BREF [109, COM 2009]. Some techniques applicable to increase the energy efficiency of STS activities are as follows:

a. Appraising the costs and benefits of different energy options.
b. Monitoring of energy flows (consumption and generation by source) and the targeting of areas for reductions.
c. Defining and calculating the specific energy consumption of the activity (or activities), and setting key performance indicators on an annual basis (e.g. MWh/tonne of product or per tonne of solvent used). For example, based on the primary energy consumption for the products or raw material inputs which most closely match the main purpose or production capacity of the plant.
d. Carrying out an energy survey to identify the opportunities for further energy savings.
e. Using combined heat and power (CHP).
f. Applying operating, maintenance and housekeeping measures to the most relevant energy consumption plants, such as:

- air conditioning, process refrigeration and cooling systems (leaks, seals, temperature control, evaporator/condenser maintenance);
- operation of motors and drives (e.g. high-efficiency motors);
- compressed gas systems (leaks, procedures for use);
- steam distribution systems (leaks, traps, insulation);
- room heating and hot water systems;
- lubrication to avoid high friction losses (e.g. mist lubrication);
- boiler maintenance, e.g. optimising excess air;
- other maintenance relevant to the activities within the plant;
- reviewing equipment requirements on a regular basis.

g. Using techniques that reduce energy consumption and thereby reduce both direct (heat and emissions from on-site generation) and indirect (emissions from a remote power station) emissions. For example:

- building insulation;
- use of energy-efficient site lighting;
- vehicle maintenance;
- efficient plant layout to reduce pumping distances;
- phase optimisation of electronic motors;
- heat recovery;
- ensuring equipment is switched off, if safe to do so, when not in use;

- ensuring on-site vehicle movements are minimised and engines are switched off when not in use.

h. Applying basic, low-cost, physical techniques to avoid gross inefficiencies, including insulation, containment methods (for example, seals and self-closing doors) and avoiding unnecessary discharges of heated water or air (for example by fitting simple control systems).
i. Applying energy efficiency techniques to building services.

Achieved environmental benefits
Reduction of energy consumption and associated emissions.

Technical considerations relevant to applicability
The level of detail and nature of the energy efficiency plan will generally be related to the nature, scale and complexity of the installation and energy types used. It may not be applicable if the STS activity is carried out within a larger installation, provided that the energy efficiency plan of the larger installation sufficiently cover the STS activity.

Example plants
Widely applied.

Reference literature
[109, COM 2009]

17.5.2 Energy balance record

Description
An energy balance record provides a breakdown of the energy consumption and generation (including energy export) by the type of source (e.g. electricity, fossil fuels, renewable energy, imported heat and/or cooling). This includes:

(i) defining the energy boundary of the STS activity;
(ii) information on energy consumption in terms of delivered energy;
(iii) information on energy exported from the plant;
(iv) energy flow information (e.g. Sankey diagrams or energy balances) showing how the energy is used throughout the process.

The energy balance record is adapted to the specificities of the plant in terms of process(es) carried out, materials, etc.

Monitoring and measurement are an essential part of checking in a ‘plan-do-check-act’ system, such as in energy management (see also the ENE BREF [109, COM 2009]). It is also a part of the effective control of processes.

Technical considerations relevant to applicability
The level of detail and nature of the energy balance record will generally be related to the nature, scale and complexity of the installation and energy types used. It may not be applicable if the STS activity is carried out within a larger installation, provided that the energy balance record of the larger installation sufficiently cover the STS activity.

Reference literature
[109, COM 2009]

17.5.3 Thermal insulation of tanks and vats containing cooled or heated liquids and of combustion and steam systems

Description
This may be achieved for example by:

- using double-skinned tanks;
- using pre-insulated tanks;
- applying insulation to combustion equipment, steam pipes and pipes containing cooled or heated liquids.

See the ENE BREF for more information [109, COM 2009].

Technical considerations relevant to applicability
Generally applicable.

17.5.4 Heat recovery by cogeneration – CHP (combined heat and power) or CCHP (combined cooling, heat and power)

Description
Recovery of heat (mainly from the steam system) for producing hot water/steam to be used in industrial processes/activities. CCHP is a cogeneration system with an absorption chiller that uses low-grade heat to produce chilled water. It is also called trigeneration.

See the ENE BREF for more information [109, COM 2009].

Technical considerations relevant to applicability
Applicability may be restricted by the plant layout, the characteristics of the hot gas streams (e.g. flow rate, temperature) or the lack of a suitable heat demand.

17.5.5 Heat recovery from hot gas streams

Description
Energy recovery from hot gas streams (e.g. from dryers or cooling zones), e.g. by their recirculation as process air, through the use of heat exchangers, in processes, or externally.

See the ENE BREF for more information on heat recovery in general, as well as from compressed air systems and drying processes [109, COM 2009].

Technical considerations relevant to applicability
Applicability may be restricted by the plant layout, the characteristics of the hot gas streams (e.g. flow rate, temperature) or the lack of a suitable heat demand.

17.5.6 Oxidiser heat saving during shutdown periods

Description
Oxidiser heat is kept inside chambers during production shutdown periods (e.g. weekends).

Example plant
Plant #121 in [155, TWG 2016].

17.5.7 Flow adjustment of process air and off-gases

Description
Adjustment of the flow of process air and off-gases according to the need. This includes reduction of air ventilation during idle operation or maintenance. See also Section 17.10.3.

Technical considerations relevant to applicability
Generally applicable.

17.5.8 Spray booth off-gas recirculation

Description
Capture and recirculation of the off-gas from the spray booth in combination with efficient paint overspray separation. Energy consumption is less than in the case of fresh air use.

Technical description
The off-gases from the spray booth, usually in combination with dry paint overspray separation, are captured and recirculated. In some cases, off-gas recirculation with air dehumidification was refitted in existing installations with wet paint overspray separation. See also Section 17.10.3.2.

Technical considerations relevant to applicability
Applicability may be restricted by health and safety considerations.

17.5.9 Optimised circulation of warm air in a large volume curing booth using an air turbulator

Description
Air is blown into a single part of the curing booth and distributed using an air turbulator which turns the laminar airflow into the desired turbulent flow.

Achieved environmental benefits
Reduction of energy consumption in curing.

Technical considerations relevant to applicability
Only applicable to spray coating sectors.

Example plant
Plant #078 in [155, TWG 2016].

Reference literature
[155, TWG 2016]

17.5.10 Proper dimensioning of the waste gas extraction system and of the abatement system

Description
The dimensioning of the extraction system and the selection of the abatement technique take into account:

- the emissions pattern (continuous/discontinuous);
- the energy content of off-gases and the effect of energy consumption below autothermal conditions;
- the costs and benefits of treating emissions with low VOC concentrations, in terms of energy consumption.

See also Section 17.10.1.

Technical considerations relevant to applicability
Generally applicable. It is considered a standard process in the design of the plant or in cases of major upgrades.

17.5.11 Optimisation of the waste gas extraction and abatement processes

See also Section 17.10.1.

This optimisation is based on:

- the amount of air to be extracted;
- the type and likely level of solvents;
- the type of treatment and its costs and benefits and cross-media effects (e.g. material, energy consumption);
- the number of hours per year in operation.

17.6 Raw material management (including substitution)

17.6.1 Use of raw materials with low environmental impact

Description

Systematic evaluation of the adverse environmental impacts of the materials used (in particular CMR substances and substances of very high concern) and substitution by others with no or lower environmental and health impacts where possible, taking into consideration the product quality requirements or specifications.

A very efficient technique is the substitution of high-volatility VOC substances with others containing organic compounds that are non-VOCs or VOCs of a lower volatility (e.g. esters). See also Section 17.7.2.

Technical description

Surface treatment using solvents uses a wide range of chemicals in a wide range of processes. The IED lists one of the criteria for determining BAT to be the use of less hazardous substances (Annex III (2)).

The use of less harmful substances (substitution) can be achieved in one of three ways:

1. Direct replacement of one substance by a less hazardous one. This is usually limited to simpler systems, for example replacement of low-flashpoint cleaners by high-flashpoint ones (see Section 17.9.5).
2. Replacement by different process chemistries or techniques using less hazardous substances. This is used where there is no direct replacement. Different coating process chemistries give treatments with different properties, even for the same materials. For examples, see
3.
4. Table 17.4. This is the principle route for replacing harmful substances in this sector, and is dealt with in the appropriate activity and industry chapters.
5. Eliminating the surface treatment process in the installation and using, for example, pre-coated materials in production (e.g. for producing white goods or construction panels). This type of substitution may be shown to be environmentally beneficial (e.g. in life cycle studies) and may be considered by an operator to achieve various objectives including reducing VOC emissions. However, the IED refers to the installation and the activities used. This type of substitution (in effect, cessation of the process within the installation) is therefore not a technique likely to be considered in determining BAT and is not discussed further in this document.

Table 17.4: Examples of solvent substitutes used in the STS sector

Low-solvent coatings	High-solids
	Two-component (chemically interacting)
	Water-based
	Powder slurry
Solvent-free coatings	Hot melts
	Powder coating
	Powder polyester coating
	Radiation-cured coating

Substitution not only applies to solvents used in cleaning substrates, equipment and facilities, but also to other components used in the processes, such as pigments, preservatives, binders, surface active agents, etc.

Some substances are covered by other European and/or national legislation or guidance, and the risk phrases/hazard statements supplied with manufacturers' data can be a useful start to identifying materials with significant health and environmental hazards. The following are possible hazard attributes for substances used in this sector.

A. Classification as SVHC (substances of very high concern)

A substance may be proposed as a SVHC if it meets one or more of the following criteria given in Article 57 of the REACH Regulation [47, EU 2006]:

- it is carcinogenic;
- it is mutagenic;
- it is toxic for reproduction;
- it is persistent, bioaccumulative and toxic according to the criteria set out in Annex XIII to the REACH Regulation (PBT substances);
- there is 'scientific evidence of probable serious effects to human health or the environment which give rise to an equivalent level of concern'; such substances are identified on a case-by-case basis.

Article 58 of the IED requires the replacement of CMR substances as far as possible by less harmful substances or mixtures within the shortest possible time, stating that: 'Substances or mixtures which, because of their content of volatile organic compounds classified as carcinogens, mutagens, or toxic to reproduction under Regulation (EC) No 1272/2008[45], are assigned or need to carry the hazard statements H340, H350, H350i, H360D or H360F, shall be replaced, as far as possible by less harmful substances or mixtures within the shortest possible time.'

B. Current situation for Cr(VI)

The traditional chromium(VI) (chromate) rinses used in conversion coatings in coil coating after the pretreatment and/or surface preparation before painting have generally been replaced with Cr(VI)-free alternatives. Under the REACH Regulation, the Cr(VI) compounds used in these rinses are listed as Annex XIV substances and require specific authorisation for each use following their sunset date of 21 September 2017.

At the time of drafting this document, applications for authorisations have been registered, but only one has been approved. Considerations in this document have been based on the likelihood of continued use in the aerospace industries and possibly for certain coil-coated products.
Paint pigments have contained toxic metals such as cadmium, hexavalent chromium, nickel and lead for the colour of their compounds and for corrosion resistance. However, their use is now strictly limited by regulations to activities which are not within the scope of this document, see Section 1.2.3. There was a REACH sunset date of 22 January 2019 for various Cr(VI) substances potentially used in paint pigments, some having slight solubility in water. In October 2017, there were applications from about 10 manufacturers for CAS number 7789-06-2 (strontium chromate) for use in aerospace coatings and one for CAS 11103-86-9 for unspecified use in primers, sealers and coatings.

C. Other factors

In addition, other factors may be considered which are related to specific effects of the solvents used:

- **Physico-chemical effects**: the following risk phrases are not regarded as measures of environmental impact (except where subject to [53, COM 2003]): explosive, oxidising, extremely flammable, highly flammable and flammable.
- **Photochemical oxidant formation (ozone formation potential, OFP).**

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[45] Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006.

- **Stratospheric ozone depletion potential (ODP).**
- **Global warming potential (GWP)**: the GWP of a substance is a measure of the extra amount of heat that is trapped in the atmosphere when 1 kg of the substance is released instantaneously into it, relative to the case when 1 kg carbon dioxide is released.
- **Odour:** many VOCs have an odour. In certain circumstances, emissions of VOCs can give rise to localised odour nuisance problems (see Section 17.13).

Achieved environmental benefits

Reduction in the use of harmful substances, e.g. solvents, and the amounts of hazardous VOC substances subsequently emitted to the environment, either planned (e.g. in waste gases) or unplanned (e.g. fugitive emissions, leaks, accidents in handling).

There may be other improvements in environmental performance, such as the saving of energy in the process or in off-gas treatment, the use of less raw material in the process or waste water treatment, less water usage, the generation of less waste classified as hazardous, etc.

Environmental performance and operational data

Safety data sheets may be used as an important input for assessing the environmental impact of materials used and could provide useful input which could inform any substitution decision.

Cross-media effects

These effects depend on the individual alternative techniques. Some may have effects such as increased energy usage, increased waste generation or increased water or raw material consumption. Some alternative materials may increase health and safety risks, may have a higher photochemical reactivity or increase other environmental risks. One simple approach for assessing if the health risks are increased is to use the Vapour Hazard Ratio (see Technical considerations relevant to applicability, below). Further information can be found in the ECM REF [50, COM 2006].

Technical considerations relevant to applicability

Generally applicable.

The scope (e.g. level of detail) and nature of the evaluation will generally be related to the nature, scale and complexity of the plant and the range of environmental impacts it may have, as well as to the type and quantity of materials used.
Substitution decisions have to be made on a case-by-case basis, and the substitution must adequately achieve the final performance characteristics required (i.e. have suitable functionality). In all cases, it is essential to discuss the changes with the customer in advance of making the substitution. It is good practice not to make changes without full knowledge of the final performance characteristics required. Because of the risk of failure to meet these characteristics, it is advisable for both operator and customer to monitor quality and performance to, and exchange information on, the required specifications.

In some processes using single substances, substitution may not be possible, e.g. it is not currently possible to replace toluene in publication rotogravure printing.

Given the wide range of chemicals used in this sector, it is doubtful that all chemicals with the potential to cause harm to the environment can be suitably replaced. Some processes may depend on harmful substances where there is no suitable substitute or the cross-media effects (see above) outweigh the benefits.

To assist with comparing possible alternative substances, ratios may be derived. For example, for physiological effects, the Vapour Hazard Ratio (VHR) compares the tendency of a product to evaporate with its OEL (Occupational Exposure Limit) as shown below:

$$\text{VHR} = \frac{\text{Equilibrium vapour concentration (at 20 °C)}}{\text{OEL}}$$

As a consequence:

- for products with a similar OEL, choose the product with the lowest volatility;
- for products with a similar volatility, choose the product with a higher OEL.

Where the data are less easy to interpret, the calculation of the VHR may have to be made.

Other factors, such as toxicity and ecotoxicity can be judged on a simple basis, such as using a substance with a lower hazard statement. Alternatively, other metrics (such as ozone-forming reactivity) can be used. In some cases, such as with OFP, a ratio analogous to VHR could be developed.

Economics

Substitutes may be more cost-effective but this needs to be determined on a case-by-case basis. They may enable the installation to meet more than one set of legislative requirements (see Driving force for implementation, below). Savings may be found in, for example:

- decreased energy, water and raw material usage;
- decreased waste gas and waste water treatment;
- increased health and safety compliance in the workplace;
- improved quality and reliability of the process.

Driving force for implementation

Health and safety of employees is a major driver for using less harmful substances. (Note: care should be taken with replacement for occupational health reasons to ensure that the substitutes are in fact less harmful according to all the evidence available).

Customer (health) quality demands are another driving force.

Other environmental legislative drivers include the REACH Regulation and the Seveso III Directive[46].

Reducing regulation is another driver: In some cases, the solvent reduction achieved can result in the lowering of the solvent use below the threshold levels considered for the IED or other regulations.

Example plants

See Sections 2.4.3, 3.4.2, 4.4.4, 6.4.2, 10.4.1, 3.4.2 and 14.4.2.

Reference literature

[23, COM 2006] [38, TWG 2004] [42, Envirowise 2003] [50, COM 2006]
[52, COM 2000] [73, COM 2012] [78, TWG 2005] [116, ESIG 2005]

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[46] Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC, OJ L 197.

17.6.1.1 Replacement of halogenated solvents

Description
Halogenated solvents can be replaced by less hazardous solvents, e.g. where powerful solvent action is required for cleaning. Powerful solvents such as ethanolamine can be used. Where paints are based on halogenated solvents, alternative paint systems can be used (see Section 17.7).

Achieved environmental benefits
Reduced risk of emissions during handling and to air and reduced hazardous waste generation.

Environmental performance and operational data
Chlorinated hydrocarbons are sometimes used for degreasing surfaces in the production of friction lining, and as the solvent for some coatings for agricultural and construction vehicle coating.

In flexible packaging, halogenated solvents such as methylene chloride were used to remove persistent contamination. However, they have been replaced by non-volatile solvents such as ethanolamine.

Cross-media effects
None identified.

Technical considerations relevant to applicability
Applicability depends on the specific technique and its use. Substitution has been applied successfully in the printing industry (through legislation and EU-wide industry agreements), in friction lining manufacturing, and is commonly applied in all industry sectors. Paint systems are available that can replace paints using halogenated solvents.

Driving force for implementation
Health and safety in the workplace. The IED sets an emission limit value of 20 mg/Nm^3 where the mass flow of halogenated VOCs with the hazard statements H341 or H351 is equal to, or greater than, 100 g/h.

In Germany, the use of halogenated solvents is considered obsolete.

Example plants
Halogenated solvents have been replaced on a wide scale (e.g. in Germany).

Reference literature
[1, INTERGRAF and EGF 1999] [4, Germany 2002] [38, TWG 2004] [78, TWG 2005]

17.6.2 Optimisation of the use of organic solvents in the process

Description
Optimisation of the use of solvents in the process by a management plan (as part of the EMS (see BAT 1)) that aims to identify and implement necessary actions (e.g. colour batching, optimising spray pulverisation).

Technical description
This technique involves setting up and implementing a management plan to optimise the use of organic solvent in the process. The management plan aims to identify and implement actions to optimise the use of solvents. There are various techniques that could be considered, e.g. colour batching, optimising spray pulverisation. The management plan for the optimisation of the use of organic solvents is an important part of the environmental management system (EMS) and the decisions on the techniques to be applied are based on the interaction with other EMS

constituents. The solvent mass balance (SMB) provides the relevant quantitative data.

Achieved environmental benefits
Reduced VOC emissions to air.

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally applicable.

Example plants
Widely used, see examples in vehicle coating (see Section 17.6.2.1).

Reference literature
[155, TWG 2016]

17.6.2.1 Colour grouping (batch painting)

Description
Modification of the sequence of products to achieve large sequences with the same colour.

Technical description
Colour grouping, also called batch painting or block-to-block painting, means that a series of a specific products is painted in the same colour. This will result in less frequent changes to a different colour.

In vehicle coating, in order to reduce rinsing operations between two different colours of car painting in solvent-based paint shops, the production is reorganised to achieve large sequences with the same colour. At the end of the primer stage, after the oven, the conveyors used to empty the oven at the end of production are also used to store and reschedule car bodies in order to create a small convoy of car bodies with the same colour.

Achieved environmental benefits
Benefits include the reduction of rinsing solvent use by reducing the number of rinsing operations between different colours. The benefit is directly linked to the length of pipe between the colour tank and the painting tool. Less paint residues are generated.

Environmental performance and operational data
Sufficient storage space has to be available for the products as well as an appropriate logistical planning system. It also depends on the number of different colours and their relative abundance in the production programme. For the automotive industry, the average colour group length is between two and six units.

Cross-media effects
None identified.

Technical considerations relevant to applicability
This technique is commonly applied in the coating of cars, trucks and commercial vehicles and in the coating of metal packaging. Limitations in its applicability may occur due to manufacturing planning, customer requirements, and logistics requirements [ACEA comment #201 in [212, TWG 2018]].

An analogous technique is applied in the manufacturing of adhesive tapes focusing on decreasing the number of different products during the production period (therefore longer campaigns) and thus avoiding the need for interim cleaning (see also Section 7.3.2.2).

Economics

Savings in paint, solvents and cleaning/downtime may be offset by the higher storage capacity costs.

Example plants

Commonly used in most automotive plants.

Reference literature

[5, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005] [212, TWG 2018]

17.7 Coating processes and equipment

17.7.1 Pretreatments prior to painting (other than cleaning)

Water-based pretreatments are applied for three reasons: to remove grease and dirt from previous operations, to improve corrosion resistance and to improve adhesion of the subsequent paint layers. The usual pretreatments applied are degreasing, phosphating and chromating. These techniques are described in the STM BREF [23, COM 2006], together with associated BAT for material conservation and maintenance, and are therefore not discussed in full here.

17.7.1.1 Phosphating

Description
Phosphate conversion coatings are used to enhance corrosion resistance and the adhesion of subsequent paint coatings to steel substrates. They typically contain iron, zinc, nickel and manganese. They can be applied by spraying, but are currently usually applied by dipping to give a more complete and consistent coating. More information can be found in the STM BREF [23, COM 2006].

17.7.1.2 Chromium(VI)-free conversion coatings

Current situation on Cr(VI) use
The traditional chromium(VI) (chromate) rinses used in conversion coatings in coil coating after the pretreatment and/or surface preparation before painting have generally been replaced with Cr(VI)-free alternatives. Under the REACH Regulation [47, EU 2006], the Cr(VI) compounds used in these rinses are listed as Annex XIV substances and require specific authorisation for each use following their sunset date of 21 September 2017.

At the time of drafting this document, applications for authorisations have been registered, but only a limited number have been approved. Considerations in this document have been based on the likelihood of continued use in the aerospace industries and possibly for certain coil-coated products. See also Section 6.4.2.1 for additional information on alternatives.

Description
Some chrome-free conversion coating systems are available, based on treatments with organic composites zirconium fluoride solutions, titanium fluoride, tartrate, phosphoric acid, or treatment with organic silicon derivatives (silanes). They may require a subsequent polymer layer to achieve the required corrosion resistance.

In the vehicle manufacturing industries, e-coat immersion primer coating is applied directly over the phosphate layer without chromating to achieve high-quality corrosion protection.
The chrome-free pretreatment with titanium, phosphoric acid and organic polymer has been further developed with a chemical provider for the usual spray and dip processes. Since 1998, a company has used the method successfully in coil coating machines.

Chromium-free conversion coatings are now in use for anodising in the aircraft industry, based on tartrate and phosphoric acid.

17.7.2 Material-based techniques

In the following sections, the main identified material-based techniques which are common for more than one STS sector are discussed. It is noted that, generally, the selection of the surface treatment techniques may be restricted by the activity type, the substrate type and shape, and product quality requirements, as well as the need to ensure that the materials used, coating application techniques, drying/curing techniques and off-gas treatment systems are mutually compatible.

17.7.2.1 High-solids solvent-based paints / coatings / varnishes / inks / adhesives

Description
Use of paints, coatings, liquid inks, varnishes and adhesives containing a low amount of organic solvents and an increased solids content.

Technical description
The solids content amounts to more than 65 vol-%: for example in yacht coating 450 g/l epoxies are used for under waterline areas; solids contents of 70-95 % are applied in coil coating processes. The film formers used are mainly based on epoxy, two-component (2-K) polyurethane, polysiloxane, oxirane or alkyd resin.

Achieved environmental benefits
Reduction of solvent consumption and of VOC emissions.

Environmental performance and operational data
The use of higher-solids paints reduces solvent use compared with conventional, solvent-based paints, while still applying the requisite amount of coating. Reductions in extracted VOCs place a lower demand on the abatement equipment. Reduced solvent loadings within the ovens may allow reductions in extracted airflows or increased line speeds for a certain concentration in the air. This reduces the gas consumption in the oxidiser, reduces the use of solvents and lowers the volumes to transport.

Cross-media effects
The reduction of solvent vapours in the waste stream may increase the demand for gas/fossil fuel in the oxidiser, and/or reduce the energy recovered for preheating the oven air.

Technical considerations relevant to applicability
Generally, the selection of the surface treatment techniques may be restricted by the activity type, the substrate type and shape, and product quality requirements, as well as the need to ensure that the materials used, coating application techniques, and drying/curing techniques and off-gas treatment systems are mutually compatible.

For the painting of agricultural and construction machines or household devices, high-solids paints based on acrylate and polyester isocyanate are mostly used.

Some pigments do not work well in high-solids paints and result in quality issues.

In the coating of ships and yachts, high-solids epoxy coatings are commonly applied onto the underwater parts of ships and yachts.

In the coating of aircraft, high-solids coatings are sometimes applied in the topcoat.

In the coating of trains, high-solids paint is only applied in the one-coat topcoat.

In the coating of buses, high-solids paints are applied in the one-coat topcoat system.

In coil coating, high-solids coatings are commonly applied.

In manufacturing of winding wires, high-solids enamel coatings are commonly applied.

In flexography and non-publication rotogravure printing, high-solids varnishes and adhesives are applied.

Economics

High-solids paints are more expensive than conventional paints, but as they have greater coverage the cost per m^2 is usually lower. Savings can be expected on labour costs.

Driving force for implementation

- Potential cost reduction for some coating activities (e.g. coil coating, see Section 6.4.2.3).
- Health and safety requirements for VOC levels in paint/coating/ink/adhesive handling areas.

Example plants

Widely used in various sectors.

Reference literature

[5, DFIU et al. 2002] [11, InfoMil 2003] [38, TWG 2004] [78, TWG 2005]
[155, TWG 2016] [212, TWG 2018]

17.7.2.2 Water-based paints / coatings / inks / varnishes and adhesives

Description

Use of paints, coatings, liquid inks, varnishes and adhesives where organic solvent is partially replaced by water.

Technical description

Paints

Water-based paints contain water-based or water-dispersible film-forming agents. Water-based paint systems can be one-component paints; however, two-component and UV radiation-cured paints are mainly applied. They are mainly based on alkyd, polyester, acrylate, melamine and epoxy resin. Water-based powder coatings are discussed in Section 17.7.2.6

Water-based paint systems normally have a water content of 10-65 wt-% and often also contain < 3-18 % organic solvents as a solubiliser and for an improvement of the properties of the wet film layer. Completely organic solvent-free paints are also available. Biocides may be part of the formulation as preservatives for the storage of the paints, in architectural applications and for electrocoating (which is kept and used in tanks).

The main improvements of these materials are their corrosion protection and exterior resistance against climatic impacts.

Two-component water-based paints show an improved resistance, especially mechanically, and also a very good isolating function even on woods rich in natural oils.

Adhesives

Water-based adhesives do not contain organic solvents or contain up to 0.5 % solvent as softener (see also Section 7.4.1.2).

Achieved environmental benefits

Reduced VOC emissions.

Environmental performance and operational data

Paints

The main advantages of water-based paints are the reduction of VOC emissions and the possibility to recycle the paint in certain applications, e.g. using ultrafiltration. Cleaning of spraying devices and other tools can be carried out with water/solvent mixtures with a solvent proportion of about 5 % to 20 %.

In addition, there are no flashpoint hazards associated with the use of this paint, minimising the risks of ignition and explosion.

Water-based paints can cause significant corrosion problems in storage, pumping and application equipment, especially spraying systems, due to the presence of water and oxygen. A substitution with water-based paint for conventional installations usually requires significant modification of the facility, such as replacement of the paint supply lines by materials made of high-grade stainless steel.

There may also be problems with corrosion in the ovens and exhaust ducting.

Increased blocking of spray equipment is reported in the coating of wooden surfaces. It is not known if this is a process problem or can be solved by training and adaptation.

If water-based paints are processed, the following requirements generally have to be met:

- the ambient temperature has to be between 18 °C and 28 °C;
- the surface temperature of the workpieces may not be lower than 15 °C;
- an optimum processing is given at air humidity between 55 °C and 75 °C;
- water-based paints may not be stored below 0 °C (frost damage);
- good airflow across the surface.

Since water-based paints have lower application efficiencies, paint consumption may be increased. However, in practice, reduced transfer efficiency is valid for high-rotation electrostatic bell application if external charging is used (5 % less as the maximum). Reduced transfer efficiency may occur in electrostatically assisted manual application where voltage is limited for safety reasons. Alternative techniques (internal charging) are available and widely used. As water-based coatings are mostly used in new or redesigned installations, efficiency is usually improved due to better performance of equipment and possibly higher ‘right first time’ rates. Evidence from automotive applications shows comparable transfer efficiencies with solvent-based systems.

Compared to organic solvents, water requires higher evaporation energy. Therefore, the energy demand for the drying of water-based paints may be expected to be higher if the same drying rate as for solvent-based paints has to be achieved. However, compared to atomisation, acclimatisation of spray booths, heating of substrates, oven losses, etc., the energy demand for evaporation of volatile compounds is only around 1 % for many industrial processes. Water, instead of organic solvents, has a minor impact on total process energy. The additional energy requirement is only significant for drying at ambient conditions and in the case of wet-on-wet processes.

Water-based systems usually use amines for pH stabilisation. One company encountered major problems concerning employee protection with these amines.

Water-based systems can present difficulties in cleaning operations on the coater equipment, demanding more powerful cleaning agents than those used in the case of solvent-based coatings.

Adhesives
Water-based adhesives eliminate related solvent emissions.

Cross-media effects
Paints and inks
Coil coating: Due to the solvent content of about 10-35 %, and the high yearly load, an off-gas treatment is needed. Thermal off-gas treatment may require additional natural gas to achieve the desired emission levels.

There may be an increased BOD and COD load in the waste water, and more substances such as biocides, organotin catalysts and ammonia which have to be treated accordingly.

Solvent and water-based wastes must be separated for onward recycling or disposal. Water-based chemicals are harder to remove from waste water [ACEA comment #312 in [212, TWG 2018]].

The nature of the wastes will differ from those generated by solvent-based processes. Although these will not necessarily be substantially better or worse, or lesser or greater in quantity than for solvent-based processes, the sludge is likely to contain more oil or hydrocarbon-based residues than solvent-based residues [ACEA comment #313 in [212, TWG 2018]].

Adhesives
More energy is required for drying.

Technical considerations relevant to applicability
Paints
Water-based paints have been available on the market for many years and are widely used. Due to the permanent development of these materials, their range of application is steadily increasing.

They are commonly applied in the vehicle coating industry although they are not used for clear coat applications. In the coating of trucks and commercial vehicles, they are commonly applied in cataphoric dip coating, primer/filler and in base coats on commercial vehicles, truck cabs and chassis and on axles. In the coating of buses, water-based paints are used in some cases (cataphoric dip coating and underbody protection). However, a major potential restriction in the use of water-based paint technologies is the necessary plant size. A vehicle coating line increases by approximately 30 % for the installation of water-based paints and some sites cannot physically incorporate this requirement.

In the coating of plastic workpieces, water-based coating systems are commonly applied for the ground coat, base coat and sometimes for the clear coat.

In the coating of trains, two-component chromate-free water-based paints based on epoxy are applied for the ground coat, primer/filler and sometimes for the topcoats. Water-based paints are also applied for protection of the underbody.

In the coating of agricultural and construction equipment, they are commonly applied in cataphoric dip coating and also in one-coat topcoats.

In the coating of ships and yachts, although water-based paints are available for several applications, they are used only in a limited number. Water-based applications use an airless spray or roller, and not a high-rotation electrostatic bell.

In coil coating, if water-based coatings are used, the application is mostly limited to primers and backing coats (see also Section 6.4.2.4).

In the coating of metal packaging, water-based paints are used; however, they contain up to 38 % organic solvents. External drum coating uses water-based coatings with < 10 % organic solvents.

In the coating of wooden surfaces, two-component and UV-cured water-based paints are commonly applied on some flat furniture parts before assembly. However, there are technical limitations, such as fibre swelling, depending on substrate. When switching to water-based products the total volume of products to be dried increases, since more painting and drying steps are needed, with additional intermediate sanding and polishing. Both sanding and additional drying result in increased energy and raw material use as well as increased labour. As an alternative, other types of drying systems could be introduced. This may need new development work and would increase costs. The finishing of assembled furniture is not possible with UV-cured paints.

In the manufacturing of adhesive tapes, water-based adhesives are applicable in new and existing plants. They are suitable for the production of the lower-quality range of packaging and masking tapes as well as for double-sided tapes.

Economics

Water-based coating systems do not cause major cost increases in use. Replacement of equipment with stainless steel alternatives to counter corrosion is typically more expensive.
Costs for changing existing automated painting lines may be very high in some cases. Retrofitting is usually done at the end of the technical lifespan of the existing installation. Where painting is applied manually, costs for retrofit are less but still significant, and will depend on the ratio of manual to automatic equipment.

Sites can also make potential savings in specialist equipment requirements associated with solvent use.

Driving force for implementation

VOC emission reductions, although it is noted that the technology may have additional energy requirements resulting in additional CO_2 emissions.

Example plants

Widely used.

Reference literature

[2, IFARE et al. 2002] [5, DFIU et al. 2002] [6, DFIU et al. 2002] [11, InfoMil 2003] [38, TWG 2004] [78, TWG 2005] [116, ESIG 2005] [27, VITO 2003] [96, Presti 2005] [212, TWG 2018]

17.7.2.3 Radiation-cured inks / coatings / paints / varnishes and adhesives

Description

Use of liquid inks, coatings, paints, varnishes and adhesives suitable to be cured by the activation of specific chemical groups by UV or IR radiation, or fast electrons, without heat and without emission of VOCs.

Technical description

Radiation-curing coatings rely, for their cure, on the activation of particular chemical groups by UV or IR radiation (see Section 17.8.5.1), or fast electrons (see Section 17.8.5). This property can be found in both resins and liquid diluents, thus it is possible to produce liquid coating systems that cure and harden without heat and without any emission of VOCs. Alternatively, similar chemical functionality can be incorporated into water-based or even solid (powder) coatings. The base resins include epoxy, polyester, polyurethane but all with acrylic or vinyl functionality. The curing reaction is initiated directly by electron beam (EB) radiation or by ultraviolet (UV) radiation via an added photoinitiator.

Composition of radiation curable coatings
[216, Kopeliovich D. 2018]
Radiation-cured coating consists of the following components:

- Oligomers (prepolymers) - reactive substances of relatively low molecular weight (intermediate between monomer and polymer), which are capable of further polymerisation. Cured (polymerised) oligomers determine the major properties of the radiation-curable coating (adhesion to the substrate, strength, flexibility, corrosion protection). The function of oligomers is similar to that of binders in solvent-based paints and water-based paints. The following oligomers are used in radiation curable coatings:
  - epoxy acrylate (the most popular oligomer);
  - urethane acrylate;
  - polyester acrylate;
  - polyether acrylate;
  - acrylic acrylate;
  - silicone acrylate.
- Monomers – low-molecular-weight substances reducing the viscosity of the radiation-curable coatings. Monomers act similarly to solvents in solvent-based paints. If lowering viscosity is the only function of a monomer, it is called a monofunctional monomer (e.g. isobornyl acrylate). Multifunctional (di-, tri-, tetra-, etc.) monomers also have other functions, for example they are involved in the formation of polymer network participating in cross-linking of oligomers during radiation curing.
- Photoinitiators absorb light (UV or visible) and initiate cross-linking reactions. The mechanism of the initiation is triggered by production of either free radicals (in free-radicals-polymerised systems) or cations (in cationic photoinitiated systems). Photoinitiators are added in concentrations of 1-20 %.
- Additives are used to modify and improve various functions of radiation-curable coatings: pigments, fillers for viscosity control, wetting agents, defoamers and other additives for paints.

For more information on:

- UV (ultraviolet) radiation curing: see Section 17.8.5.4;
- UV-curing adhesives: see Section 7.4.1.3;
- infrared radiation curing: see Section 17.8.5.1;
- EB (electron beam) radiation curing: see Section 17.8.5.5.

Achieved environmental benefits

- Neither water-based nor solvent-free radiation curing paints generate waste water or VOC emissions.
- Low energy consumption
- Low fire hazard.
- High production rate.

Environmental performance and operational data

UV-cured paints can be applied by several techniques, such as brushing, rolling, casting, spraying and vacuum coating.

Technical considerations relevant to applicability
Widely applicable in wood and plastic substrates but less use of radiation-cured coatings on metals.

In the coating of metal packaging, UV-cured coatings are widely applied in three-piece can manufacturing to a wide range of products: aerosols, food cans, general line containers, closures and caps. UV varnishes are also used for aerosols, food cans and some general line, mainly for the outside of the cans as there are restrictions concerning food contact. However, it is not applied in DWI can and aluminium tube manufacture.

In the coating of plastic workpieces, UV-cured coatings are applied in clear coats, e.g. on wheel covers.

In furniture and wood painting, UV-cured water-based coatings are commonly applied in some furniture and wood coatings. This is usually where flat panels can be coated separately and the coating is carried out prior to assembling the furniture.

UV-cured coatings are currently not applied in the automotive industry (with the exception of automotive plastic parts), in the coating of aircraft, ships, trains, agricultural and construction equipment, or in coil coating (see also Section 19.4.1).

Economics
Costs will depend on the specifications, quantities and supplier. As an example, costs for UV water-based paints (about 50 % solids) are about EUR 6.50 per kg, which is more than conventional paints (e.g. two-component PU paint costs EUR 4.35 per kg) (2006 data). However, with pure UV-cured paints (which are 100 % solids), the overall costs per m^2 will be lower because with the high solids content a higher efficiency will be achieved and at least 50 % of the overspray can be reused.

The approximate price per kg for UV-cured powder coating is in the range of EUR 3.01-5.38 (2006 data).

Investment costs for a new UV-curing powder coating unit are about EUR 875 000 – comprising about EUR 275 000 for the application booth and drying installation and EUR 600 000 for automation, material buffers, conveying system, etc. (2006 data). Operational costs are more or less the same as a conventional existing solvent-based application unit.

Example plants
Coating of plastic surfaces: Plant 128.
Metal packaging: Plants #112, #121, #122, #123, #116, #118, #119, #114, #111, #120 (only used UV-cured inks in printing), #117 and #124 [155, TWG 2016].

Reference literature
[5, DFIU et al. 2002] [27, VITO 2003] [38, TWG 2004] [105, CEPE 2006] [155, TWG 2016] [216, Kopeliovich D. 2018]

17.7.2.4 Solvent-free two-component adhesives

Description
Solvent-free two-component adhesive materials including a first component which acts as a resin and a second component which acts as a hardener. See also Section 12.4.2.7.

17.7.2.5 Hot-melt adhesives

See Section 7.4.1.1.

17.7.2.6 Powder coatings

Description
Use of solvent-free coating which is applied as a finely divided powder and cured in thermal ovens.

Technical description
Powder coatings are solvent-free materials that consist of powder with a particle size in the range of 25-60 µm. Section 17.7.2.3 discusses the development of radiation-curing of powder coatings but the majority of the powder coatings are cured in conventional high-temperature ovens.

The main film-forming agents are polyester or epoxy resins. The powder particles are normally applied by electrostatic charging in spray guns or a cloud chamber and are then attracted to the earthed substrate.

To cure, the material is heated in a convection oven where it melts and fuses into a film.

However, there are also the following disadvantages:

- The control of the film thickness is difficult (see Environmental performance and operational data, below). For example, in the automotive industry, a higher layer thickness (approximately 65 µm) will be created than is necessary, which results in higher paint consumption; however, increasingly nowadays, thinner layers (approximately 55-60 µm) are also achievable.
- Higher curing temperatures (approximately 140-200 °C) are necessary and because of this the technique cannot be applied to all substrates. However, low-temperature powder coatings are becoming more readily available which are cured at temperatures of around 60-100 °C.
- Application conditions are strictly defined (temperature, humidity).
- Manual application is only possible if certain safety regulations (against dust, electrostatic voltages) are followed.

Achieved environmental benefits
Emissions of VOCs are eliminated or significantly reduced.

Environmental performance and operational data
Film thickness in powder coatings is not a simple subject. The possible applied film thickness range is limited by the particle size distribution of the powder as well as by the application speed and cure conditions. Thus, it is technically possible to apply as thin a coat as 5 microns, but the powder needs to be very finely ground and precisely controlled. This may increase the relevant cost. In addition, these very fine powders have poor flow and transport properties so they are difficult to apply. Powder coatings capable of application at 30 microns are certainly available for some end uses. At the other extreme, very thick coatings can be applied by powder sintering, but here the limitation is the time needed for the transferred heat to melt, flow and fuse the powder. If the formulation is thermoset (heat hardening), the surface may be cured before full melting and fusion has occurred, trapping air bubbles within the film. Unless demanded by a particular end use, film thicknesses of over 90 microns are unusual simply on the basis of economics.

Environmental performance and operational information
Powder coating systems show the following positive properties:

- almost free of solvent emissions;

- there is a potential for reduced gas consumption, as exhaust oxidation may no longer be needed;
- no water is necessary in order to absorb lacquer particles in the paint booth;
- no waste water is produced, so no treatment and use of additives (such as coagulation agents) is necessary;
- low waste generation if the possibility of paint recycling is used;
- paint recycling is technically possible (up to 95 %) and necessary for economic reasons;
- high application efficiency, up to 100 %;
- application tools and the complete booths can all be cleaned by vacuum cleaning or by blowing with compressed air; in this way, resources are saved and solvent emissions are avoided;
- the high proportion of circulating air in the paint booth results in a reduction of energy consumption.

There are possible occupational health risks due, for example, to mutagenic substances such as triglycidyl isocyanurate (TGIC) being used.

There may be potential electrostatic hazards.

Cross-media effects

Film thickness limitations may increase the quantities of coating materials used. The development of reaction products may emit odour in the curing oven during the fusion and reaction of the powder which may require the continuous use of an abatement technique anyway.

High curing temperatures are required. However, curing by combinations of infrared and air circulation techniques has a higher energy efficiency compared to conventional curing techniques.

Some low levels of VOCs may be emitted during curing – due to the reaction chemistry.

Technical considerations relevant to applicability

In several sectors, the application of powder coatings is already a well-established technique. Regarding environmental advantages, there are possibilities for automation and good profitability due to the possibility of recycling the overspray, and the use of powder coatings is continuously increasing. Powder coatings require electrostatic application techniques and are, therefore, primarily suitable for metal.

In the automotive industry, powder coatings are not used in Europe for coating of cars and vans and only used by some manufacturers for CV-cabs and chassis painting (see also Section 2.4.3.2). Currently, due to the operational problems associated with process change (such as maintaining the correct colours and finish), a powder coat system does not meet most European manufacturers' quality specifications.

They are currently not applied in the coating of aircraft, ships or trains. They are applied in the coating of vehicle components (as described in Chapter 3 on coating of plastic and other metal surfaces). In the coating of plastic surfaces, it is currently only applied in small batches in the coating of small parts, such as composite parts of metal and plastics for car radiators. The reason that the techniques is not applied for the coating of aircraft and ships is that a forced drying step is needed, and in these industries it could therefore only be applied to components small enough to be enclosed.

This technique is ready for the serial production of agricultural and construction equipment.

In coil coating, powder coating is only used to a limited extent, because of difficulties of speed and control. It is especially used for construction sector products, e.g. for flat panels, window frames, sanitary cabins and by the sheet metal processing industry.

In the coating of metal packaging, powder coating may be applied onto the welding of three-piece cans. However, it cannot be applied on the coating of DWI cans.

In furniture and wood painting, it is currently only successfully applied onto MDF.

Economics

Costs will depend on the specifications, quantities and supplier. Currently, the price for powder coating systems is still higher than for conventional coating systems. The price per kg was in the range of EUR 3.01-5.38 (data for 2006).

Capital equipment and operating costs for a powder line are less than for conventional liquid lines[47].

Retrofitting a conventional solvent-based application unit with a powder coating unit only requires replacement of the paint application systems; the ovens may not need to be changed. However, in the automotive industries, powder coatings require completely new spray booths, supply systems and curing ovens.

Driving force for implementation

Elimination of solvents.

Example plants

In the coating sector, there are a few full-width powder coating installations in Europe for aluminium and steel coils.

Reference literature

[5, DFIU et al. 2002] [27, VITO 2003] [38, TWG 2004] [78, TWG 2005] [105, CEPE 2006] [116, ESIG 2005] [42, Envirowise 2003] [43, Envirowise 1998] [212, TWG 2018]

17.7.2.7 Pre-coated materials

Description

Use of materials that are coated before cutting and/or shaping and/or assembling. Although this is a commonly used technique, it is not related to the environmental performance of the plant as it mainly refers to ‘outsourcing’ of emissions.

Technical description

Pre-coated materials can be used in the assembly of products, reducing the number of paint coatings or eliminating the need to paint. In the case of coating substrates of uniform dimensions, such as coil-coated metals, wood or fibreboards, etc., coatings can be applied using techniques which are more difficult to apply to the assembled products or product parts, but which are more environmentally beneficial (see Section 17.7.3).

Achieved environmental benefits

- Significant reduction of VOC emissions when the spraying activities that are replaced by applying coil-coated materials.
- More efficient use of materials.

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[47] Evolution of the Automotive Body Coating Process—A Review, Coatings 2016, 6, 24.

- More efficient drying or curing.
- More efficient collection and destruction of emissions during coil coating, as the application of the coatings and extraction of off-gases for a continuous flat surface is easier and more efficient than for coating formed components and bodies.

Environmental performance and operational data
Pre-coated materials are produced by coil coating, see Chapter 6.

Cross-media effects
The emissions are transferred to the coil coating installation; however, they are reduced (see Achieved environmental benefits above).

Technical considerations relevant to applicability
Coil-coated metal is usually supplied complete with finish coat, but can also be supplied in primer-ready for subsequent coat(s). It is used for a growing number of applications including: building and construction products, electrical appliances (white goods), the automotive industry, caravans and mobile homes, metal cabinets, etc.

In the coating of trains, coil-coated materials are increasingly used for the production of freight wagons.

In agricultural and construction equipment, some manufacturers apply electrocoating and topcoating before assembly takes place; coil-coated materials might be an option here.

In the coating of metal packaging, coil-coated materials are commonly used in three-piece can manufacturing.

Economics
Reduction in production steps and concentration on core business.

Driving force for implementation
Reduction in emissions to the workplace and environment.

Example plants
Widely used in metal packaging and coil coating.

Reference literature
[5, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005]

17.7.2.8 Use of laminate film for web or coil coatings

Description
Use of polymer films applied onto a coil or web in order to give aesthetic or functional properties, which reduces the number of coating layers needed.

For detailed information for its application to coil coating, see Section 6.4.2.6. It is also applied in the coating of plastic and other metal surfaces, coating and printing of metal packaging, flexography and non-publication rotogravure printing, coating of aircraft, wooden surfaces, textiles, foils and paper as well as in adhesive tape manufacturing.

17.7.3 Paint application processes and equipment

Processes with a high application efficiency include filling, rolling, casting, dipping, flooding and vacuum coating. These processes generate less overspray than spray applications but are not universally applicable. There are two dipping processes: conventional and electrocoating.

Spraying may be with or without electrostatic assistance. For electrostatically assisted spraying, an electric field is generated between the workpiece and the spray gun. Then the following advantages concerning the environment as well as coat effectiveness are reached:

- lower material consumption, lower emissions, smaller amounts of paint sludge and a reduced soiling of painting areas (less cleaning);
- improved possibilities for automation of painting processes, faster coating and, therefore, higher productivity;
- less air consumption (less energy demand).

Disadvantages of electrostatically assisted spray applications are the risk of edge runners and layer thicknesses which are too deep into cavities and interior edges due to a concentration of paint materials onto these areas. Several electrostatically assisted spray applications are in use, and they are described in the following sections. Also, there may be special requirements concerning the quality achieved, geometry, paint materials, electrical conductivity (e.g. affecting the ability to recoat surfaces) and workplace safety relating to the high voltages used.

Despite the increasing use of electrostatic application techniques, spraying without electrostatic charge is still widely used for various applications and traditional manual spray systems can be more appropriate in some circumstances, for example for lower-volume manufacturers. In comparison to electrostatic processes, the investments are significantly smaller. Also, there are no special requirements concerning geometry, paint materials, electrical conductivity and workplace safety. The disadvantages of these application techniques are low efficiencies. Thus, several techniques were developed for a minimisation of the overspray and their efficiency is comparable to electrostatic processes [78, TWG 2005] [212, TWG 2018].

It is noted that generally the selection of the application techniques may be restricted at plants with low throughput and/or high product variety as well as by the substrate type and shape, product quality requirements and the need to ensure that the materials used, coating application techniques, drying/curing techniques and off-gas treatment systems are mutually compatible.

The coating application techniques are presented in the following order:

- non-spraying application techniques (Sections 17.7.3.1, 17.7.3.2, 17.7.3.3, 17.7.3.4, 0, 17.7.3.6, 17.7.3.7);
- spraying atomisation techniques (Sections 17.7.3.8, 17.7.3.9, 17.7.3.10, 17.7.3.11, 17.7.3.12, 17.7.3.13; for the ‘spray, squeegee and rinse’ technique, see Section 17.7.3.14).

Automation of application is discussed in Section 17.2.5.

17.7.3.1 Roller coating

Description

Application in a machine where rollers are used to transfer or meter the liquid coating or ink from an inkpot onto the moving strip.

Technical description

Application takes place by rotating rubber- or foam-coated rollers; two-side coating is also possible. The application weight can be adjusted by a variation of space between the rollers. If the workpiece and the roll are moving in the same direction, only layers of up to 12 µm can be applied, and only coating materials with a certain viscosity can be used. These problems do not occur in reverse coating processes where the roller rotates in the reverse direction to the movement of the workpiece. See also Section 6.4.3.3 and Figure 6.18.

A doctor blade (see Section 17.7.3.2) can also be fitted to adjust the thickness of ink/coating at the pressure or metering roller.

A particular use of reverse coating is the application of fillers to wood. In automated processes, the filling material is applied by rolling in reverse coaters and excess material is wiped off. After hardening, abrasion is necessary to obtain a smooth surface.

Achieved environmental benefits
Depending on the workpiece and the processing conditions, material efficiencies of about 90-100 % can be achieved.

Environmental performance and operational data
See Section 6.4.3.3.

Cross-media effects
See Section 6.4.3.3.

Technical considerations relevant to applicability
Only applicable to flat substrates.

Roller coating is especially applicable for one- and two-component materials and polymerisation materials with high viscosity or 100 % solids content.

In the coating of metal packaging, roller coaters are commonly applied for the application of the external coating of cans. In three-piece can manufacturing, roller coaters are used exclusively for painting the sheets and the ‘side stripes’ might also be applied by using rollers. In extruded aluminium tube manufacturing, roller coaters are used exclusively for applying the base coat.

This technique is widely applied in coil coating, see Section 6.4.3.3.

In the coating of wooden surfaces, rolling is mainly applicable to flat workpieces, such as panels (plates) made of wood composites, but slightly curved products such as wooden panels can also be processed. For more curved surfaces, fillers are applied by hand equipment such as palette knives.

It is also used in marine industries for the coating of fishing nets.

Economics
A lightweight filling machine applied in the wood and furniture coating industry with a working width of 1.3 metres and an installed electrical load of 5.5 kW cost EUR 55 000 in 2000. In another example, a foam roller with a working width of 1.3 metres and an electrical load of 3 kW cost about EUR 26 000. A machine applying two rollers (double system) with the same working width and an electrical load of 6 kW cost EUR 52 000. Both examples are from the year 2000.

Driving force for implementation
Very high transfer efficiency and, therefore, minimal waste of materials.

Example plants
Mainly in coil coating, wood coating and metal packaging plants.

Reference literature
[5, DFIU et al. 2002] [78, TWG 2005] [155, TWG 2016]

17.7.3.2 Doctor blade (doctor knife) over roller

Description
The coating is applied to the substrate through a gap between a blade and a roller. As the coating and substrate pass, the excess is scraped off.

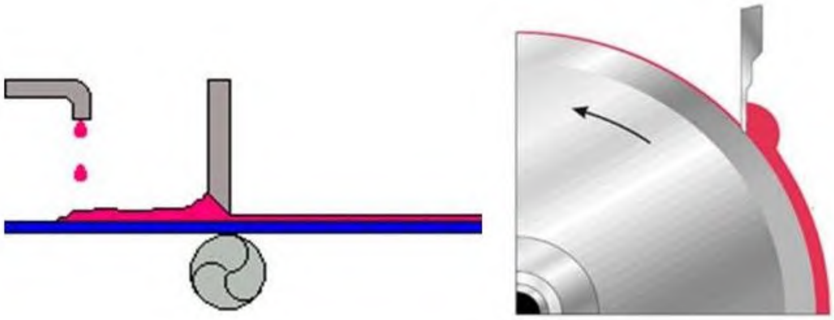
Technical description
The doctor blade (doctor knife) removes the excess ink/paint and allows only the required weight (thickness) to be transferred to the substrate.

This process relies on a coating being applied to the substrate which then passes through a ‘gap’ between a ‘knife’ and a support roller. As the coating and substrate pass through, the excess is scraped off.

Achieved environmental benefits
Low raw material consumption.

Environmental performance and operational data
This process can be used for high-viscosity coatings and very high coat weights, such as plastisols and rubber coatings. There are various versions of this relatively simple process.

Technical considerations relevant for applicability
Generally applicable.



Source: [208, TCI et al. 2017]

Figure 17.8: Doctor blade (doctor knife)

Example plants
Widely applied in flexography and coating of textiles, foils and paper.

Reference literature
[208, TCI et al. 2017]

17.7.3.3 No-rinse (dry-in-place) application in the coating of coil

Description
Application of conversion coatings which do not require a further water rinse using a roller coater (chemcoater) or squeegee rollers.

See also Section 6.4.3.2.

17.7.3.4 Curtain coating (casting)

Description
Workpieces are passed through a laminar film of coating discharged from a header tank.

Technical description
The paint or coating is held in a header trough and is discharged in a laminar film through which the workpieces/substrate are passed. Excess coating material is caught in a reservoir and pumped back into the sinkhead.

Mostly solvent-free lacquers based on polyester are applied but other types of coating materials can also be processed. Curtain coating can achieve very even layers.

Achieved environmental benefits
Benefits include optimisation of materials. Depending on the workpiece and the processing conditions, material efficiencies of about 90-98 % can be achieved.

Environmental performance and operational data
Curtain coating systems incorporate a closed-loop capture and recirculating facility.

Technical considerations relevant to applicability
The technique is only applicable to flat substrates. In curtain coating, plain or almost plain workpieces are coated. According to the machine type, application weights from 40 g/m^2 to 500 g/m^2 can be processed.

Curtain coating is mainly used in the furniture industry for the coating of doors, wall units and other panels.

It is also widely used in the coating of printed circuit boards (more information can be found in the STM BREF [23, COM 2006]).

In the metal packaging sector, it is used for the external protection of food cans. It is applied in two-piece draw and wall ironed (DWI) can manufacture.

Economics
A casting installation applied in the wood and furniture coating industry with a working width of 1.3 metres and an installed electrical load of 3 kW cost EUR 35 000 in 2000.

Driving force for implementation
Cost and environmental benefit.

Reference literature
[5, DFIU et al. 2002] [27, VITO 2003] [23, COM 2006] [29, UKDEFRA 2003]
[38, TWG 2004] [212, TWG 2018]

17.7.3.5 Flooding

Description
The workpieces are transported via conveyor systems into a closed channel, which is then flooded with the coating material via injection tubes. The excess material is collected and reused.

In winding wire manufacturing, a similar variation of this technique is used where winding wires pass through an enamel application unit, where enamels are provided in excess and the excess material is stripped off by an enamel die and transferred back into the enamel tank for 100 % reuse.

Achieved environmental benefits
Depending on the workpiece and the processing conditions, efficiencies of 95-99 % can be achieved.

Cross-media effects
In comparison to dip applications, the evaporation losses are higher.

Technical considerations relevant to applicability
Generally applicable. The process is especially suitable for large workpieces with a large surface area, such as for heating elements, for the painting of parts for trucks or agricultural machines and also for the application of cavity sealings in the automotive industry.
Application weights of 60-200 g/m^2 can be processed.

It is also applicable for winding wire manufacturing.

Example plants
All the winding wire manufacturing sites; for other sectors, no information was provided.

Reference literature
[5, DFIU et al. 2002] [212, TWG 2018]

17.7.3.6 Electrocoating

Description
Paint particles dispersed in a water-based solution are deposited on immersed substrates under the influence of an electric field (electrophoretic deposition). It is a specific type of dip coating.

Technical description
This is also known as electropainting, electrophoretic dipping, e-coat, ELPO, cataphoretic dipping, etc.

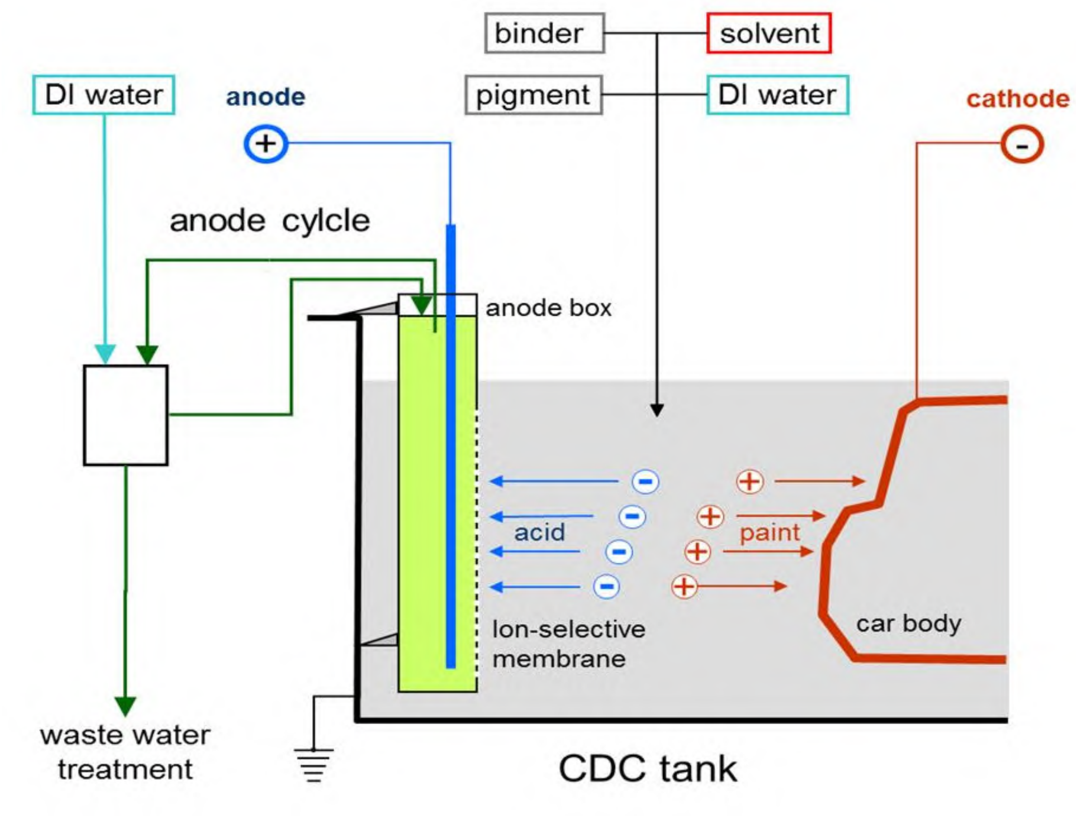
Pretreated vehicle bodies are electrically charged while being passed through a bath of electro-immersion coating. The solids components of the e-coat paint are deposited on the car body by an electrophoretic process. Through this process, it is possible to coat all interiors and exteriors of the car bodies including all cavities. The calculated e-coat area is typically between 70 m^2 and 130 m^2 per vehicle, depending on size and design.

It is necessary to distinguish between cathodic or anodic deposition. Cathodic dip coating is widely used and is able to fulfil the high quality requirements.

The coatings are typically water-based and are diluted with deionised water. They are usually based on amine-functional modified epoxy resin.

The combination of paint resin and deposition process creates a very resistant film after curing that makes a substantial contribution to corrosion protection for interiors and exteriors.
The solvent content of the e-coat paint is typically in the range of 2-4 %.

The coating process is followed by a multistage cascade rinse to remove paint particles that have not been electrodeposited. The rinsing medium is cleaned via ultrafiltration. The paint components concentrated in the retentive are fed back into the CDC (cathodic dip coating) tank, the filtrate (water and low-molecular CDC chemicals) can be reused in the rinse cycle. Optionally, the paint transported from the last deionized water (DI) rinse stage can be separated and fed back into the treatment bath.



Source: [183, ACEA 2017]

Figure 17.9: Electrocoating process

Achieved environmental benefits
With the introduction of two-component e-coat paints (binder solution and pigment paste), the solvent content could be minimised. Due to the low solvent content of this material and the fact that the material is not atomised as with spray operations, VOC emission levels are very low.

Typical emissions are between 2 g and 4 g VOCs/m^2, depending on the electrocoated surface area of the car being painted. With abatement of off-gas from the oven, emission levels lower than 1 g VOCs/m^2 can be achieved.

All electrocoatings used are lead-free.

A very high proportion of paint dragged out in rinsing is recovered (nearly 100 %), by combining reverse cascade rinsing with membrane filtration.

In addition to the paint consumption being low, a small amount of waste is generated.

Cathodic dip coating represents a very high application efficiency.

Environmental performance and operational data
Application takes place in a purpose-built facility with air extraction. The e-coated bodies must pass through an oven before subsequent coatings are applied.

Coating is performed in an enclosed dip tank. The deposition voltage lies between 300 V and 450 V. At high amperages, an energy amount of 5 kWh to 10 kWh per vehicle body is input into the CDC bath. Due to this deposition process and the friction heat from the pumps, the dip coat bath heats up and must be cooled to < 30 °C with the help of a paint cooling system. Electro-dip paints are constantly stirred in the dip tank in order to avoid the settling of pigments, fillers and binders.

There is a need for biological/bacterial control of effluent and significant effluent treatment requirements, including the storage and treatment of large quantities of high-COD/BOD effluent.

Technical considerations relevant for applicability
This technique is only applicable to metal substrates. This technique can be used for whole vehicle bodies and metal components (as well as non-automotive) including inside cavities and other surface areas that are difficult to reach.

At present, this immersion technique is widely used, but only for the application of the e-coat (cataphoretic application). The optical quality of the lacquer finish is very important in car production, therefore only spraying techniques are used for the application of primer and topcoat.

Economics
As electrocoating is usually highly automated and provided complete with countercurrent multiple rinsing systems and membrane filtration to recover the dragged out paint, there are usually high investment and material costs.

Driving force for implementation

- Low VOC emissions.
- Ability to coat internal surfaces.
- Low labour costs
- Low workplace safety impacts.

Example plants
Widely used in the vehicle production industry; all VW plants; Cropu SA, Burgos, Spain (for components).

Reference literature
[5, DFIU et al. 2002] [23, COM 2006] [78, TWG 2005] [127, TWG et al. 2003] [128, Czech Republic 2006] [129, ACEA 2003] [169, VDI 2013] [183, ACEA 2017] [212, TWG 2018]

17.7.3.7 Co-extrusion

For a detailed description, see Section 12.4.2.8.

Co-extrusion is applied in flexography and non-publication rotogravure printing, adhesive tape manufacturing and coating of wooden surfaces.

17.7.3.8 Air-assisted airless spraying

Description
An airflow (shaping air) is used to modify the spray cone of an airless spray gun.

Achieved environmental benefits
The material efficiency for the air-assisted airless technique is about 35-70 %.

Environmental performance and operational data
Air-assisted airless spraying typically performs better than airless spraying. With a good training of the operator, the same performance can be achieved as with conventional spraying, especially for primers. Fast colour changes are not possible due to the essential high-pressure pumps, although they are not required in the automotive industry as airless spraying is used for high-viscosity, non-cosmetic paints. The use of airless spraying gives a rough profile which may need sanding before further, more refined coatings are applied [ACEA comment 325 in [212, TWG 2018]].

Cross-media effects
Less waste is created by overspray, but the waste from purges is higher. There is possibly slightly less waste overall, but the nature and therefore management of the wastes differ. The lack of requirement for compressed air also results in some energy savings [ACEA comment 324 in [212, TWG 2018]].

Technical considerations relevant to applicability
Generally applicable. This technique is mainly applied for coating large pieces or surfaces. It is commonly applied in wood and furniture painting. The use of air-assisted airless spraying is becoming more common in yacht finishing.

Economics
Investment costs including a spray gun, a pump and other necessary equipment is in the range of EUR 2 600-5 200 (2005 data). Additional costs are necessary for training the operators.

In one specific case, the initial costs for applying this technique were EUR 2 900 while savings of EUR 3 100 per month were made on the consumption of paint. In this particular case, the payback time was less than a month (2005 data).

Driving force for implementation
Airless spraying is an effective way of spraying high-viscosity materials [ACEA comment 326 in [212, TWG 2018]].

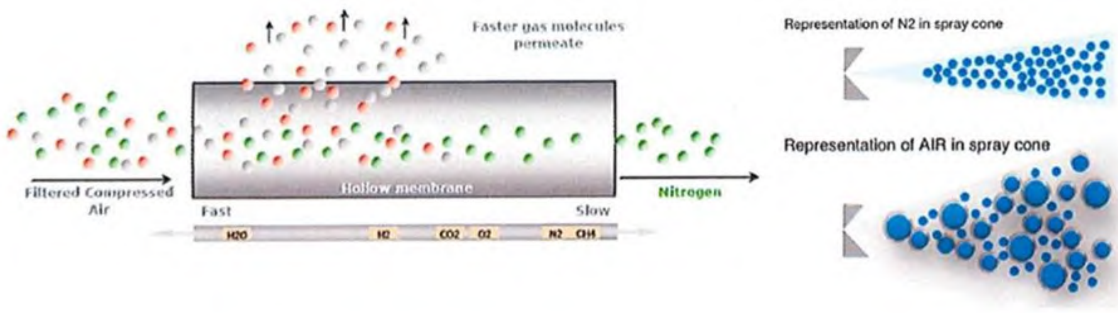
Example plants
Widely used in various sectors.

Reference literature
[5, DFIU et al. 2002] [27, VITO 2003] [78, TWG 2005] [155, TWG 2016]
[212, TWG 2018]

17.7.3.9 Pneumatic atomisation with inert gases

Description
Pneumatic paint application with pressurised inert gases (e.g. nitrogen, carbon dioxide).

Technical description
Nitrogen-assisted spraying is a spray-painting method that allows spraying with nitrogen instead of normal compressed air. A stand-alone machine can produce nitrogen directly from the compressed air using a polymeric membrane (‘molecular discriminator’).



Source: [183, ACEA 2017]

Figure 17.10:(a) Production of nitrogen using polymeric membrane and (b) comparison of spray cones

The nitrogen-rich air can then be used for paint atomisation and shaping the spray jet.

Nitrogen molecules are approximately twice as fast as air and have less turbulence. This is because with conventional air there is a mix of molecules which move erratically rather than the almost pure nitrogen which moves in unison, see Figure 17.10.

An alternative option is to use carbon dioxide (CO_2). In this process, the air is replaced by CO_2, which is fed to the highly viscous paint material. The paint-CO_2 mix is processed at temperatures of 40-70 °C and with a pressure of approximately 100 bar. Atomisation is done via an airless spray application. Due to the fast evaporation of the CO_2, a bell-shaped spray sheet with a lower velocity of paint particles is used compared to regular airless spraying.

Achieved environmental benefits

The nitrogen-assisted spray-painting technique results in a partly higher paint transfer efficiency. The possible increasing transfer efficiency depends on the workpiece shape and has to be regarded as 'best case'. In the case of significantly higher transfer efficiency, it can reduce the amount of paint overspray; this reduces the amount of paint used. By reducing the amount of paint used, dust emissions and VOC emissions are also reduced.

Environmental performance and operational data

The technique provides many benefits:

- less overspray / improved transfer efficiency;
- improved pattern control;
- smaller nozzle size and therefore finer atomisation;
- improved temperature control;
- improved ionising control.

Cross-media effects

For the case of nitrogen use, no information was provided.

In case of CO_2 use, energy is used for heating. The CO_2 released has a global warming effect, although the quantity may not be significant.

Technical considerations relevant to applicability

The technique may not be applicable to the coating of wooden surfaces.

CO_2 atomisation is applicable in several sectors. CO_2 atomisation does not work with epoxy resins as the CO_2 reacts with the curing agent. The substrate should be heat-resistant as the paint/CO_2 mix is processed at temperatures of 40-70 °C. This temperature is sometimes too high for wood (risk of staining).

Driving force for implementation
Better transfer efficiency.

Example plants
Plant #065 in [155, TWG 2016].

Reference literature
[183, ACEA 2017] [191, Nitrosystem 2017] [155, TWG 2016] [212, TWG 2018]

17.7.3.10 High-volume low-pressure (HVLP) atomisation

Description
Atomisation of paint in a spray nozzle by mixing paint with high volumes of air with a low pressure (maximum 1.7 bar). HVLP guns have a paint transfer efficiency of > 50 %.

Technical description
The atomisation of paint material is carried out mechanically by using compressed air. For atomisation, paint material and compressed air are introduced into a jet where the paint is atomised in a spray gun. The discharging air transports the paint particles onto the surface. With higher air pressure, more paint will be sprayed, but the overspray losses are also higher due to the distracted airflow. If the air pressure is too low, the result will be a poor surface quality. HVLP atomisation results in a smaller amount of atomised small paint particles compared to the conventional spraying techniques, because a reduced air pressure is applied.

The HVLP concept was developed in the 1980s with the main idea of achieving 60 % transfer efficiency by limiting atomising pressure to 0.7 bar. This pressure, however, does not achieve the required quality of finish or the speed of application. New designs of air caps have been developed to give the required transfer efficiency as well as desired quality of finish and speed of application but working under higher atomising air pressure. The atomising pressure in these guns is higher than the pressure related to HVLP atomisation but still less than half of the pressure used in conventional air-atomising spray guns. Low-pressure guns can be fed from any type of paint container, attached to gun, pressure-fed tank or pump. The paint container can be on top of the gun or placed under the gun; the container on top can be used until completely empty.

Achieved environmental benefits
HVLP atomisation achieves a material utilisation in the range of 40-80 %. In comparison to high-pressure compressed air spraying, material savings of up to 20 % are achievable if the paint container is on top of the spray gun.

Environmental performance and operational data
Most surfaces can be coated. High surface qualities can be achieved, although the use of conventional high- and low-pressure spraying is not considered to be the most suitable method for high-quality finishes [ACEA comment #321 in [212, TWG 2018]].

Due to the generation of larger paint particles, the optical appearance can be different compared to conventional spraying. However, modern low-pressure guns yield coatings of a quality equal to that achieved with high-pressure guns with a similar workload. The work rate using HVLP atomisation can be slow and there is little dry film thickness control.

Application weights of up to 250 g/m^2 can be processed.

Cross-media effects

The consumption of resources is high compared to the other application techniques and this technique is associated with higher VOC emissions due to low transfer efficiencies. The process also generates high levels of sludge [ACEA comment #320 in [212, TWG 2018]].

Technical considerations relevant to applicability

Generally applicable. HVLP atomisation can be applied to all surfaces. In wood and furniture painting, HVLP atomisation is applied for low viscosity wood stains, however also increasingly for other paint systems. In the automobile industry, HVLP painting is sometimes used in combination with electrostatically assisted bells for the application of metallics (base coat) but it is not used in the topcoat application. In this case, only a thin layer is applied with HVLP [ACEA comment #320 in [212, TWG 2018]]. To a lesser extent, it could be a variant in the coating of agricultural and construction equipment. Since trains are coated manually, HVLP atomisation can be applied for the topcoats. It is also applied for the coating of plastic workpieces but not for and on parts for passenger cars [DE comment #183 in [212, TWG 2018]].

This technique is not commonly applied in the coating of ships (where HVLP atomisation is used in some topcoat applications and possibly for varnish) or aircraft.

Economics

HVLP spray guns cost about EUR 275-550 (2005 data), excluding the costs for adapting the compressor and the compressed air tubes to the higher flows. Costs for the training of personnel for about 1 to 2 days also need to be taken into account.

The payback time is often less than 1 year, depending on the amount of paint applied and current efficiencies achieved.

Example plants

Widely used.

Reference literature

[5, DFIU et al. 2002] [27, VITO 2003] [38, TWG 2004] [78, TWG 2005]
[155, TWG 2016] [212, TWG 2018]

17.7.3.11 Electrostatic atomisation (fully automated)

Description

Atomisation by high-speed rotating discs or bells and shaping the spray jet with electrostatic fields and shaping air.

Technical description

Although the bells atomise the paint materials physically by centrifugal forces, the electrical properties of the paint material are very important. Compared to electrostatic atomisation without additional shaping air, these processes show a higher flexibility with regard to paint materials and material flows.

The charge can be loaded externally or internally. Internal charging realised with galvanically isolated systems is more expensive but often leads to higher transfer efficiencies.

In an external charging device, the paint particles are loaded in the electrostatic field outside the atomiser after leaving the bell cup. External charging is often used for the application of water-based paints.

If special and sensitive paint systems (metallic paints) are applied, a variance in the colour and the surface quality may occur but can be adjusted with an appropriate modification of the application parameters.

Environmental performance and operational data
The process' material consumption and waste generation are minimised due to the high transfer efficiency.

Depending on the workpiece and the processing conditions, efficiencies in the range of 70 % to 95 % can be achieved. Compared to conventional spraying, less overspray is generated and spray booths are less polluted so fewer cleaning agents are needed.

Due to possible high material flows and an achievable transfer efficiency of 70 % to 95 %, the process is the most efficient application method for universal industrial painting operations like the serial production of passenger cars and plastic materials for the automotive, trucks and commercial vehicles industry.

Highly conductive water-based paints can also be processed.

Water-based paints can also be loaded electrostatically before leaving the bell (internal charging). If special lacquers (metallic paints) are applied, a variance in the colour and the surface quality may occur.

Compared to air atomisation, these processes show a higher sensitivity to paint resistance or electrical conductivity.

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally applicable.

Typical applications, among others, are the painting of profiles and bicycle frames. This process is suitable for almost all paint materials including water-based paints.

Material flows of up to 1 000 ml/min can be achieved. A change of colour can be made within several seconds.

Due to material flows of up to 1 500 ml/min and a material efficiency of up to 95 %, the process is eligible for universal industrial painting operations.

This technique can be used only with automatic applications due to the high rotation speed of the bells.

Electrostatically assisted high-rotation bells are widely used in the automotive industry for the primer, base coat and clear coat application, and increasingly for automotive parts.

In the coating of trucks and commercial vehicles, electrostatically assisted spray application is commonly applied.

Economics
Internally charged processes typically cost between EUR 250 000 and EUR 1 600 000 (2005 data) depending on the size and amount of automation.

Driving force for implementation

Electrostatically assisted high-rotation bells have high transfer efficiency, thereby reducing material usage and VOC emissions. They also give a consistent and high-quality paint finish, and can meet high production speeds. Painting time is also reduced.

Example plants

This technique is the standard application technique for vehicle painting and coating of plastic parts worldwide.

Reference literature

[5, DFIU et al. 2002] [78, TWG 2005] [155, TWG 2016] [212, TWG 2018]

17.7.3.12 Electrostatically assisted air or airless spraying

Description

Shaping the spray jet of pneumatic or airless atomisation with an electrostatic field. Electrostatic paint guns have a transfer efficiency of > 60 %. Fixed electrostatic methods have a transfer efficiency of up to 75 %.

Technical description

For electrostatically assisted compressed air, airless and air-assisted spraying, the paint material atomisation is similar to regular compressed air spraying except for the airless technique. There, atomisation is realised via the hydrostatic pressure of the material. Additionally, the paint particles are electrostatically charged; however, this does not happen when applying water-based paints. According to the application conditions, the material flows for compressed air amount up to 1 000 ml/min. For airless or air-assisted airless techniques, the material flow can be up to 3 000 ml/min.

This technique is also used for the application of powder coatings. The powder particles are electrostatically charged and sprayed onto the earthed workpiece using compressed air. Material efficiencies in the range of 80-95 % are achieved. Spray booths and application tools can be cleaned by vacuum cleaning or by blowing with compressed air. In this way, resources are saved and emissions of VOCs are avoided.

Achieved environmental benefits

The material efficiency is about 85 %. When powder coatings are used, the material efficiency could be up to 95 %. In the painting of furniture and wood, efficiency levels in the range of 50-70 % are achievable. Compared to conventional spraying, fewer leftovers are generated and spray booths are less polluted so fewer cleaning agents are needed. Painting time may also be reduced.

Environmental performance and operational data

The painting time is usually reduced.

In the coating of plastic workpieces, electrostatically assisted spray applications are commonly applied, although a conductive primer is required [ACEA comment #334 in [212, TWG 2018]].

According to the implemented supply equipment (only one pump or one pump for each colour), the time needed for colour changes varies.

Complex geometries with depressions can be painted via compressed air spraying.

Cross-media effects

Generation of waste is the main cross-media effect. However, due to the higher transfer efficiency compared to other systems which are not electrostatically assisted, less waste is generated.

Compressed air requires energy.

Technical considerations relevant to applicability

Generally applicable. All the electrostatic techniques can be used for water-based and conventional materials. These techniques can be fully automated or can be operated manually. In the painting of furniture and wood, airless or air-assisted airless techniques are mainly used for high material consumption or high surface throughputs, such as for the automated coating of furniture (workpieces with depressions), automated coating of window frames or manual coating of large workpieces.

In the coating of aircraft, electrostatically assisted spray applications are commonly applied.

In the coating of trains, airless spraying systems can be used for applying ground coats; however, no information was submitted on electrostatically assisted spraying of trains.

In the coating of plastic workpieces, electrostatically assisted spray applications are commonly applied.

This technique is not commonly applied in the coating of ships, because in the open air there is too much air movement and in other poorly ventilated areas there is a risk of explosion. However, it is used in some yards in the Netherlands.

Driving force for implementation

Less generation of waste and reduced painting time.

Example plants

Plant #141 in [155, TWG 2016]. See also Technical considerations relevant to applicability above.

Reference literature

[5, DFIU et al. 2002] [78, TWG 2005] [155, TWG 2016] [212, TWG 2018]

17.7.3.13 Hot spraying

Description

Pneumatic atomisation with hot air or heated paint, used for application of high-viscosity paint.

Technical description

The atomisation of paint material can be carried out by using compressed air or by using hot airless spraying. The paint material and/or the compressed air are heated, the viscosity of the paint system is therefore lowered and the amount of thinners can be reduced which results in lower VOC emissions. The heating (to 60-70 °C) of the paint material is carried out in the spray gun container or via heated pipes for compressed air and the paint material. Flow heaters for the heating of the compressed air are utilised for paint materials that otherwise would already start to react at these temperatures. This can be used with water-based, solvent-based or solvent-free two-component epoxy systems.

Achieved environmental benefits

The reduced amount of thinners results in lower or even no VOC emissions. Compared to conventional spraying, the number of layers can be reduced.

Material efficiencies of 40-60 % can be achieved. An efficiency improvement of up to 10 % can be achieved compared to conventional spraying.

Environmental performance and operational data
The technique is commonly used for paints with a high solids content, but is also applicable for hot-wax spraying. It can be operated under the following conditions:

- 60-200 bar when spraying paints containing a high solvent or water content;
- 200-400 bar when spraying paints containing a high thick solid content;
- two-component paints if online mixing is applied (see Section 17.2.4.1).

With the increased temperature, higher layer thicknesses can be applied without the formation of edge runners. However, the following restrictions also apply:

- pot life is very short;
- equipment is expensive;
- single-integer volume mix ratio is needed;
- high-solids/solvent-free epoxy paint is used;
- operator needs training because the equipment is difficult to use.

Cross-media effects
Energy is used for heating.

Technical considerations relevant to applicability
The necessary reheating after colour changes makes this technique unsuitable for processes with frequent colour changes.

Hot spraying is sometimes used in the painting of furniture, e.g. on cupboards. The technique might be applicable for the coating of ships and yachts.

Economics
Because thicker layers are applied, costs for labour are lower compared to conventional coatings and their application methods.

Example plants
Axle paint shop Mercedes-Benz Kassel, Germany.

Reference literature
[183, ACEA 2017] [212, TWG 2018]

17.7.3.14 ‘Spray, squeegee and rinse’ application in the coating of coil

Sprays are used for application of cleaners, pretreatments and for rinsing. After spraying, squeegees are used to minimise solution dragout, which is followed by rinsing.

For a detailed description, see also Section 6.4.3.1.

17.8 Drying and/or curing techniques

Drying/curing is one of the most energy-consuming processes. Drying/curing is used for:

- drying/curing of paint;
- drying/curing of ink;
- drying/curing of adhesives;
- evaporation of retained water or other liquids from pretreatment or rinsing zones;
- gelling and solidification of adhesives or underbody protection materials;
- pretreatment of workpieces (against cold surfaces or trapped air in the lacquer finishing of wood).

In the next sections the main identified drying/curing techniques are discussed. It is noted that the selection of the drying/curing techniques may be restricted by the substrate type and shape, product quality requirements and the need to ensure that the materials used, coating application techniques, drying/curing techniques and off-gas treatment systems are mutually compatible.

17.8.1 Inert gas convection drying/curing

Description
The inert gas (nitrogen) is heated with gas or steam via heat exchangers or fuel oil, enabling solvent loading above the LEL. By applying inert gas instead of normal air, solvent loads of > 1 200 g/m^3 of nitrogen are possible.

Achieved environmental benefits
Inert gas can contain much more solvent than normal air. For an inert gas drying process, for example, a gas volume of 2 000 m^3 is circulated for a solvent amount of 400 kg/h. Air drying would need up to 10 times as much volume to meet 40 % of the LEL value.

Energy is saved and off-gas treatment systems can be designed for smaller capacities compared to the use of normal air. The flammability is reduced.

Environmental performance and operational data
Where inert gas is used for drying, condensation may be used as a technique for recovering solvents (see Section 17.10.6.1).

Technical considerations relevant to applicability
Applicable to new and existing plants and installations. However, retrofitting might be difficult.

This technique is commonly applied as a pre-drying step in the manufacturing of adhesive tapes.

The technique is not applicable where dryers need to be opened regularly. When opening the dryer purging is necessary, i.e. replacing air with inert gas. This is costly and takes time. This is the reason why it is not applied in industries where job changes are a daily occurrence such as in some printing processes.

Reference literature
[6, DFIU et al. 2002] [38, TWG 2004] [95, CEI-BOIS 2006] [212, TWG 2018]

17.8.2 Induction drying/curing

Description
Online thermal curing or drying by electromagnetic inductors that generate heat inside the metallic workpiece with the oscillating current induced by the oven.

Technical description
Electromagnetic coils mounted close to the painted coil induce oscillating currents within the metal that can be tuned to generate heating rates of hundreds of degrees per second.

Achieved environmental benefits
No emissions from fossil fuel use.

Environmental performance and operational data
Electrical heating is very controllable and efficient with no local emissions.

Cross-media effects
Use of electricity to replace gas and subsequent translocation of emissions to electricity-generating plants.

Technical considerations relevant to applicability
Only applicable to metal substrates.

For existing installations, there is a necessity to redesign the off-gas treatment unit because the heating times are much shorter compared to conventional dryers.

This technology is routinely used for metal tempering and annealing, but is also appropriate for rapid paint curing. It is applied if the substrate or object to be dried conducts electricity. It might be applicable as a replacement for or supplement to existing gas-fired ovens. The potentially very high electricity demand may limit the applicability.

In the printing of metal packaging, it is applicable to all heatset coating or printing materials and on ferromagnetic substrates. However, coating formulations may need fine-tuning for different heating rates. There may be some limitations on the paint film thickness achievable with the very fast heating rates.

Induction is mainly used in special applications such as the hardening of structural bonding (adhesives) in the automotive industry. It is used in a few lines in coil coating.

Economics
Only economically viable for new installations or when an oven requires replacing.

Example plants
Coil coating plants #152, #172 and #173 in [155, TWG 2016].

Reference literature
[5, DFIU et al. 2002] [22, ECCA 2004] [38, TWG 2004] [95, CEI-BOIS 2006] [155, TWG 2016] [212, TWG 2018]

17.8.3 Microwave and HF drying/curing

Description
Drying or curing using microwave or high-frequency radiation.

Technical description
In this process, the wet paint layer is heated via electromagnetic microwaves. The two available techniques are microwave drying and high-frequency drying (HF). Due to the impact of these electromagnetic waves, the dipoles are oscillated and, thus, the electromagnetic energy is transformed into heat energy. In this way, the contained water is evaporated rapidly and needs to be extracted.

HF dryers consist of a high-frequency generator, the transmission unit, collector electrodes and the appropriate flash-off zone for removal of the evaporated water. Alternatively, the wet paint layer is heated via electromagnetic microwaves. Evaporation and drying takes place from the inside of the paint layer to its outside. The heating is homogeneous.

Achieved environmental benefits
No emissions from fossil fuel use.

Technical considerations relevant to applicability
Electromagnetic wave dryers are exclusively applicable to water-based coatings and inks, and non-metallic substrates.

HF dryers are not applied in the manufacturing of abrasives, in the manufacturing of adhesive tapes or in the winding wire industry [DE comment #194 in [212, TWG 2018]].

Microwave drying is applied for the coating of wood, for workpieces prior to assembly and for pieces with small dimensions as large products need a large microwave oven with higher energy costs.

Economics
A 2-minute microwave dryer applied in the coating of wooden surfaces with an installed electrical load of 60 kW and an air output of 1 500 m^3/h cost EUR 75 000 in 2000. Electrical control and conveying units are excluded.

A 2-minute HF dryer applied in the coating of wooden surfaces with an installed electrical load of 120 kW and an air output of 1 500 m^3/h cost EUR 150 000 in 2000. Electrical control and conveying units are excluded.

Reference literature
[5, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005] [95, CEI-BOIS 2006]
[212, TWG 2018]

17.8.4 Combined convection and IR radiation drying/curing

Description
Drying of a wet surface with a combination of circulating hot air (convection) and an infrared radiator.

Technical description
A combined convection and IR radiation dryer (also called a thermal reactor) is a radiator that emits infrared radiation as well as convection heat. The infrared radiation is generated by combustion of natural gas or propane.

Achieved environmental benefits
Reduction of energy consumption.

Environmental performance and operational data
The energy demand is lower compared to dryers applying only circulated air.

Depending on the paint system and kind of production, the total drying time is in the range of 6 to 10 minutes.

Technical considerations relevant to applicability
Generally applicable. Applicable to all heatset coating or printing materials, either solvent-based or solvent-free, and powder coatings. Thermal reactors are also suitable for water-based paint systems.

The geometry of the coated or printed substrate is not relevant; however, it should be heat-resistant.

Although some costs are given below, the technique is not known to be applied commercially in the coating of wood. There is a risk of staining and burning of the wood if the temperatures are too high.

Economics
A thermal reactor with a 6-minute drying time for the coating of wooden surfaces with an installed electrical load of 10 kW and an air output of 2 000 m^3/h heated with natural gas cost EUR 95 000 in 2000. Electrical control and conveying units are excluded.

Reference literature
[5, DFIU et al. 2002] [38, TWG 2004] [95, CEI-BOIS 2006] [212, TWG 2018]

17.8.5 Radiation curing processes

Radiation curing is applied based on resins and reactive diluents (monomers) which react on exposure to radiation (infrared radiation (IR), near-infrared radiation (NIR), ultraviolet (UV)) or high-energy electron beams (EB).

The resins are generally polyesters, polyurethanes or epoxies, with acrylate or methacrylate functionality, though other coating chemistries may also be used. The formulations are liquid and curing can be very fast, just a few seconds, generally at ambient or slightly raised temperatures.

Specific radiation curing processes are discussed in the following sections.

17.8.5.1 Infrared radiation drying/curing

Description
Drying/curing of paints with infrared radiation.

Technical description
For infrared radiation drying/curing, the workpiece is heated via absorption of infrared radiation. The drying process starts from the inside to the surface. The intensity of the infrared radiation depends on the wavelength range and therefore of the temperature of the radiator. The absorption of the rays depends on the surface smoothness, the colour or lightness, its reflectivity and its chemical composition.

Achieved environmental benefits

Reduction of energy consumption.

Environmental performance and operational data

The energy demand is lower compared to dryers applying circulated air.

It is a fast heating technique (1-5 seconds in the case of NIR medium or long wave, see Section 17.8.5.3, but IR may take longer) and, when the temperature of the substrate during paint drying/curing is low, it requires only short cooling times. The solvent composition needs to be adjusted to the energy of the radiation.

There is a risk of the formation of shades on edges and in niches.

Different radiators are available, according to the wavelength used. Flow-path- or programme-controlled installations are applied according to drying and surface quality conditions.

Cross-media effects

Due to the radiant heat from the dryers, solvents are evaporated as for conventional heating processes.

Technical considerations relevant to applicability

Applicable to specific coatings and inks. There is no limitation of layer thickness, except where very fast cure times are required (e.g. where the substrate is moving rapidly, as in coil coating).

The geometry of the coated or printed substrate is not relevant. However, it should be heat-resistant. In some cases, the temperature can be too high for wood, where there are risks of staining and burning.

Infrared curing is used on a small number of coil coating lines. For existing situations in coil coating, there is a need to redesign the off-gas treatment unit because the heating times are much shorter compared to conventional dryers.
The technique is commonly applied in the automotive industry for the pre-drying of topcoats that are applied by the wet-on-wet technique. It is also increasingly used in adhesive tape manufacturing.

It is not applied in the manufacturing of abrasives.

In the printing industry, it is no longer used due to improved inks. The disadvantages of using infrared radiation curing were the heat produced in the pile of the printed sheets and the blocking (i.e. the printed image reproduces itself on the back of the sheet above).

Economics

Investment costs are relatively low; however, retrofitting existing dryers can be costly. In the coil coating industry, this technique is only economically viable for new installations or when an oven requires replacing.

Driving force for implementation

- Low energy demand.
- Speed of drying.
- Flexibility of the process.

Example plants

Vehicle coating: Opel Eisenach GmbH, Germany,
Coil coating: plants #099, #105 in [155, TWG 2016].

Reference literature
[5, DFIU et al. 2002] [22, ECCA 2004] [38, TWG 2004] [78, TWG 2005]
[95, CEI-BOIS 2006] [155, TWG 2016] [212, TWG 2018]

17.8.5.2 Catalytic IR drying and curing with VOC reduction

Description
IR radiation is generated by catalytic oxidation of gas including oxidation of evaporated VOCs from the dryers. The method uses less energy compared to traditional drying methods and provides a low drying temperature and a short drying time. At the same time, more than 50 % of the VOC emission from the drying oven is burnt together with the gas.

Technical description
IR radiation is generated by a catalytic flameless burning of gas using VOC-containing air from the drying oven. The drying temperature is as low as 110 °C compared to 200 °C in traditional drying ovens. This is an advantage for drying of wood materials and other materials, which cannot resist high temperatures.

The catalytic panels are produced in different sizes with different performance – typically from 17 kW/m^2 to 26 kW/m^2.

The process can be applied in a flat-line process, in a conveyer process or in a drying box. It is also possible to use a flexible mobile IR plant where a fixed installation is not suitable.

Achieved environmental benefits
The VOC emissions are reduced by at least 50 % because the VOC-containing air from the drying process is used for the catalytic oxidation process. The energy consumption is reduced 60-80 % because the drying time is short and the drying temperature is low. Also, the consumption of lacquer is lower than in a traditional drying process because coating has better mechanical properties so less lacquer is required to obtain a specified quality.

The advantages are:
- reduced drying time (60-80 %);
- considerably less energy costs compared to other drying methods (60-80 % less);
- reduced VOC emission (60 %);
- less space required than most other drying methods (60-90 % less);
- reduced consumption of lacquer (10-45 % less);
- a simple drying process, which is quick and easy to install;
- ATEX approved[48].

Environmental performance and operational data
VOC-containing air from the drying process is used in the catalytic system for generating IR radiation. This will reduce the VOC emission by 50-60 %. Furthermore, it is also possible to use VOC-containing filtered air from the spraying process in the catalytic burner. Hereby it is possible to reduce the VOC emission by 70-80 % in total compared to the painting process. This is achieved without investment in an expensive off-gas treatment system.

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[48] According to Directive 94/9/EC of the European Parliament and the Council of 23 March 1994 on the approximation of the laws of the Member States concerning equipment and protective systems intended for use in potentially explosive atmospheres.

Cross-media effects

None identified.

Technical considerations relevant to applicability

The IR drying system can be used for all metals but aluminium and bright metals may reject the IR radiation. It is also applicable for drying of wet items before coating and before powder coating.

It is especially suitable for drying of wood, plastic and textile items where a low surface temperature is required. The surface temperature could be kept as low as 45-50 °C or in the range of 45-100 °C when required.

Another advantage of IR curing is a good relation between the IR wavelength and the receiving wavelength for varnish, paint, water and plastic materials (6-8 µm).

The drying system is also suitable for windmill components, for the offshore industry and for steelworks. For those items, the surface temperature is often between 75 °C and 200 °C.

Economics

A complete IR drying system will probably cost 25-50 % more than most traditional drying systems. However, the savings of energy and lacquer as well as the reduction of VOC emissions, the very short drying time and the small footprint indicate a payback time of 1-3 years.

The equipment has a lifetime of more than 10 years but the catalytic materials have to be renewed after 20 000-25 000 hours of operation.

Driving force for implementation

- Lower operation costs,
- Lower energy consumption (less CO_2),
- Very short drying time and at least 50 % lower VOC emission than a traditional drying process.

Example plants

More than 100 of this kind of IR drying systems have been installed in Denmark, Norway, Finland, Sweden, Germany, Poland, Hungary, the Czech Republic, China, Malaysia and Canada. A total of 50 % of the plants are for metal materials, 40 % are for wood materials and 10 % for plastic materials. The painted items include components for windmills, components for mobile phones, furniture, kitchen elements and containers.

A total of 40 % of the systems used are drying boxes, 20 % are conveyer lines, 10 % are flat-line and 30 % are mobile drying boxes.

Selected reference plants:

- Dancoat A/S, Gram, Denmark/ Coating of very large components for windmills and offshore industry. Installed IR effect of 585 kW. Drying time reduced from 18 hours to 2 hours by using IR instead of a conventional drying process.
- Cimbria Manufacturing A/S, Thisted, Denmark, Coating of containers and silos used for storage and transport of seeds. A conveyer plant with a 225 kW IR effect and a box plant with an 80 kW IR effect.

Reference literature

[DK comment #17 in [212, TWG 2018]]

17.8.5.3 Near-infrared radiation (NIR) curing

Description
Thermal curing of paints with infrared light with a very short wavelength.

Achieved environmental benefits
Shorter curing period.

Environmental performance and operational data
Near-infrared radiation (NIR) curing is used where there is a need to reduce the curing time from minutes to seconds. NIR absorption depends on the choice of pigments.

NIR emitters operate at very high temperatures, producing very-short-wavelength infrared radiation at very high power density. Absorption of the specific wavelength by the coating and short dwell times can reduce the heating of the substrate.

Cross-media effects
The demands for electrical power are high. NIR requires a reliable high power electrical supply.

Technical considerations relevant to applicability
Due to very short (1-5 seconds) curing times, this technique is very suitable for heat-sensitive materials such as wood and plastic. Powder coatings are commonly cured by applying NIR curing as well as water-based paints on wood. For the coating of wooden surfaces, the NIR technique achieves the shortest drying and cycle times.

NIR curing is starting to be used in coil coating for the fast curing of thin coatings and in powder coatings. Its extension into general processing lines will depend on further trials.

Driving force for implementation
Shorter more compact ovens, high speed and controllable power.

Example plants
Plant #086 in [155, TWG 2016].

Reference literature
[5, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005] [155, TWG 2016]

17.8.5.4 Ultraviolet (UV) curing

Description
‘Cold’ cross-linking of appropriate paints with UV light (the paints need to be UV-curable).

Technical description
Medium-pressure mercury vapour lamps or electrode-less gas-filled lamps generate ultraviolet radiation with a wavelength of 200-400 nanometres. The radiation starts a chemical cross-linking within the paint or ink layer. UV curing requires the presence of a photoinitiator.

Achieved environmental benefits
UV-cured systems use less or no solvent. Energy consumption is low.

Environmental performance and operational data
Wooden or plastic substrates can show a yellowing and may become brittle. This technique requires little floor space and curing occurs within a few seconds (high speed).

The lamps may be equipped with semi-elliptical or parabolic reflectors to focus the light onto the curing coating. UV lamps are also equipped with a shield protecting the personnel from the ultraviolet radiation.

Cross-media effects
Ozone emissions occur and the ozone is commonly extracted and routed to an ozone eliminator with catalysts or to a thermal oxidiser. Mercury vapour lamps are used, which contain mercury and must be disposed of through suitable waste treatment facilities.

Technical considerations relevant to applicability
Only applicable to UV-curable paints.

Applicable to new and existing installations.

The technique is applicable to unsaturated polyesters, polyacrylates, epoxy resins, etc. It is especially applicable to clear coats and glazes up to high layer thicknesses. For pigmented coatings, UV curing is only applicable for small layer thicknesses. Also, UV-cured inks are dried via UV curing.

The coated or printed substrates should be resistant to UV curing and preferably flat or two-dimensional. The curing of powder-coated three-dimensional wooden or plastic parts is more complicated; however, well performing drying systems are available.

UV radiation is widely applied to substrates of paper and cardboard. It is applied for the drying of painted furniture, where flat panels can be coated separately and coating is done before assembling the piece of furniture. It is also increasingly applied in the production of adhesive tapes.

In coil coating, the technique is currently under evaluation (see also Section 19.4.1).

Economics
Compared to conventional dryers, energy costs can be reduced by up to 70 %. Compared to a conventional gas-fuelled oven (including ventilator) for water-based paints, the energy costs are reduced by 40-50 %. In printing, the energy consumption may be as high as with conventional drying. Energy utilisation is reduced by 50 % using flash cure systems, where the lamp only operates when the actual substrate is underneath the lamp. This has economic benefits, for instance, when non-web printing is taking place.

Example plants
Flexography and non-publication rotogravure: Plants #012, #019 and #028.
Metal packaging: Plant #122.
Coating of wooden surfaces: Plant #177.

Reference literature
[5, DFIU et al. 2002] [27, VITO 2003] [38, TWG 2004] [78, TWG 2005]
[197, FPE 2017] [155, TWG 2016]

17.8.5.5 Electron beam curing (EB)

Description
'Cold' cross-linking of EB-curable paints with high-velocity electrons.

Technical description
EB curing is initialised by an electron beam emitted from a hot cathode tube. Polymerisation and, thus, hardening of the paint is caused by the impact of electrons onto the monomers. A

high level of automation is possible. Electrons are accelerated to a high velocity, penetrating the coating substance and curing it in a very short time.

Unlike UV energy, which is concentrated on the surface, electron-beam energy is able to penetrate many materials, enabling a full through-cure for very thick coating layers. The absorption of EB energy is not affected by the colour of the coating or the substrate.

Achieved environmental benefits

- EB-cured systems use less or no solvent.
- Low energy consumption.

Environmental performance and operational data

- There is a risk of the substrate becoming brittle and of discoloration.
- Very little floor space is required.
- Radiation imposes a risk to the workers. The workers have to be shielded from the electron beam by lead plates or concrete walls.

Technical considerations relevant to applicability
Applicable to EB-curable paints: unsaturated polyesters, polyacrylates, polyurethanes, epoxy resins, etc. There is no limit to layer thickness or pigmentation.

All geometries are suitable for substrates transparent to EB radiation (especially paper, wood or foils); for metals, EB is limited to flat substrates. Because of high investment costs, this technique is currently only applied to large surface throughputs.

EB curing is increasingly applied in the production of adhesive tapes.

In the coil coating industry, EB may be considered an emerging technology (see also Section 19.4.1).

Economics
EB curing has higher investment costs than conventional dryers. However, the energy consumption of EB curing can be much lower.

Reference literature
[5, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005]

17.8.6 Convection drying/curing combined with heat recovery

Description
Heat from off-gases is recovered and used to preheat the input air of the convection dryer/curing oven. The air is in direct contact with the object or surface to be dried.

Technical description
In convection drying, heated air is circulated in the dryer or oven to transport heat to the workpiece. The air is in direct contact with the object or surface to be dried. The drying time depends on the object or substrate, the type of coating and the coating thickness, and varies between a few seconds to a full hour. Reuse of the excess energy from off-gas oxidation reduces the energy consumption for drying.

For the drying of water-based coatings or a pre-drying step of wet-on-wet layer constructions, dehumidified air is used, with convection dryers with an additional dehumidification step. Due to the uptake of water, the drying times can be significantly reduced.

The dryers are built as flat-line dryers, nozzle dryers, tray systems or tower dryers. The energy demand depends largely on the heat losses of the dryer.

Normally, during the drying process, flammable substances are released by evaporation and curing.

The European Standard EN 1539 defines the permitted operating ranges with respect to the admissible drying temperature and the maximum admissible concentration of released flammable substances inside the dryer.

The units typically contain three to six independent zones and can be up to 50 metres long.

Achieved environmental benefits

The overall impact of the curing technique on environmental performance not only depends on the ovens themselves but also on the surrounding air treatment and air circulation devices. When solvent-based curing techniques are used (as in the case of coil coating), it is necessary to dilute the VOC concentration in the ovens below the LEL with a significant input of air. The VOC-containing air then needs to be oxidised at high temperature. The energy balance of the curing section is then the result of the efficiency of the oxidiser and the reuse of the excess energy liberated at the oxidiser.

The optimal configuration and energy usage will depend on the kind of products the line is running, the way the line is programmed and the degree of reuse of the hot air.

Environmental performance and operational data

Their stable operational profile and reliability means that they are capable of providing high-quality cured coatings.

For the case of convection drying in the coil coating industry, see Section 6.4.4.1.

Cross-media effects

Energy requirements for air heating and distribution.

Technical considerations relevant to applicability

In dryers used for fast-moving, continuous substrates such as paper and plastic foil webs or continuous streams of small objects such as beverage cans, the drying time is measured in seconds and the length of the dryer in centimetres. Not the temperature, but the airflow is most important. Energy can be saved by recirculating air, but this is limited by the need to avoid fire or explosion and to avoid odour in the end product. Dryers are heated by flame, steam, thermal oil or electricity.

Applicable to all heatset coating or printing materials, either solvent-based or solvent-free. There is no limitation on layer thickness or pigmentation. The geometry of the coated substrate is not relevant; however, it should be heat-resistant.

Convection dryers can be used for drying layers of water-based paints, for a pre-drying step or for wet-on-wet layer constructions. They are commonly applied in the coating of plastic bumpers, in coil coating processes (see below), in wood and furniture painting, in the manufacture of adhesive tapes and in the automotive industry.

Hot air ovens are the most common curing technique of a coil coating line (see also Section 6.4.4.1). The process window is large, and the efficiency of the technique is not dependent on the substrate.

The simple hot air ovens are catenary ovens, with three to six independent zones that allow good control of the temperature profile. The overall length of such ovens depends on the line speed and generally lies in the range 25-50 metres.

Flotation ovens are an alternative technique based on hot air jets very close to the strip. Although the electricity consumption of these units is higher than catenary ovens, the flotation technique facilitates shorter curing times because of the efficient heat transfer to the strip. Moreover, there is no catenary of the strip in the oven. Therefore, the process window is larger than with normal convection ovens and the ovens are more compact.

Convection dryers are commonly applied in the manufacturing of abrasives and the manufacture of winding wires.

Economics

In terms of the investment cost, hot air ovens are cheaper than alternative curing techniques. The operating cost strongly depends on the kind of products, the way the line is programmed and the general design of the curing-incinerating-recirculating system.

The costs for drying mount up to 15-20 % of the total energy costs of the painting line in the automotive industry.

A 10-minute convection dryer applied in the coating of wooden surfaces with an installed electrical load of 30 kW and an air output of 1 500 m^3/h cost EUR 60 000 in 2000. The electrical control and conveying unit is excluded.

Driving force for implementation

There is no limit in the capability and it is a well-known technique considered the ‘normal’ curing technique.

Example plants

Widely used in various sectors, e.g. coil coating, winding wire manufacturing, metal packaging and vehicle coating.

Reference literature

[5, DFIU et al. 2002] [27, VITO 2003] [4, Germany 2002] [38, TWG 2004]
[78, TWG 2005] [155, TWG 2016] [212, TWG 2018]

17.9 Cleaning techniques

[97, TWG 2006] [108, ESVOCCG 2006] [155, TWG 2016]

Cleaning activities may have a significant impact on VOC emissions, especially on fugitive emissions as well as other environmental parameters (e.g. waste generation). Therefore the selection of the appropriate cleaning technique (process and cleaning materials) has an influence on the overall environmental performance of the plant. In the following sections, the main identified cleaning techniques are discussed. It is noted that the selection of cleaning techniques may be restricted by the type of process, the substrate or equipment to be cleaned and the type of contamination.

17.9.1 Minimisation of the use of solvent-based cleaning agents

Description
Minimise the need to clean and select cleaning methods that:

- are compatible with the surfaces to be cleaned and contamination type;
- reduce consumption of solvent-based cleaning agents, waste generation and emissions.

There are various options for the cleaning of equipment parts and/or substrates [ACEA comment 347 in [212, TWG 2018]]:

- using a washing machine (repeatedly if necessary);
- with powerful low-volatility solvents;
- with high-pressure water after using powerful solvents, or with an abrasive added;
- using ultrasonic cleaning;
- using dry ice blasting;
- fluidised bed cleaning;
- hot caustic wash;
- steam cleaning.

Some of those options are discussed in more detail in the following sections.

Manual cleaning using volatile solvents may be necessary in various cases (e.g. difficult to access equipment, sensitive equipment) but in general it may be avoided due to elevated VOC emissions, when automatic cleaning options are feasible.

Achieved environmental benefits
Reduction of VOC emissions.

Environmental performance and operational data
Selection of the correct cleaning system can reduce solvent emissions. When selecting the cleaning techniques to be used, the following issues need to be considered.

1. Type of cleaning:

- Process equipment cleaning. In all activities, the process equipment will be cleaned. This takes two forms:
    - Operational or interim cleaning. Cleaning of the application system is necessary at regular intervals, e.g.
        - for colour change and quality reasons;
        - cleaning of spray booths;

        - between printing jobs.
    - Maintenance, periodic or in-depth cleaning. It is periodically necessary to clean application equipment thoroughly to remove accumulated deposits and clean parts of equipment that are more difficult to clean quickly. This usually requires some disassembly.

  The type of technique used will depend on whether the equipment is cleaned *in situ*, or dismantled completely or partially.

- Substrate or workpiece cleaning. For some activities, such as painting and varnishing, cleaning of the substrate or workpieces to remove grease, dirt, etc. is essential prior to coating. In some activities, such as printing, it is not necessary.

2. Type of contamination:

- For process equipment:
    - Non-persistent contamination. The contamination is fresh, e.g. it is non-drying, it still has some of the original solvent present, or its coating reaction is not complete. This type of contamination is easy to remove, e.g. manually (see Section 17.9.4), with the original or similar solvent used in the coating, with low-volatility solvents (depending on the need to dry the components, see Section 17.9.5), in washing machines (see Section 17.9.7), etc.
    - Persistent contamination. This may be from dried solvent-based products, UV or other radiation-cured products, water-based, or reactive (two-component) products, etc. Cleaning by hand with volatile solvents is not effective. The parts may be cleaned, for example:
        - in a washing machine (repeatedly if necessary), (see Section 17.9.7);
        - with powerful low-volatility solvents (see Section 17.9.5);
        - with high-pressure water after using powerful solvents, or with an abrasive added (see Section 17.9.9);
        - using ultrasonic cleaning (see Section 17.9.10);
        - using dry ice blasting (see Section 17.9.11).
- For substrates and workpieces, contamination depends on the previous processes, and may include corrosion from storage, press oils, dirt and debris from cutting, shaping and grinding, fingermarks from handling, etc. These options for cleaning are discussed in the STM BREF [23, COM 2006]. In this sector, the parts are usually hand cleaned with wipes or rags (see Section 17.9.4) or in water-based detergent systems for high throughputs (see Section 17.9.6). Solvents can be used in washing machines for smaller components (see Section 17.9.7). Ultrasonic or dry ice techniques can also be used (see Sections 17.9.10 and 17.9.11).

3. Choice of technique and/or solvent. The technique and/or the solvent used should:

- be capable of achieving the cleanliness required in the process;
- be compatible with the parts being cleaned (whether they are substrates, workpieces or equipment parts);
- be compatible with the process, and the surface treatments; for example, in the printing of flexible packaging the system has to be dry of all solvents before adding new inks; in other activities, the cleaning systems can be compatible with the process and drying may not be necessary;
- reduce the emission of solvents;
- take into account the time available; in some cases, the time available for cleaning is limited; in other cases, cleaning systems that take more time can be used.

In some processes, disassembly of the equipment and some manual cleaning is inevitable for maintenance cleaning.
For operational cleaning, automated systems may be used.

There are overlaps between the techniques discussed in this section and also with those techniques discussed in Section 17.7.2 (Material-based techniques). The factors discussed here are summarised in Table 17.5, with the possible techniques from the two sections. Techniques may also be combined and/or repeated to achieve the necessary cleanliness.

Table 17.5: Examples of applicability of cleaning techniques and options

Cleaning techniques		Process equipment		Substrate or workpiece
Section	**Technique**	**Non-persistent contamination**	**Persistent contamination**	
This section	Minimisation of cleaning	Yes	Yes	Yes
17.9.2	Protection of spraying areas and equipment	Yes	Yes	No
17.9.3	Solids removal prior to complete cleaning	Yes	No	No
17.9.5	Use of low-volatility agents	Yes	Yes	Yes
17.9.6	Water-based cleaning	Yes	Yes	Yes
17.9.4	Manual cleaning with impregnated wipes	Yes	No	Yes
17.9.7	Enclosed washing machines	Yes	Yes	No
17.9.8	Purging with solvent recovery	Yes	No	No
17.9.9	Cleaning with high-pressure water spray	No	Yes	No
17.9.10	Ultrasonic cleaning	No	Yes	Yes
17.9.11	Dry ice (CO_2) cleaning	No	Yes	Yes

Cross-media effects

Changing from conventional techniques may result in more energy use, more waste water to be treated, or more waste being produced.

Technical considerations relevant to applicability

See Technical description above and individual techniques in Sections 17.9.2 to 17.9.12. The applicability of cleaning techniques in certain industries is also discussed in the industry-specific sections.

Economics

Site- and technique-specific.

Driving force for implementation

- Workplace health and safety.
- Quality and customer demands.

Example plants

Cleaning is carried out in all installations.

Reference literature

[108, ESVOCCG 2006] [212, TWG 2018]

17.9.2 Protection of spraying areas and equipment

Description

Application areas and equipment (e.g. spray booth walls and robots) susceptible to overspray and drips, etc. are covered with fabric covers or disposable foils where foils are not subject to tearing or wear.

Achieved environmental benefits

Reduction of VOC emissions.

Environmental performance and operational data

This technique minimises the need for cleaning and the consumption of cleaning materials used, especially solvents.

Source: [181, COM 2017] Plant #146 in [155, TWG 2016]

Figure 17.11: Robot applicator of sealant protected by a fabric cover

Cross-media effects

Generation of waste from the used protective covers.

Technical considerations relevant to applicability

Generally applicable in spraying coating or where robot application of sealants/wax occurs, e.g. in serial coating of vehicles (see Figure 17.11).

Driving force for implementation

Raw material savings and less frequent cleaning.

Example plants

Plant #146 in [155, TWG 2016].

Reference literature

[181, COM 2017] [155, TWG 2016]

17.9.3 Solids removal prior to complete cleaning

Description
Solids are removed in a (dry) concentrated form, usually by hand, with or without the aid of small amounts of cleaning solvent. This reduces the amount of material to be removed by solvent and/or water in subsequent cleaning stages, and therefore the amount of solvent and/or water used.

Technical description
Removing as much of the coating material, paint or ink as possible from the equipment in its concentrated form reduces the amount of material to be removed using solvents and/or water. Raw-material-saving techniques may be used, such as those described in Section 17.2.4.

Equipment parts are cleaned using solvents or water-based detergent systems. Physical rubbing, scraping or scouring is applied by brushes, wipes, abrasive pads, hand tools, etc. depending on the persistence of the contamination. The solvent is applied by rag or brush from a small supply (e.g. jug), tap or spray (fountain) or in open baths. Wipes pre-impregnated with solvents can be used (see also Sections 5.2.2.2, 6.4.3.4, and 17.2.2).

Achieved environmental benefits
Reduced solvent use and VOC emissions in subsequent cleaning stages.

Environmental performance and operational data
This technique reduces the use of solvents, cleaning materials and water which may require pretreatment prior to discharge. It can save raw materials.

When solvents are used, VOC emissions can be controlled by the following:

- Limiting the amount of solvent (e.g. by measuring and restricting the amount to be used in a jug, using pre-impregnated wipes).
- Applying volatile solvents by hand, and allowing the spent solvent to overflow immediately into a closed container. No open surface of liquid solvent should be exposed in the workstation close to the object to be cleaned. This also reduces occupational exposure. Equipment is available that consists of a closed drum containing solvents that can be pumped when required through a tap or sprayed onto the object to be cleaned in a partially enclosed work area above the drum. The surplus solvent runs back (through coarse filters) into the drum. The solvent is pumped from the surface of the solvent, leaving contamination to settle out. The solvent may be recycled when it can no longer be used.
- Using low-volatility solvents (see Section 17.9.5).

Cross-media effects
Generation of waste, and when solvents are used: consumption of solvents, emissions of VOCs and solvent/paint waste.

Technical considerations relevant to applicability
The applicability may be restricted by the type of process, the substrate or equipment to be cleaned and the type of contamination.

Some manual cleaning is almost inevitable in all sectors, although workplace health and safety often limits its use.

It may increase downtime. It may also increase staff contact with hazardous materials. Workplace health and safety may limit the application of this technique.

Economics
Low cost, but it may increase downtime.

Driving force for implementation

- Low cost.
- Savings in solvent use for subsequent cleaning steps.

Example plants
Widely used.

Reference literature
[1, INTERGRAF and EGF 1999] [5, DFIU et al. 2002] [27, VITO 2003] [180, COM 2017]

17.9.4 Manual cleaning with pre-impregnated wipes

Description
Wipes pre-impregnated with cleaning agents are used for manual cleaning. Cleaning agents may be solvent-based, low-volatility solvents or solvent-free.

Technical description
Wipes pre-impregnated with cleaning agents including tack-rags (a dry, impregnated, sticky rag) are used where manual cleaning is necessary; this limits the amount and type of solvents used. Wipes may be disposable or recycled for cleaning and reuse.

Achieved environmental benefits

- Minimised and controlled solvent usage,
- reducing solvent emissions,
- small savings in energy, water and raw materials.

Environmental performance and operational data
Manual labour is required. Workplace safety measures have to be considered to prevent inhalational or dermal exposure.

Cross-media effects
In the case of disposable pre-impregnated wipes, generation of waste.

Technical considerations relevant to applicability
The applicability may be restricted by the type of process, the substrate or equipment to be cleaned and the type of contamination.

In addition, health and safety considerations in the workplace may limit its applicability.

Economics
Low cost.

Example plants
Used in coil coating and the aircraft industry.

Reference literature
[212, TWG 2018]

17.9.5 Use of low-volatility cleaning agents

[78, TWG 2005]

Description

Manual or automated cleaning with organic solvents with low volatility and high cleaning power.

Technical description

As the coating is usually most readily soluble or resuspended in the original solvents, occasional use of traditional low-flashpoint cleaning agents will be necessary to assist in difficult cleaning tasks. A small amount of these (e.g. some 5 % of the total) will have to be kept in stock.

The evaporation rate of solvents determines the amount of solvent that will evaporate during the cleaning activity and the later storage of the contaminated wipes (a standard test may be used: DIN 53170[49]). Low-volatility cleaning agents may be classified in the following subclasses:

a) flashpoint of > 40 °C;
b) flashpoint of > 55 °C;
c) flashpoint of > 100 °C (high-boiling solvents, HBS);
d) vegetable cleaning agents (VCAs);
e) powerful non-volatile solvents.

The evaporation rate of traditional solvents is significantly higher than the evaporation rate of solvents with a flashpoint of > 40 °C. Consequently, the evaporation during cleaning can be reduced by using medium-flashpoint solvents. These solvents may be useful as an intermediate step when switching from volatile cleaning agents to less volatile cleaning agents.

In comparison with solvents with a flashpoint of more than 55 °C, the evaporation rate of traditional solvents can be some 100 times higher. Consequently, the evaporation during cleaning can be reduced dramatically by using high-flashpoint solvents.

Cleaning agents which have a flashpoint of > 100 °C are also called high-boiling solvents (HBS). They show even less evaporation (nearly zero) than solvents with a flashpoint of > 55 °C.

Vegetable cleaning agents (VCAs) are included in the group of cleaning agents with a flashpoint > 100 °C. The first generation of VCAs were simply refined vegetable oils, which were found to be rather thick and difficult to handle. The present generation of VCAs are mono-esters of different fatty acids with differing degrees of saturation (iodine numbers) and fatty acid content (acid numbers). Automatic cleaning systems especially constructed to be used with VCAs are available.

Powerful solvents can be used where a powerful solvent action is required, usually in cleaning. They can replace halogenated solvents.

Achieved environmental benefits

Benefits include reduced emissions to air during use as well as during storage of used solvents and cleaning materials and reduced hazardous waste generation. The risk of soil contamination from solvent-enriched air is also reduced.

As less solvent evaporates, solvent stays in contact with soiling and solvent consumption decreases.

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[49] DIN 53170: Solvents for paints and varnishes – determination of the evaporation rate, German Institute for Standardisation.

Reduction of VOC emissions to air depends on the situation at the start: substituting solvents with a flashpoint of < 21 °C may achieve a reduction of about 90 %; substituting solvents with a flashpoint of 21-55 °C can result in a reduction of about 50 %.

Vegetable cleaning agents (VCAs) are made from a renewable source and will, therefore, be considered greenhouse gas neutral.

Environmental performance and operational data

Higher-flashpoint solvents may not be as effective and efficient in cleaning as traditional solvents and the cleaning will require more time, but, with more experience, the results tend to become acceptable at some cases.

It is important to consider the health and safety and environmental impacts of low-volatility agents (see Section 17.6.1). For instance, very low OELs sometimes occur, e.g. 1 ppm or 2 ppm versus 150 ppm for ethyl acetate. Some VCAs are reported to possibly contain up to 15 % solvents or toxic ingredients (although these have not been defined further). Obviously, such VCAs may not add any environmental value or health and safety protection. The use of VCAs discussed in this section is based on VCAs that are free of solvents and toxic ingredients.

When used at room temperature, powerful low-volatility solvents have no emissions and limited health and safety equipment is needed. However, when used at a higher temperature to improve their effectiveness, these advantages may disappear.

Advantages occur when the alternative cleaning agent meets the following criteria:

- there is not a substantially lower occupational exposure limit or other toxicological impacts;
- the change in solvent does not lead to heating being required;
- the solvent is not dried by forced evaporation with high-pressure (HP) air.

N-methyl-2-pyrrolidone (NMP, a powerful, non-volatile solvent) has now been classified as a CMR substance.

Cleaning with HBS requires an after-cleaning step that is carried out with water. The water consumption and effluent discharge will also increase, because HBS is normally diluted with water. Water-HBS mixtures can be treated by applying filtration, after which the HBS can be reused and the water residue can normally be discharged into the sewerage system.

Some examples of the occasions where volatile cleaning agents may need to be used are the following:

- cleaning dampening rollers;
- maintenance;
- cleaning UV-cured inks;
- difficult colour changes.

Where alternative solvents with a lower volatility/higher flashpoint are used for cleaning floors, these solvents do not (by definition) evaporate rapidly, and therefore leave the floor slippery. It is therefore necessary to dry the floors, sometimes with small quantities of volatile solvents [97, TWG 2006].

Cross-media effects

In printing, paper losses may increase, as after intermediate cleaning it takes longer for the cleaning agents to disappear, which might result in the breaking of the web.

The less solvent that evaporates, the more that may be left as waste to be treated or disposed of. Cleaning with HBS and VCAs requires an after-cleaning step that is carried out with water, increasing water consumption and effluent discharge.

Technical considerations relevant to applicability

The applicability may be restricted by the type of process, the substrate or equipment to be cleaned and the type of contamination.

Before a low-volatility solvent is chosen for a specific application, it must be evaluated through tests to avoid insufficient cleaning results due to a wrongly selected cleaning solvent chemistry.

These solvents are applied in manual and automatic cleaning. They are commonly applied in heatset web offset printing where mixtures of VCAs and high-flashpoint solvents (55-100 °C) are often used in order to attain the right drying speed.

In the printing industry, where automatic cleaning systems are used in offset printing plants, it should be confirmed that there are no manufacturers' objections against the use of VCAs. Some automatic systems may be damaged by the use of these products. Automatic systems from before 1996 might especially require some adaptations in the dosing and spraying systems. Sometimes seals have to be replaced.

Applying HBS or VCAs requires a different working method compared to conventional solvents. The results of applying HBS or VCAs are therefore variable; however, often the results are favourable. This is mostly the case where presses are cleaned by hand. However, training and experience helps.

VCAs are applicable in sheetfed offset plants. In coldset and heatset web offset printing processes, it is used only for the final cleaning of the press. This is because during printing, the rinse water can easily break the paper web. A survey carried out in Denmark showed that about 65 % of the sheetfed offset printers use VCAs regularly, only using volatile solvents when it is necessary to remove dried ink. The consumption of VCAs at those plants accounts for about 2 % of all the solvents used. Other reports, e.g. from the Netherlands, show that these cleaning agents are not applicable in heatset web offset printing and not always in sheetfed printing. It is also reported that in heatset web offset printing the difference in emissions between HBS and VCAs does not justify the extra costs and time lost.

In flexography and non-publication rotogravure printing, high-flashpoint solvents are commonly used in small quantities to remove very persistent contamination. For daily cleaning of cleaning machines, however, these high-flashpoint cleaning agents are not commonly used, although some experiments are being carried out which have not been successful yet.

The uses of VCAs should be limited to those whose toxicology and other cross-media effects are known. VCA solvents may not be suitable for most of the water-based paint formulations in the automotive industry and plastic surfaces coating industry and the application of these VCAs has to be examined taking into consideration the cleaning efficiency in relation to the requested cycle time.

Economics

In printing, as cleaning may require more time and as press time is very expensive, the use of lower-volatility solvents rapidly becomes prohibitively expensive if press time is indeed lost. For example, loss in production time due to slower evaporation of the solvent can easily run up costs of over EUR 1 000 per hour in heatset web offset printing (2006 data).

Powerful non-volatiles: These are more expensive than traditional solvents.

VCAs: Often VCAs are four times more expensive than conventional cleaning agents. However, the volume of VCAs needed to clean a constant blanket surface is half of the volume of conventional cleaning agents. Generally, this technique is self-funding; however, the following conditions have to be taken into account (for example in the printing industries):

- retrofitting costs for automatic cleaning in old plants may be high;
- modern automatic cleaning units, if they still use high-volatility solvents, only use a few ml per cleaning cycle;
- even a small loss in production time per cleaning cycle makes this technique very expensive if expressed as EUR/kg not emitted.

Example plants

Widely used, but not applicable in all situations.

Reference literature

[1, INTERGRAF and EGF 1999] [7, Germany 2003] [8, Nordic Council of Ministers 1998] [11, InfoMil 2003] [12, Netherland 1996] [14, Aminal et al. 2002] [38, TWG 2004] [19, Austria 2003] [78, TWG 2005] [97, TWG 2006] [116, ESIG 2005] [212, TWG 2018]

17.9.6 Water-based cleaning

Description

Cleaning systems using water-based detergents or water-miscible solvents such as alcohols, glycols or amines.

Technical description

Water-based cleaning can be used on a continuous basis in vats using water-based cleaning or degreasing techniques based on detergent systems. It is also used to clean substrates or workpieces for subsequent water-based treatment techniques, e.g. see Section 17.7.1. Water-based systems can also be used to clean components and sub-assemblies, on a batch basis manually or in washing machines, for atomisers and handling tools for cleaning process lines, equipment and infrastructure, (see also Section 17.9.7, 17.9.8, and 17.9.9).

A range of chemical systems are used, based on combining detergents with alkalis (mostly amines) and others substances, depending on the substrates and the materials to be removed. These, and their associated maintenance options, are discussed in the STM BREF [23, COM 2006].

Paint supply lines and attached application equipment (spray bells or guns) with water-based paints can be purged with a 10 % to 15 % butylglycol-water mixture or with an aqueous rinsing medium on tensides with up to 1 % organic solvents [ACEA comment #505 in [212, TWG 2018].

Achieved environmental benefits

Reduced solvent consumption and fugitive VOC emissions.

Environmental performance and operational data

It may take longer to clean components than using solvent-based techniques, and a cleaning facility is required. Alternative practices (e.g. solvent-impregnated wipes) may just require a cleaning station.

While the solvent content can be significantly reduced, it should be noted that water-based cleaners may contain up to 15 % solvent.

Cross-media effects

A drying stage/oven is required and hence the process may require additional heating. As water use occurs, subsequent treatment of the waste water generated may be needed.

Technical considerations relevant to applicability

The applicability may be restricted by the type of process, the substrate or equipment to be cleaned and the type of contamination (e.g. 2K or UV-cured coatings are considered difficult).

Water-based cleaning agents are used in the automotive industry where water-based paints are used. They are applicable for various plastic parts including bumpers, wing mirrors, front fenders etc.

This technique is also used in the flexography and non-publication rotogravure printing industry.

Economics

More expensive than conventional solvent.

Driving force for implementation

Minimising emission concentrations and for quality reasons.

Example plants

In all VW plants, water-based cleaning agents are used for primer and base coat.
Examples for rinsing media based on tensides: Plant #046, Plant #045, Wrzesnia.
For the flexographic sector: Plant #014 in [155, TWG 2016].

Reference literature

[1, INTERGRAF and EGF 1999] [38, TWG 2004] [78, TWG 2005] [183, ACEA 2017] [197, FPE 2017] [212, TWG 2018] [155, TWG 2016]

17.9.7 Enclosed washing machines

Description

Automatic batch cleaning/degreasing of press/machine parts in enclosed washing machines. This can be done using either:

a) organic solvents (with air extraction connected with VOC abatement and/or recovery of used solvents); or
b) VOC-free solvents; or
c) alkaline cleaners (with external or internal waste water treatment).

Technical description

This is an enclosed machine which is loaded with components on a batch basis. The components can either be workpieces to be coated or process machine parts to be cleaned during maintenance or between orders.

The machine contains the cleaning material (VOC solvents, VOC-free solvents or alkaline cleaners) which are used to clean the parts by (i) immersion, (ii) spray or (iii) a vapour phase of low-boiling solvent which condenses on the components, therefore always depositing clean solvent on the components to be cleaned. When solvent-based, the solvents are contained, and collected for reuse. The solvent is usually heated.

Achieved environmental benefits

Solvent emissions are reduced significantly compared with uncontained cleaning.

Source: [180, COM 2017] Plant #133 in [155, TWG 2016]

Figure 17.12:Enclosed automatic washing machine

Environmental performance and operational data

The emission of VOCs from venting can be reduced considerably by directing them to an off-gas treatment system in the installation (e.g. thermal oxidation or adsorption on activated carbon).

Some cases of difficult deposits or persistent contamination may require removal with halogenated solvents where non-halogenated solvents do not have the same performance. These solvents shall be used in fully enclosed systems with treatment of the vented solvents. Article 57 of the IED requires substitution of those substances as soon as possible and the application of a relevant ELV (Annex VII).

Cross-media effects

The vessel of the machine holding the parts requires venting of the solvent vapours before the contents can be removed. These vented vapours are sometimes released to air.

Energy is used in pumping solvent.

Activated carbon is used if adsorption systems are employed, and the carbon needs regenerating or discarding as waste.

Technical considerations relevant to applicability

The applicability may be restricted by the type of process, the substrate or equipment to be cleaned and the type of contamination.

Driving force for implementation

Workplace health and safety. The IED sets specific ELVs for some halogenated solvents.

Example plants
Widely used in many industries.

Reference literature
[108, ESVOCCG 2006] [155, TWG 2016] [212, TWG 2018]

17.9.8 Purging with solvent recovery

Description
Collection, storage and, if possible, reuse of the solvents used to purge the guns/applicators and lines between colour changes.

Technical description
Solvent is used in a closed system to purge the guns/applicators and lines between colour changes to prevent cross-contamination. The purge and cleaning solvent is collected, stored and, if possible, reused.

Purging with solvent is used to clean the atomisers, guns/applicators, in/out double-door systems, handling tools, and lines between colour changes to prevent cross-contamination. Cleaning solvent is used to clean the equipment and booths. The purge and cleaning solvent can be collected, stored and reused as a solvent feedstock or destroyed. Not all recycled solvents can be used later for all processes, e.g. due to residual water content. Some modern plants are equipped with a recovery installation for the used cleaning agents.

Modern paint supply equipment including recovery of the purge solvents is commonly applied. Recovery is made by piping the cleaning agents from the application equipment to storage tanks.

Achieved environmental benefits
Typically most of the cleaning and purge solvents can be recovered for reuse.

Environmental performance and operational data
Problems are reported with two-component materials, which frequently lead to clogging of the recovery tank piping.

Technical considerations relevant to applicability
The applicability may be restricted by the type of process, the substrate or equipment to be cleaned and the type of contamination. The technique is mostly used for solvent-based cleaning processes, although it is expensive to retrofit.

Economics
In the automotive industry, a typical solvent recovery system cost EUR 0.4 million per spray booth to install in 2004.

A saving will be achieved because of the reduced consumption of solvents and reduced amounts of hazardous waste. In large plants, the savings will approximately outweigh the investment.

Driving force for implementation
Solvent recycling and VOC emission reduction.

Example plants
The technique is standard practice in the automotive industry and widely used in other sectors.

Reference literature
[1, INTERGRAF and EGF 1999] [5, DFIU et al. 2002] [26, CITEPA 2003] [32, ACEA 2004], [38, TWG 2004] [212, TWG 2018]

17.9.9 Cleaning with high-pressure water spray

Description
High-pressure water spray and sodium bicarbonate systems or similar are used for automatic batch cleaning of press/machine parts.

Achieved environmental benefits
Benefits include reduction of solvent emissions. Washing floor grids in paint cabins with subjacent paint overspray abatement systems ensures that optimum downdraught is maintained and avoids a reduction in abatement efficiency [ACEA comment #365 in [212, TWG 2018]].

Environmental performance and operational data
In the automotive sector, it is used for water washing of equipment parts after caustic dipping, and regularly for cleaning of floor grids and carriers (regular cleaning of floor grids between the spray booth and the venturi scrubber). High-pressure cleaning is allowed at a hydrostatic pressure of 40 bar to 250 bar. Because of the high pressure of the water jet (40-250 bar), vehicle bodies are not cleaned by high-pressure cleaning. However, spray cleaning with low pressure (5-20 bar) is standard and usually integrated in the dip cleaning process [ACEA comment #365 in [212, TWG 2018]].

Cross-media effects
Water consumption is increased and more waste water will be generated although this can be minimised using high-pressure spray washing.

Technical considerations relevant to applicability
The applicability may be restricted by the type of process, the substrate or equipment to be cleaned and the type of contamination. This technique is used for in-depth cleaning of doctor blades, cylinders and anilox rollers used in flexography and non-publication rotogravure printing. Sodium carbonate is added to the high-pressure water. It has also been reported by coil coating plants.

Driving force for implementation
Workplace health and safety, and maintaining abatement efficiency.

Example plants
Used in various sectors; for coil coating: Plant #105 in [155, TWG 2016].

Reference literature
[1, INTERGRAF and EGF 1999] [38, TWG 2004] [212, TWG 2018] [155, TWG 2016]

17.9.10 Ultrasonic cleaning

Description
Cleaning in a liquid using high-frequency vibrations to loosen the adhered contamination.

Technical description
An ultrasonic cleaner generates high-frequency vibrations through a liquid (usually water-based detergents), i.e. ranging from about 20 000 to 100 000 cycles per second. The vibrations create microscopic bubbles in the liquid that then collapse on items that are immersed in the liquid, creating a cleaning action.

The cleaning performance may be improved if the temperature of the water-based mixture is between 40 °C and 60 °C [PT comment #3 in [212, TWG 2018]].

Achieved environmental benefits
No solvent-based cleaning agents are used and VOC emissions are eliminated. However, sometimes a small post-cleaning process with VOC-containing solvents may be necessary.

Cross-media effects
Noise levels might increase. And energy consumption may increase due to the need to heat the water-based mixture.

Technical considerations relevant to applicability
The applicability may be restricted by the type of process, the substrate or equipment to be cleaned and the type of contamination.

The technique is applied in flexography and non-publication rotogravure printing for in-depth cleaning of cylinders and anilox rollers.

It is not applicable for substrates and parts that might be damaged by the ultrasonic vibrations.

Driving force for implementation
Workplace health and safety.

Reference literature
[8, Nordic Council of Ministers 1998] [23, COM 2006] [38, TWG 2004] [212, TWG 2018]

17.9.11 Dry ice (CO_2) cleaning

Description
Cleaning of machinery parts and metallic or plastic substrates by blasting with CO_2 chips or snow.

Dried paint or ink can be removed by blasting with dry ice pellets. For cleaning using CO_2 snow, see Section 17.9.11.1.

Achieved environmental benefits
Solvent emissions are completely avoided.

Environmental performance and operational data
The preparation takes a lot of time as the parts of the machine to be cleaned must be totally isolated to prevent damage to other parts.

Cross-media effects
Blasting requires energy and creates noise (in-house) and dust from removed paint or ink.

Technical considerations relevant to applicability
The technique is widely applicable for maintenance cleaning rather than daily cleaning processes as disassembly of machine parts is usually involved.

In printing, the technique is used to get rid of very persistent contamination on parts of the presses. It is applied every few months for periodic intensive cleaning in publication rotogravure and heatset web offset printing plants, where toluene or special mixtures of solvents are normally used as a cleaning solvent.

Dry ice cleaning is well established in the pretreatment for plastic parts before further coatings. The CO_2 cleaning process for cleaning contaminated spraying equipment in the spray booth is not yet developed [ACEA comment #440 in [212, TWG 2018]].

Economics

Costs are comparable to conventional cleaning techniques.

Driving force for implementation

Workplace health and safety.

Example plants

The technique is used in flexography and non-publication rotogravure, publication rotogravure and heatset web offset printing plants Europe-wide. It is also used in the pretreatment of plastic surfaces before coating.

Reference literature

[1, INTERGRAF and EGF 1999] [7, Germany 2003] [23, COM 2006] [38, TWG 2004] [212, TWG 2018]

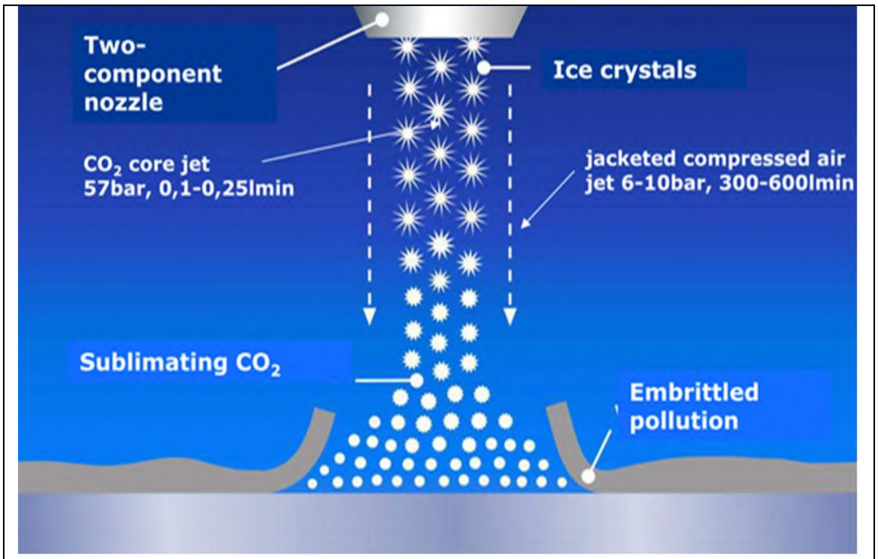
17.9.11.1 CO_2 snow cleaning

Description

Surface cleaning by use of accelerated CO_2 snow with an applicator (nozzle array) installed on a robot.

Technical description

Liquid CO_2 passes the nozzle under pressure and cools down due to the expansion behind the nozzle. The CO_2 ice crystals are accelerated by air (see Figure 17.13 below).



Source: [190, ESVOC 2017]

Figure 17.13:Liquid CO2 discharge

The energy which is released when the ice crystals collide with the surface to be cleaned removes dust and other dirt.

The CO_2 snow cleaning installation consists of the following components:

- robot with six or seven axes equipped with application equipment:
- process valves installed on the robot housing between Arm 1 and Arm 2;
- applicator (nozzle arrays) installed on the robot hand axis;
- application cabinet outside the robot zone:
  - CO2 cooler;

  - air filter device;
  - robot controller cabinet;
- CO2 supply system consisting of a CO2 tank, compressor and cooling system.

Source: [190, ESVOC 2017]

Figure 17.14: (a) Applicator robot, (b) High-pressure CO_2 tank, (c) Low-pressure CO_2 tank

Achieved environmental benefits

- Lower energy use.
- No dryer needed, reduced energy consumption.
- No use of water/chemicals.

Environmental performance and operational data

This technique replaces the power wash pretreatment and water dryer oven.

Less maintenance:

- no dosing of chemicals needed;
- flexible system with good reachability due to the use of the robot;
- same operation as application robots;
- same spares as for the application robots.

Process advantages:

- no use of water/chemicals;
- only a few process parameters to be adjusted;
- elimination of surface errors caused by water.

Operation environment needed:

- soundproofed booth design (noise level outside the booth):< 75 dBA, noise level on the nozzles approximately 105-110 dBA);
- air return plenum under the conveyor;
- lack of non-ventilated areas in the booth;
- safety-protected booth doors and booth entrance;
- operation of the booth must be in underpressure;
- fresh air blade in the entrance and exit of the booth in order to maintain the CO2 concentration inside the booth;

- the MAK (maximum allowed concentration in the workplace) values must be controlled inside and outside the booth with CO_2 sensors, category 3, redundant:
    - air downdraught velocity: 0.4-0.5 m/s;
    - fresh air portion: approximately 2025 %;
    - temperature: > 20 °C;
    - relative humidity: max. 55 %;
    - ionisation portals after the cleaning zone.

Technical considerations relevant to applicability

The technique is applied in plastic parts cleaning and for the cleaning of general industrial components.

Some residues cannot be removed by snow cleaning; therefore the following preconditions have to be met:

- no outside storage of parts in open air;
- no fingerprints, grease, oil, mould-release agents and other strong adhesive dirt/residues on the part;
- short time period between the moulding process and painting;
- clean room principle for the whole paint line.

Economics

- Investment cost for retrofitting.
- Cost reduction due to material and energy savings.
- Higher first run (no surface errors caused by water).

Driving force for implementation

- Higher quality, no water spots on the bumper surface. Elimination of surface errors caused by water.
- Reduction of cost per unit.
- No blowing zone necessary.
- Reduction of footprint. Only one booth for the cleaning robot. No cooling zone necessary.

Example plants

Rehau Viechtach, Germany, 2008.
Plastic Omnium, Gliwice, Poland, 2012.
Rehau Györ, Hungary, 2013.
Volkswagen Wolfsburg, Germany, 2013.
Rehau, Port Elizabeth, South Africa, 2009 and 2013.
Plastic Omnium, Mexico.
Plastic Omnium, Chattanooga, US.

Reference literature

[190, ESVOC 2017] [212, TWG 2018]

17.9.12 Plastic shot-blast cleaning

Description

Excess paint build-up is removed from panel jigs and body carriers by shot-blasting with plastic particles.

Technical description

Customised shot-blasting cabinets are used for jigs, with specified ranges of blast pressures and nozzle sizes to achieve optimum cleaning, depending on the size and contamination level of the jigs.

A customised compartment is required for larger equipment such as paint dollies and scrap painted bumper parts.

It is also used in the removal of coating from aircraft or other metal and plastic surfaces.

Achieved environmental benefits

Elimination of the use of hazardous cleaning chemicals which were previously necessary.

Environmental performance and operational data

- Cleaning method does not use harmful chemicals.
- Extends life of production equipment and tools.
- Potential to minimise scrap plastic painted parts by allowing removal of paint and subsequent respray.
- To be trialled on scrap plastic bumpers to allow repainting.

Technical considerations relevant to applicability

Several other materials have been considered for shot-blasting. These include metal, sand and glass. All were too abrasive and caused damage to the jigs after several cleans.

Other cleaning technologies have also been considered:

- An aqueous energy ultrasonic tank considered was unable to breakdown a 2K clear coat.
- An insulated reactor containing sand heated to 450 °C caused damage due to the abrasive nature of the process.

Economics

- Reduced cleaning cost by 50 %.
- Requires initial cost investment to buy shot-blasting equipment and the custom-building of a chamber for cleaning larger body carriers.

Driving force for implementation

- Cleaning cost reduction.
- Reduced contamination of jigs and transfer to painted bodies.
- Improved quality and less rework.

Example plants

Honda of the UK Manufacturing Ltd. (HUM), Swindon, UK.
Aircraft maintenance: EAB AE, GR.

Reference literature

[190, ESVOC 2017]

17.10 Off-gas extraction and treatment

This section discusses applied off-gas treatment systems. It not only discusses the different types of treatments that are available, but also the design and layout. The section also covers techniques to optimise or minimise the airflow that has to be treated and techniques to recover the abated solvents, such as distillation.

Especially for VOC emissions, Annex 21.6 provides a summary of off-gas treatment techniques for VOC emissions abatement (oxidation, adsorption, condensation and biological treatment) and their applicability. A comparison of the removal efficiencies of the most widely used techniques is given for different types of solvents and for various inlet concentration ranges [97, TWG 2006]. Removal efficiencies as reported in the STS data collection [155, TWG 2016] are also presented and discussed.

17.10.1 System selection, design and optimisation

Description
An off-gas treatment system is selected, designed and optimised taking into account parameters such as:

- amount of extracted air;
- type and concentration of solvents in extracted air;
- type of abatement system (dedicated/centralised);
- health and safety;
- energy efficiency.

The following order of priority for the system selection may be considered:

- segregation of off-gases with high and low VOC concentrations;
- techniques to homogenise and increase the VOC concentration (see Sections 17.10.3.2 and 17.10.3.3);
- techniques for the recovery of solvents in off-gases (see Section 17.10.6);
- VOC abatement techniques with heat recovery (see Section 17.10.5);
- VOC abatement techniques without heat recovery (see Section 17.10.5).

Technical description
Air extraction systems containing solvents are usually primarily designed to keep atmospheres within working areas and equipment well below the LEL and the solvent concentrations lower than the OEL. The extracted air from key point sources of solvents is directed to off-gas treatment systems.

In some cases (such as drying ovens, washing machines using solvents), the air is exhausted to treatment with the primary aim of reducing solvent emissions. Also, in many cases, the original purpose of treating the off-gas is to reduce odour nuisance.

Capturing emissions is facilitated if activities are contained. The size of the containment should be the minimum necessary for the practical operation of the process step. The airflow should be the minimum necessary to ensure process safety and control occupational exposure risks (OEL). Focus should be on capturing emissions in the smallest air volumes and with the highest possible concentration in order to maximise the efficiency of the downstream treatment while optimising the relevant energy consumption. Depending on the process, localised enclosure and extraction may be considered instead of full enclosure and extraction option. Detailed design and adequate dimensioning are important to prevent unnecessarily large quantities of dilution air being drawn into the system and increasing costs and reducing abatement efficiency.

The dimensioning of the extraction system and the selection of the abatement technique take into account:

- the emissions pattern (continuous/discontinuous);
- the energy content of off-gases and the effect of energy consumption below autothermal conditions;
- the costs and benefits of treating emissions with low VOC concentrations, in terms of energy consumption.

The design of the extraction systems should take into account:

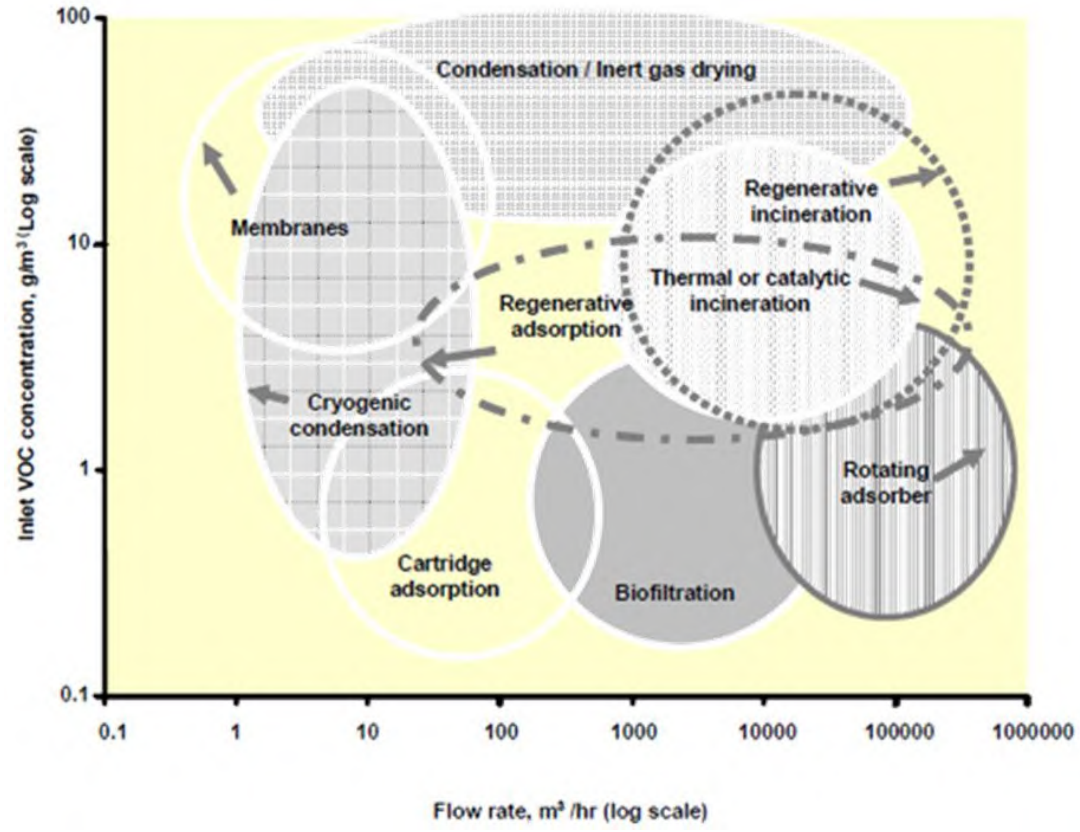
- the amount of air to be extracted;
- the type and likely level of solvents;
- the type and likely level of concomitant substances which themselves or their combustion products may cause corrosion, deposits or residues;
- the type of treatment and its cost-benefit and cross-media effects (e.g. material, energy consumption);
- the number of hours per year in operation;
- using decentralised/dedicated treatment systems so breakdown/repair only affects the systems in question;
- health and safety considerations.

Extraction of a large volume of air in proportion to solvent increases the size of the abatement system and may increase the amount of energy required as support fuel for combustion.

Fugitive emissions that are not caught by extraction systems and emissions after off-gas treatment form the total solvent emissions. This must be considered when designing an extraction and abatement system.

An example considering the cross-media effects in flexographic printing of water-based versus solvent-based inks is given in the ECM REF [50, COM 2006].

Figure 17.15 gives a schematic overview of the available VOC abatement techniques against two important criteria: VOC concentration and flow rate. This is shown for indicative purposes and is not meant to be exhaustive. A detailed assessment should be done on a case-by case basis.



Source: [24, ESIG 2000]

Figure 17.15: **Overview of application ranges of the available VOC abatement technologies**

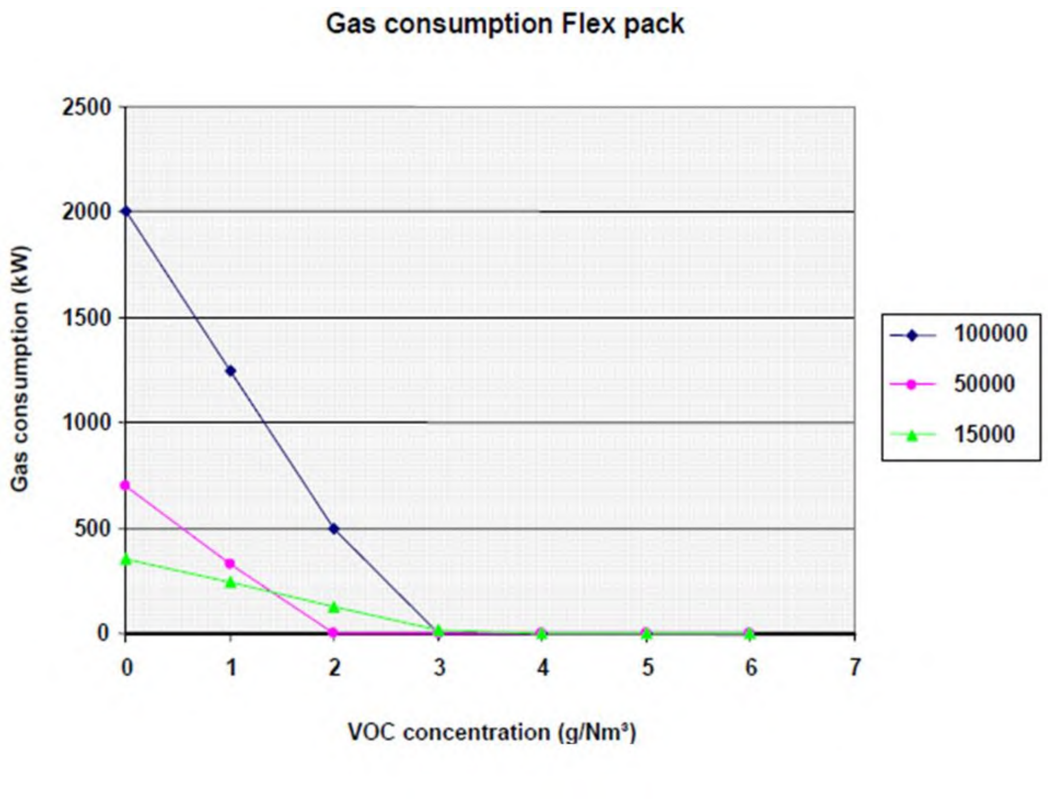
The following considerations can assist in the system selection, design and optimisation, although expert guidance may be sought:

- **Discontinuous emissions**: for discontinuous processes, variable and small load techniques such as simple thermal oxidation or adsorption are most cost-effective.

- **Selection of thermal treatment for continuous operation** [62, Verspoor et al. 2005]: where the emissions are continuous, see Section 17.10.5 on the applicable techniques.
  See also Section 17.10.3 for techniques related to maintaining the VOC concentration prior to treatment.

  In treatment techniques with regenerative preheating (regenerative thermal oxidation, RTO plants), by far the greatest share of process energy is recovered by integrated heat exchangers (> 95 %). Therefore, the energy requirement in the off-gas treatment for achieving a VOC concentration of the order of 20 mg C/m^3 in treated gas is not significantly higher than the energy needed for achieving only 50 mg C/m^3 or 100 mg C/m^3. However, there is higher energy consumption for the main fan of the extraction system, and higher maintenance costs. If process temperatures are lowered because higher VOC concentrations in treated gas are permitted, CO emissions may rise considerably.

- **Effect of energy consumption below autothermal conditions**: for the effect on the running cost of the thermal treatment system when the average solvent content structurally reduces over time, due to (for instance) a decrease in the solvent content of the coating materials in use, see Figure 17.16. This shows data for a thermal oxidiser on a flexography and non-publication rotogravure printing plant. The amount of gas used after the autothermal point increases exponentially for medium and low flows.



Source: [62, Verspoor et al. 2005]

Figure 17.16:Example of gas consumption below the autothermal point for a flexography and non-publication rotogravure printing plant for three flow rate scenarios

- **Cost-benefit of energy consumption to control low solvent emissions**: the ECM REF [50, COM 2006] describes ways of calculating and interpreting cross-media effects for alternative process options by collating emissions into seven environmental effects (themes). These effects can be compared using scales of relative effect for the individual substances released or their toxicities (see also Section 17.6.1). However, it is difficult to compare one effect against another and further cross-media evaluation is required.

An alternative method to compare these different effects is to compare the costs of the negative externalities (damage or negative marginal social costs), in this case the damage to the environment includes human health. There may be fewer data available for this, but data are available for emissions to air (see further below). This technique may be used to compare the effectiveness of different courses of action. For example, burning a support fuel to achieve lower VOC emissions in waste gas can be compared with further measures to reduce fugitive emissions. The tonnes of CO_2 released a year can be calculated for burning additional fuel to destroy a known amount (in tonnes) of VOC emission (e.g. reducing the emission levels from 10 mg C/m^3 to 3 mg C/m^3 for a described waste gas flow). These can then be multiplied by the relevant marginal social cost and compared. Comparing the damage for CO_2 with those for VOCs are simplistic: changes in NO_X also need to be taken into account (if known). Also, the CO_2 contribution from the burnt VOCs should be added in.

At the EU level, a range of average VOC damage compared with a central bound of CO_2 costs gives a range of 32-140 tonnes of CO_2 to abate one tonne of VOCs (40 000-175 000 m^3 of natural gas), see Table 17.6. However, these cost ratios give a cost of abatement of one tonne of VOCs of between EUR 14 000 and EUR 63 000, which exceeds the marginal damage of VOCs per tonne by 10 to 66 times (based on a cost of gas of EUR 7.52 to EUR 10.48 per GJ in 2006). Two countries (Belgium and the Netherlands) use cost-benefit benchmarks of EUR 3 200 and EUR 4 500 (respectively) as the total cost per tonne of VOCs abated. This would indicate that these comparisons significantly exceed the economic feasibility of burning this amount of gas at the EU-25 level. (It may be that the marginal social cost of CO_2 used is too low).

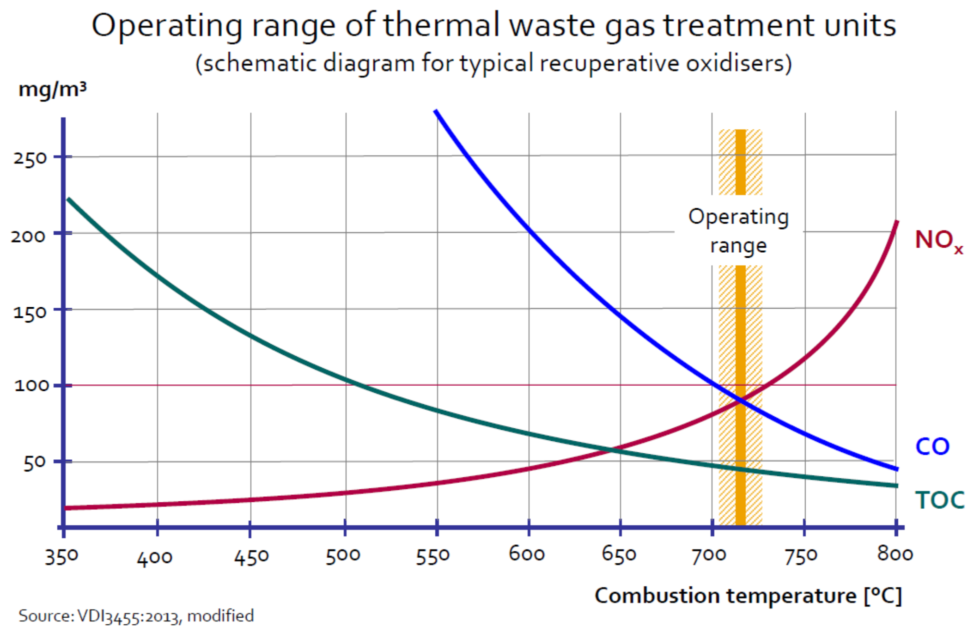
These values do not take into account any CO_2 or any NO_X impacts derived from oxidising VOCs.

Table 17.6: Comparison of marginal social costs of climate change with marginal damage costs from VOC emissions

Marginal social costs of climate change (EUR/t CO_2)	Marginal damage for VOCs (EUR/t emission)	Tonnes of CO_2 to abate 1 tonne VOCs	Thousand m^3 natural gas to abate 1 tonne VOCs (1)
10	950	95	119
10	1400	140	175
20	950	48	60
20	1400	70	88
30	950	32	40
30	1400	46	58
(1) Based on a density of natural gas of 0.8 kg/m^3 at STP (2006 data).			

- **Influence of limit value for CO**: the level of CO emitted from the thermal oxidiser mainly depends on the combustion chamber temperature and the residence time of the exhaust gas inside the combustion chamber. To lower emission levels for CO means the following:
  - Increasing the combustion chamber temperature (results in higher running costs). Usually it is enough to increase the combustion temperature to about 850 °C for regenerative thermal oxidisers or to about 750 °C for recuperative thermal oxidisers. At VOC concentrations near or above the autothermal point, this will be automatically achieved. The total influence on running and capital costs with regard to lower CO levels can be seen as negligible.
  - Increasing the combustion chamber size to have a longer residence time (results in higher investment costs).

- **Balance between CO, NO_X and VOC reduction**: a balance needs to be established between VOC, CO and NO_X emissions (optimisation curves), and this will be different for each plant. In general, emissions of CO and NO_X mirror one another, with one increasing as the other decreases. A schematic diagram for the achievable emission levels of TVOC, NO_X and CO for a typical recuperative thermal oxidiser is presented in Figure 17.17.



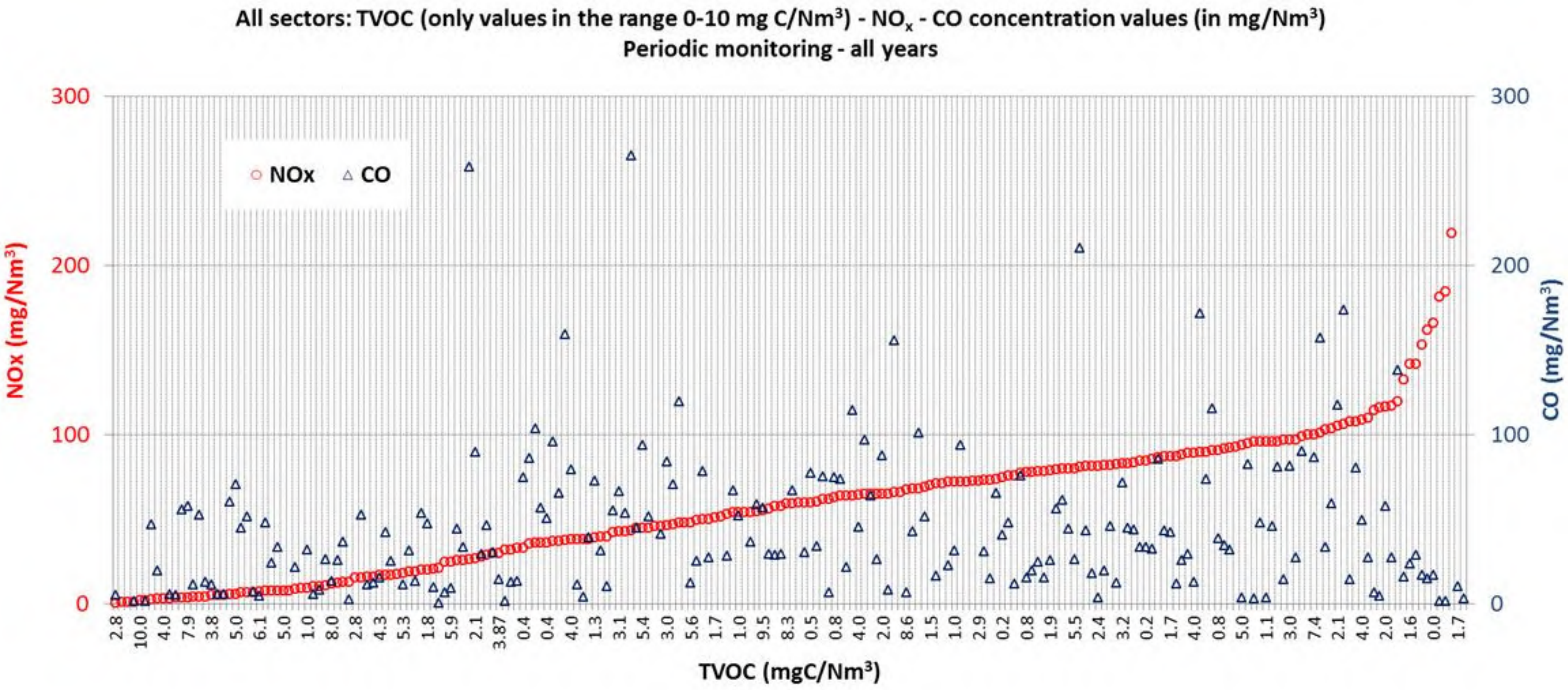
Source: [ACEA comment #371 in [212, TWG 2018]]

Figure 17.17:Schematic diagram for the achievable emission levels of TVOC, NOX and CO for a typical recuperative thermal oxidiser

However, reported data for the achievable TVOC, NO_X and CO emission levels from all STS sectors where thermal treatment of off-gases is applied show that low TVOC levels are combined with low NO_X/CO concentrations in waste gases (see Figure 17.18 (a), (b) and (c)).

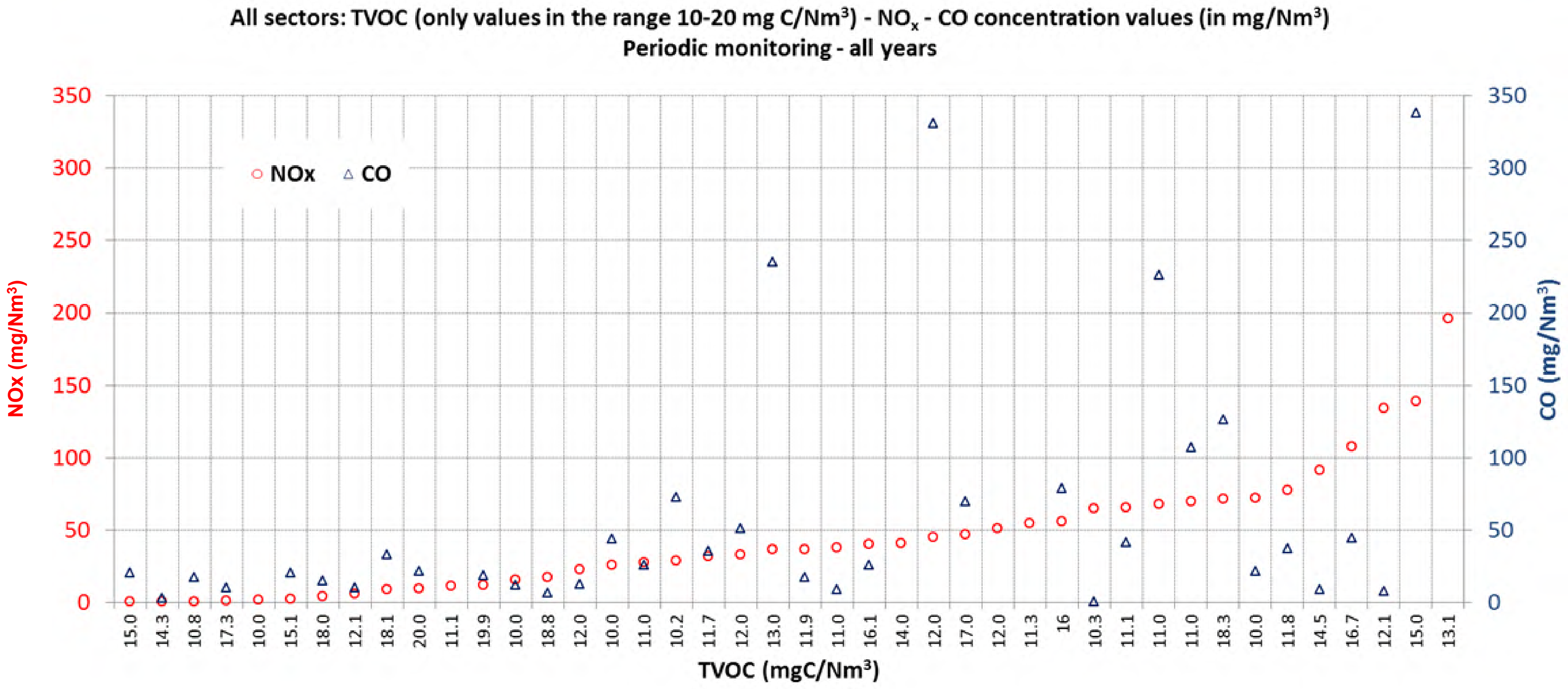
Data are presented in three ranges according to the achieved TVOC levels: a) for TVOC levels lower than 10 mg C/Nm^3, b) for TVOC levels in the range of 10 mg C/Nm^3 to 20 mg C/Nm^3 and c) for TVOC levels higher than 20 mg C/Nm^3.

a)



NB: Graph contains emission points for which data are available for TVOC and one or both of NOx and CO.

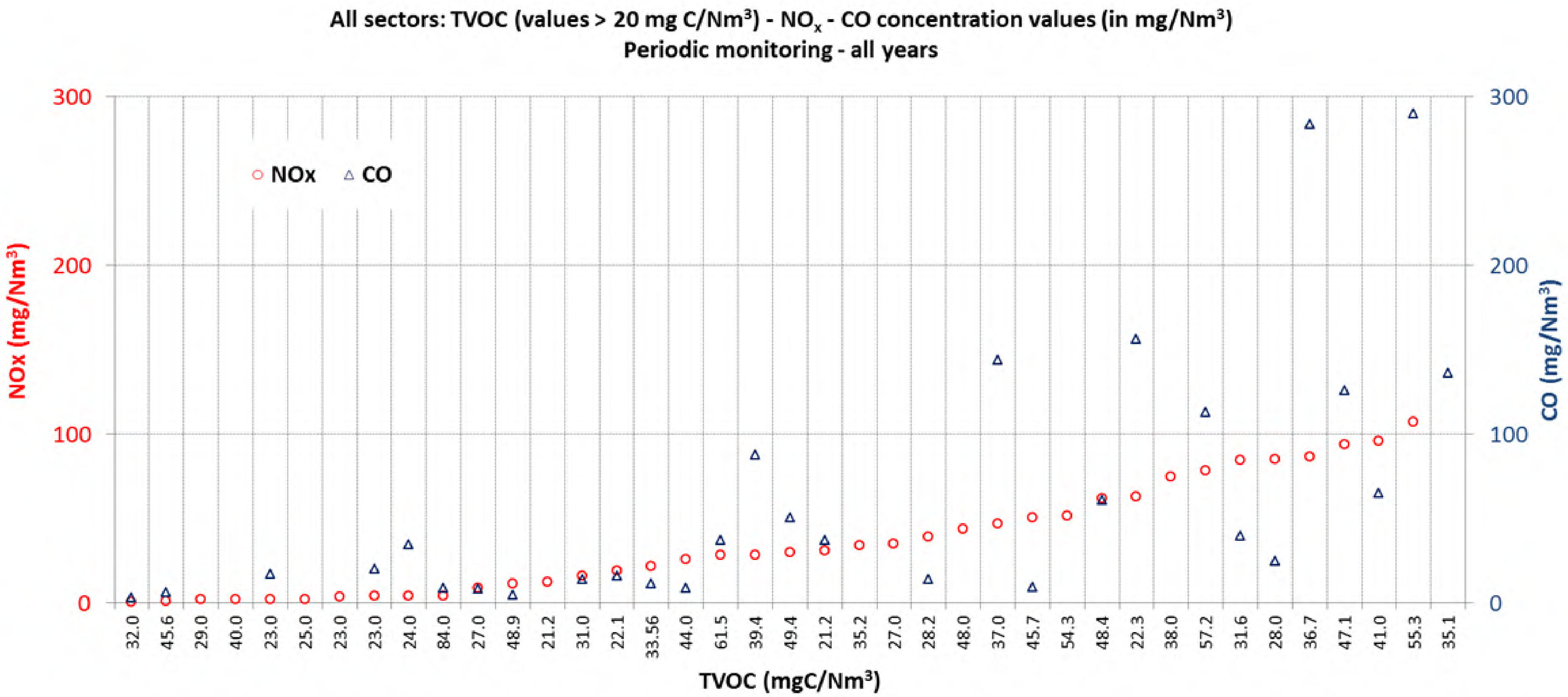
b)



All sectors: TVOC (only values in the range 10-20 mg C/Nm³) - NO_x - CO concentration values (in mg/Nm³)
Periodic monitoring - all years

NB: Graph contains emission points for which data are available for TVOC and one or both of NOx and CO.

c)



NB: Graph contains emission points for which data are available for TVOC and one or both of NOx and CO.

Source: [155, TWG 2016]

Figure 17.18: **Reported emission levels of TVOC, NO_X and CO from plants from all STS sectors where thermal treatment is applied**

- **Maintenance**: see Section 17.2.6.

Achieved environmental benefits
VOC and odour reductions can be achieved where there is appropriate selection, design and optimisation of the off-gas treatment system.

Environmental performance and operational data
For data on individual techniques, see the relevant sections.

Cross-media effects
Energy consumption in air extraction systems can be significant. Energy consumed to reach low VOC concentrations may be significant. Noise can be a significant factor.

Technical considerations relevant to applicability
Generally applicable.

Economics
Site- and technique-specific. For data on individual techniques, see the relevant sections.

Driving force for implementation

- Extraction: workplace health and safety.
- All considerations: odour nuisance, national/local legislation.

Example plants
Widely used in various STS sectors where off-gas systems are used.

Reference literature
[38, TWG 2004] [50, COM 2006] [78, TWG 2005] [113, ECN 2005]
[66, AEA et al. 2005] [114, AEA et al. 2005] [155, TWG 2016]

17.10.2 Containment and collection of off-gases

This section describes the containment and collection of off-gases from coating/inking applications and drying processes. In addition, techniques related to internal or external solvent concentration (increase of solvent concentration in the raw gas) are also discussed in Sections 17.10.3.2 and 17.10.3.3. The handling and storage of solvents is discussed in Section 17.2.2. The choice of collection and treatment systems is also discussed in the CWW BREF [31, COM 2016].

17.10.2.1 Air extraction as close as possible to the point of ink/coating application

Description
Air extraction as close as possible to the point of application with full or partial enclosure of solvent application areas (e.g. coaters, application machines, spray booths) and possible subsequent treatment of the extracted air.

Achieved environmental benefits

- Reduction of fugitive emissions and noise.
- Reduction of volume of air to be extracted (and therefore energy used for extraction).
- Reduction of size of, and energy used in, off-gas treatment.

Environmental performance and operational data
This information (where available) is detailed in this document for each type of activity in the dedicated chapters (Chapters 2 to 15).

Parts of the machinery or whole lines can be encapsulated/enclosed to avoid the release of fugitive emissions. Enclosure may also be for workplace health and safety, to reduce the risk of injuries from machinery or to reduce noise.

Air may be extracted from the application machinery used in the main process, such as printing presses, coil coating lines or automotive coating lines. The application equipment may be open (in reality, extraction is from the whole room: this is used in some industries for health and safety reasons) or partially or totally enclosed.

Cross-media effects
Energy consumption for extraction and treatment.

Technical considerations relevant to applicability
May not be applicable where enclosure leads to difficult machinery access during operation. Applicability may be restricted by the shape and size of the area to be enclosed.

Economics
For existing machines, containment is often not available from providers but needs to be designed individually, implying higher costs. Additional containment may increase operating and maintenance costs if access to machinery is made more difficult.

Driving force for implementation
Workplace health and safety.

Example plants
Widely used in various sectors.

Reference literature
[7, Germany 2003] [22, ECCA 2004] [38, TWG 2004] [78, TWG 2005]
[212, TWG 2018]

17.10.2.2 Air extraction as close as possible to the point of preparing the paints/coatings/adhesives/inks

Description
Air extraction as close as possible to the point of preparing paints/coatings adhesives/inks (e.g. mixing area). Extracted air may be treated by an off-gas treatment system.

Achieved environmental benefits
Reduction of fugitive emissions.

Environmental performance and operational data
This information (where available) is detailed in this document for each type of activity in the dedicated chapters (Chapters 2 to 15).

Cross-media effects
Energy consumption for extraction and treatment.

Technical considerations relevant to applicability
Only applicable where paints/coatings/adhesives/inks are prepared.

Driving force for implementation
Workplace health and safety.

Example plants
Widely applied in coil coating. Example plants for other sectors: Plants #015 (flexography), #128 and #136 (coating of textiles, foils and paper) and #166 (coating of plastic surfaces) in [155, TWG 2016].

Reference literature
[38, TWG 2004] [78, TWG 2005] [179, COM 2017] [155, TWG 2016]

17.10.2.3 Minimisation of fugitive emissions and heat losses from the ovens/dryers either by sealing of the entrance and the exit of the curing ovens/dryers or by applying subatmospheric pressure in drying

Description
The entrance to and the exit from curing ovens/dryers are sealed to minimise fugitive VOC emissions and heat loss. The sealing may be ensured by air jets or air knives, doors, plastic or metallic curtains, doctor blades, etc. Alternatively, ovens/dryers are kept under subatmospheric pressure.

Achieved environmental benefits
Minimisation of fugitive emissions and heat loss (energy savings).

Environmental performance and operational data
This information (where available) is detailed in this document for each type of activity in the dedicated chapters (Chapters 2 to 15).

Technical considerations relevant to applicability
Only applicable when curing ovens/dryers are used.

Example plants
Widely used, reported by the majority of plants for almost all STS sectors.

Reference literature
[22, ECCA 2004] [38, TWG 2004] [78, TWG 2005] [155, TWG 2016] [212, TWG 2018]

17.10.2.4 Extraction of air from the drying/curing processes

Description
The curing ovens/dryers are equipped with an air extraction system. Extracted air may be treated by an off-gas treatment system.

Achieved environmental benefits
Reduction of VOC emissions.

Environmental performance and operational data
This information (where available) is detailed in this document for each type of activity in the dedicated chapters (Chapters 2 to 15).

Cross-media effects
- Extraction requires energy.
- Noise levels might increase.

Technical considerations relevant to applicability
Only applicable to drying/curing processes.

Driving force for implementation
Workplace health and safety.

Example plants
Widely used, reported by the majority of plants for almost all STS sectors.

Reference literature
[7, Germany 2003] [22, ECCA 2004] [38, TWG 2004] [155, TWG 2016]

17.10.2.5 Extraction of air from the cooling zone

Description
When substrate cooling takes place after drying/curing, the air from the cooling zone is extracted and may be treated by an off-gas treatment system.

Achieved environmental benefits
While its effect on VOC emissions may be limited, it is considered relevant for occupational health or, in some cases, it could be used for energy recovery.

Environmental performance and operational data
This information (where available) is detailed in this document for each type of activity in the dedicated chapters (Chapters 2 to 15).

For the metal packaging sector, available information shows that TVOC emissions from the cooling zone could be in the range of 16-180 mg/Nm^3 (data from one plant for 2017) [226, MPE 2018].

Cross-media effects
Energy consumption for extraction and treatment.

Technical considerations relevant to applicability
Only applicable when substrate cooling takes place after drying/curing.

The technique is commonly applied in coil coating installations (see Section 6.4.5.7). It is also reported by plants from various other STS sectors: coating and printing of metal packaging, coating of vehicles, heatset web offset printing, flexography and non-publication rotogravure printing (see also example plants below).

Driving force for implementation
Workplace health and safety, and limitation of fugitive emissions.

Example plants
Plants: #001, #003, #021, #039, #042, #043, #108, #109, #113, #115, #116, #121 and #122 in [155, TWG 2016].

Reference literature
[5, DFIU et al. 2002] [22, ECCA 2004] [38, TWG 2004] [155, TWG 2016]
[212, TWG 2018] [226, MPE 2018]

17.10.2.6 Extraction of air from storage of raw materials, solvents and solvent-containing wastes

Description

Air from raw material stores and/or individual containers for raw materials, solvents and solvent-containing wastes is extracted and may be treated by an off-gas treatment system.

Technical description

For safety reasons, containers with hazardous materials with a high vapour pressure or high toxicity are stored in enclosed and vented warehouses. Large storage containers with such substances may have individual air extraction points. Extracted air may be directed to an off-gas treatment system.

Achieved environmental benefits

Reduction of fugitive emissions if the extracted off-gas is treated.

Environmental performance and operational data

This information (where available) is detailed in this document for each type of activity in the dedicated chapters (Chapters 2 to 15).

Generally, the VOC emissions are prevented by measures like application of closed systems which means that containers are always closed when stored. In the case of larger tanks under overpressure, relief valves are applied for breathing, where possible connected to an off-gas treatment system. For loading/unloading from tanks, vapour balancing is applied or the gases are directed to an off-gas treatment unit. The extraction of the air from the raw material store may be considered the final measure for VOC reduction.

Cross-media effects

- Noise levels might increase.
- Extraction increases the energy consumption.

Technical considerations relevant to applicability

The technique may not be applicable for small closed containers or for storage of raw materials, solvents and solvent-containing waste with a low vapour pressure and low toxicity.

It is applicable in new and existing plants and all closed storage for wastes containing solvent, although whether the extracted air is fed to off-gas treatment will depend on the volume and concentration. The VOC concentrations are usually low.

It is commonly applied in publication rotogravure printing plants.

Economics

The costs are low compared to the total cost of the solvent recovery system. The savings for each kg of toluene recovered are about EUR 0.50 (2006 data). The extra capacity needed does, however, cost money. The cost per kg not emitted is high.

Driving force for implementation

Workplace health and safety.

Example plants

Extraction from the storage area is widely used. Treatment of extracted air is not common.

Reference literature

[7, Germany 2003] [22, ECCA 2004] [38, TWG 2004] [78, TWG 2005]
[155, TWG 2016] [212, TWG 2018]

17.10.2.7 Extraction of air from cleaning areas

Description
Air from the areas where machine parts and equipment are cleaned with organic solvents, either manually or automatically, is extracted and may be treated by an off-gas treatment system.

Technical description
See Section 17.8.6; for in-machine cleaning, see Section 17.9.7.

Technical details vary according to the situation. For instance:

- for regular cleaning, e.g. of pumps used for transferring coatings cleaned by pumping though clean solvent, an area may be enclosed, with air extraction;
- it may be possible to relocate manual cleaning to an area that is enclosed and extracted, e.g. paint mixing.

Achieved environmental benefits
Reduction of fugitive solvent emissions.

Environmental performance and operational data
This information (where available) is detailed in this document for each type of activity in the dedicated chapters (Chapters 2 to 15).

Enclosure and extraction with treatment depends on the amount and type of cleaning and the amount of solvent used. Space required for an enclosed area and capacity in the off-gas extraction and treatment unit may also be a limiting factor.

Cross-media effects
Extraction systems require energy. Noise levels might increase.

Technical considerations relevant to applicability
Only applicable to areas where machine parts and equipment are cleaned with organic solvents.

Machinery for cleaning may be used infrequently and at irregular intervals. Connecting it to abatement equipment may require molecular sieves and or rotor adsorbers to avoid extra capacity that is rarely used.

Manual cleaning leads to very low solvent concentrations but extraction may be needed to stay well below the OEL. It may not always be practical to send this low-concentration off-gas stream to a thermal treatment system.

It is not applicable in the winding wire industry because of the high boiling point of the solvents used in the enamel.

See also Section 17.9.

Economics
Costs depend on the existing extraction system and on the capacity of the off-gas treatment technique. Retrofit might, therefore, may be very expensive. However, molecular sieves, rotor adsorbers or small thermal oxidisers could be fitted to automatic washing machines.

Driving force for implementation
Workplace health and safety.

Example plants
Widely applied. Plants: #019, #016, #161, #166 and #137 in [155, TWG 2016].

Reference literature
[7, Germany 2003] [22, ECCA 2004] [38, TWG 2004] [78, TWG 2005]
[179, COM 2017] [155, TWG 2016] [212, TWG 2018] [265, TWG 2019]

17.10.3 Maintaining the VOC concentration prior to treatment

17.10.3.1 Maintaining the VOC concentration sent to the off-gas treatment system by using variable frequency drives

Description
Use of a variable frequency drive fan in centralised off-gas treatment systems to modulate the airflow to match the exhaust from the equipment that may be in operation.

Achieved environmental benefits
Reduction of solvent emissions while minimising energy consumption for extraction and oxidation.

Cross-media effects
None.

Technical considerations relevant to applicability
Only applicable to central thermal off-gas treatment in batch processes such as printing.

Flexography and non-publication rotogravure printing is a batch process. Individual presses may be offline 30-50 % of the time for set-up and changeover. This is particularly important for regenerative thermal oxidisers, so only solvent-laden air is burnt and often autothermal operation can be sustained where no additional fuel is required.

Example plants
Reported for various sectors: heatset web offset printing: Plant #001; flexography and non-publication rotogravure printing: Plants #009, #014, #015, #017, #018, #022, #024 and #155; publication rotogravure printing: Plants #030 and #149; coating of vehicles: Plants #045, #057, #065 and #070; coil coating: Plants #081, #082, #083, #084, #086, #090, #100, #101 and #106; coating and printing of metal packaging: Plant #121; coating of plastic surfaces: Plant #131; coating of textiles, foils and paper: Plants #138, #139 and #171 in [155, TWG 2016].

Reference literature
[38, TWG 2004] [155, TWG 2016]

17.10.3.2 Internal concentration of solvents in the off-gases

Description
Off-gases are recirculated within the process (internally) in the curing ovens/dryers and/or in spray booths, so the VOC concentration in the off-gases increases and the abatement efficiency of the off-gas treatment system increases.

Technical description
There are two main cases, based on the same general principle:

1. internal accumulation of hot dryer air;
2. internal accumulation of spray-booth off-gas.

Allowing the solvent-laden air to circulate in the dryers or in spray booths (after sufficient particle separation and dehumidification) will increase the solvent concentration in the air and subsequently increase the solvent abatement efficiency of the off-gas treatment system. This can also be called ‘internal concentration’.

The reduction of the airflow is limited by the need to avoid risks of fire and explosions: the smaller the airflow, the higher the solvent concentration and thus the greater the danger of fire and explosions. A prerequisite for applying this technique in dryers is, therefore, the installation of a lower explosive limit control to assure that the ventilation rate in the dryers is designed in such a way that the maximum solvent concentrations that can possibly occur do not exceed a certain percentage of the LEL of the solvents concerned.

In Table 17.7, the LEL that are considered safe in flexography and non-publication rotogravure printing are shown.

Table 17.7: Maximum allowable levels of LEL in the dryers in flexography and non-publication rotogravure printing

Situation	Maximum % LEL
Dryers heated by open flame or electricity	25
Dryers heated by open flame or electricity with extensive safety features	50
Dryers heated by thermal oil or steam	50
Source: [1, Intergraf and EGF, 1999]	

Apart from internal concentration, ‘external’ concentration is also possible by applying, for example, an adsorption step prior to oxidation; see Section 17.10.6.2.

Achieved environmental benefits

- Increased VOC concentration in the raw gas and therefore reduction of energy consumption for the subsequent treatment.
- Reduced energy input at lower temperatures as the air has already been heated and retains residual heat, therefore recirculated air requires less energy to reach the optimum (booth) air temperature.

Environmental performance and operational data

In flexography or non-publication rotogravure printing plants, where no measures have been taken to reduce the airflow from the dryers, the average solvent concentration in the raw gas may be no more than 1-2 g/m^3.

For solvents like ethanol, ethyl acetate or MEK, the LEL at the relevant operating temperatures is somewhere near 50 g/m^3. A level of 25 % of the LEL will be some 10 g/m^3 or 12 g/m^3. This will be the maximum concentration in each individual dryer, and this concentration cannot be reached in all the dryers at the same time. Where measures have been taken to reduce the airflow, the average solvent concentration can rise to 4-6 g/m^3. These levels allow regenerative oxidation without the need for extra fuel addition.

Where the cost of the abatement equipment is not an issue, large safety margins are often employed. These, however, need to be re-evaluated when an investment in abatement equipment is necessary. The safety margin determines the maximum airflow and, therefore, the minimum size of the abatement equipment.

It is reported that recirculation without active LEL control can be carried out. The maximum recirculation allowed depends on safety regulations. Often a level of 25 % of the LEL is allowed when heating is done by steam or thermal oil. Where heating is electric or by open flame, the rules may be stricter (see also Table 17.7).

In vehicle coating paint shops (passenger cars, vans, truck cabins), cabin air recirculation in combination with dry overspray separation is installed in paint lines that were built or completely refurbished in the last 10 years.

In most existing installations, wet overspray scrubbing is installed and, due to energy consumption for dehumidifying the cabin air (to comply with operating requirements), recirculation in combination with wet scrubbing is only feasible in a few cases.

In principle, cabin air recycling is possible for water-based and solvent-based paints; however, tighter operating parameters required in the water-based spray booth for humidity might limit its applicability.

Technical considerations relevant to applicability
Applicability may be limited by health and safety factors such as the LEL and product quality requirements or specifications.

In situations where low solvent concentrations are combined with a large exhaust airflow rate, a certain solvent concentration is necessary for economical treatment. Increasing the solvent concentration in the airflow is applicable to conventional dryers and to spray booths.

For dryers, this technique is commonly applied in the printing processes such as in publication rotogravure printing (for improving the toluene recovery), flexography and non-publication rotogravure printing, and in the automotive industry. In publication rotogravure printing, new presses have such large airflows that expanding existing recovery installations is not economical.

For spray booth off-gases, internal accumulation is applied in a new installations and in a few existing installations in the automotive sector (see Environmental performance and operational data above).

It is commonly applied in the manufacturing of abrasives, where the maximum speed of the production line is adjusted so a level of 50 % of the LEL of the substance with the lowest auto-ignition point is maintained: the line speed is electronically controlled to this level.

Economics
In the printing sector, the cost of increasing solvent concentrations and reducing the airflow depends not only on the age and layout of the presses, but also the size of the reduction which is achieved. Where end-of-pipe abatement is to be installed, it is generally wise to reduce the airflow until the marginal cost of further reductions becomes equal to the marginal cost of the additional capacity of the abatement equipment. For thermal oxidisers applied in printing plants, this is approximately EUR 10-15 per m^3/h (2006 data).

Reduction of the airflow also reduces energy consumption. As less air is used, less needs to be heated. In situations where the drying temperatures are low (40-60 °C), these savings in themselves do not generally warrant the investment.

Driving force for implementation
Lower capital investment and lower running costs of abatement equipment, including lower energy requirements.

Example plants

All modern non-publication rotogravure presses, new paint shops for vehicle coating,
coating of textiles, foils and paper: example plant #139 in [155, TWG 2016].

Reference literature
[1, INTERGRAF and EGF 1999] [4, Germany 2002] [5, DFIU et al. 2002]

[7, Germany 2003] [38, TWG 2004] [78, TWG 2005] [155, TWG 2016] [212, TWG 2018]

17.10.3.3 External concentration of solvents in the off-gases through adsorption

Description
The concentration of solvent in off-gas is increased by a continuous circular flow of the spray booth process air, possibly combined with curing oven/dryer off-gases, through adsorption equipment. This equipment can include:

- fixed bed adsorber with activated carbon or zeolite;
- fluidised bed adsorber with activated carbon;
- rotor adsorber with activated carbon or zeolite;
- molecular sieve (see Section 17.10.3.3.1).

See also Section 17.10.6.2 for a detailed description of the adsorption on activated carbon or zeolites technique.

Achieved environmental benefits
A transmission of the solvent load into an external hot air stream in the ratio 1:6 to 1:30 (depending upon the raw gas concentration) is achieved. A comparatively small waste gas flow can be economically disposed of via oxidation or condensation for reuse, for example as a cleaning solvent.

Environmental performance and operational data
Rotor adsorber (rotor concentrator) [261, TWG 2016]:
Off-gases with low concentrations of VOCs pass a zeolite rotor concentrator whereby the VOCs are absorbed and the cleaned air can be emitted to the atmosphere. The rotor has 12 chambers. When a chamber has been saturated, a new chamber is used for air cleaning while the saturated zeolite is regenerated. Hot air at a temperature above 82 °C is used for the desorption of VOCs. The off-gases should have a relative humidity lower than 90 % and the VOC concentration will typically be less than 500 mg/m^3. Depending on the actual circumstances, it is possible to use very little air for desorption and thereby the VOC concentration can be increased 5 to 20 times in the desorption air compared to the treated air.

The technology can be used for both small and large airflows (from 7 500 m^3/h to 100 000 m^3/h) but it is especially feasible to use the zeolite rotor when the airflow is greater than 30 000 m^3/h on 24 h/day basis.

In the automotive industry, the air stream must be treated prior to the adsorption phase to remove dust; otherwise the function of adsorption would be affected. A dust level below the 1-3 mg/m^3 is necessary, which can be achieved by a number of techniques including:

- wet electrostatic precipitation (see Section 17.10.4.5);
- high-pressure venturi scrubber (see Section 17.10.4.2.1);
- dry scrubbing systems (see Section 17.10.4.4).

Cross-media effects
Increased energy use.

Technical considerations relevant to applicability
Applicability may be restricted where the energy demand is excessive due to the low VOC content. This is not applicable where concentrations are high enough for autothermal oxidation. This technique is only used where the cost of increasing the concentration and reducing airflow is less than the cost of additional treatment capacity.

It is usually applied where airflows with low concentrations need to be treated (e.g. < 2 g/m^3) to achieve autothermal oxidation conditions.

It is also limited to certain kinds of solvents. They must be released from the zeolite or carbon at reasonably low temperatures; otherwise they clog the zeolite or carbon and reduce its lifespan.

In the automotive industry, this technique is commonly used for waste gas from solvent-based spray booths. It can be used in water-based spray booths, but this is usually uneconomical due to the low solvent content of the airflow.

This technique is also commonly applied in adhesive manufacturing.

Rotor adsorbers with activated carbon or zeolite polymers experience a dramatic reduction in effectiveness when the solvent gas temperatures exceed 38 °C. Dryers on presses producing flexible packaging typically have exhaust off-gases with temperatures exceeding 38 °C. This makes rotor concentrators a poor choice for the flexography and non-publication rotogravure printing industry. They are not used in publication rotogravure and heatset web offset printing.

Economics

The cost of concentrating solvent for reuse versus buying in material means that this application is implemented dependent on local cost conditions and the price of buying virgin material.
Data from a rotor adsorber application with an airflow of about 75 000 Nm^3/h show a VOC concentration rate of nine times and therefore a reduction in the gas consumption of the subsequent RTO of 76 % [261, TWG 2016].

Driving force for implementation

Reduced VOC emissions and reduced energy consumption for the subsequent final treatment of the concentrated off-gas stream.

Example plants

Widely used as a pretreatment technique, reported by numerous plants for various sectors.

Reference literature

[38, TWG 2004] [78, TWG 2005] [155, TWG 2016] [212, TWG 2018] [261, TWG 2016]

17.10.3.3.1 Molecular sieve buffer for elimination of VOC peaks

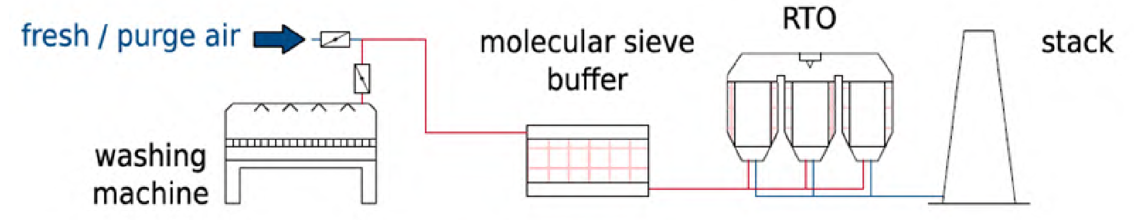
[DE comment #290 in [212, TWG 2018]]

Technical description

The molecular sieve buffer system consists of:

- inlet concentration monitoring and safety bypass system;
- flat bed of solvent-specific molecular sieve material for VOC homogenisation;
- differential pressure control.

Figure 17.19 illustrates a schematic with a molecular sieve buffer connected to the outflow of an automatic washing machine.

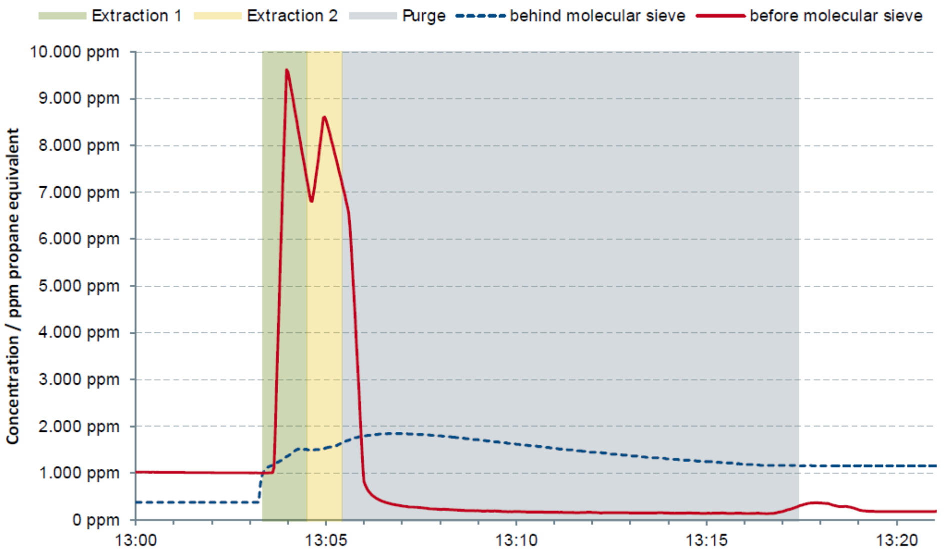


Source: [DE comment #290 in [212, TWG 2018]]

Figure 17.19: Scheme of the molecular-sieve-buffer-assisted exhaust treatment system

The molecular sieve buffer system consists of a flat bed of VOC-specific molecular sieve material. Molecular sieves are materials with pores of a constant size (see Figure 17.20). Gas traverses the material and VOC molecules are attracted and adsorbed by the inner surface. For constant temperature and pressure, the adsorption capacity of the molecular sieve is determined by the inlet concentration. The buffer will tend to its equilibrium depending on the input concentration.

If the inlet concentration drops, a balanced buffer will release solvent. If the inlet concentration increases, the buffer will adsorb more solvent. The result is a flattened concentration load curve. Peaks that occur at the inlet are reduced and low concentrations will be elevated with previously adsorbed solvent.



Source: [DE comment #290 in [212, TWG 2018]]

Figure 17.20: VOC load curve of a washing machine before and after the molecular sieve buffer

The washing machine, which is the source of the exhaust, has automated process control. After the manual loading process, the washing programme starts without exhaust ventilation. After rinsing the cleaned parts, the control starts a two-stage extraction of the solvent-saturated air inside the machine before the cover is unlocked and the operator is allowed to open it. The volume flow is 2 000 m^3/h during extraction phase 1 and reduced to 1 000 m^3/h in extraction phase 2. While the washing machine is being unloaded and reloaded by the operator, the molecular sieve buffer is purged for 12 minutes with fresh air.

The recorded VOC load curve in Figure 17.20 shows the inlet concentration in red. During the entire extraction process, the concentration level is within the explosion range. Downstream of the molecular sieve, the concentration stays below 2 000 ppm and does not require ATEX[50] measures.

Source: [DE comment #290 in [212, TWG 2018]]

Figure 17.21: Pelletised natural molecular sieve (zeolite)

The characteristics of the example plant (metal coating) above:

- solvent-based washing machine;
- cleaning of tools and machine parts soiled with paint and varnish;
- waste gas volume treated: 2 000 m3/h;
- lifetime of molecular sieve: 10 years.

Achieved environmental benefits

A molecular sieve is used instead of additional dilution air to prevent concentration overshoots. In this case, the total exhaust air volume of the emission source is reduced to one sixth. Instead, over one short (too) highly concentrated period the downstream RTO is supplied with a steady solvent concentration sufficient for autothermal off-gas treatment over a longer time.

Environmental performance and operational data

- The off-gas treatment system is considerably smaller.
- Explosion risks are handled intrinsically without dilution air.
- The natural gas consumption of the RTO is reduced, as solvent emissions are used as supporting energy during the purge cycle.

Cross-media effects

Energy consumption: The molecular sieve acts as a passive component but adds a small pressure drop to the overall exhaust system. Taking into account the absence of dilution air, the required electrical energy for the ventilation is lower compared to the initial situation.

Waste water: No waste water is generated.

Waste: No waste is generated during its lifetime. When the molecular sieve material has reached the end of its lifetime (> 10 years), it can be cleaned of solvent residues by increasing the temperature.

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[50] According to Directive 94/9/EC of the European Parliament and the Council of 23 March 1994 on the approximation of the laws of the Member States concerning equipment and protective systems intended for use in potentially explosive atmospheres.

Technical considerations relevant to applicability

Molecular sieve buffers for VOC load curve smoothing can be applied in new plants and for upgrading of existing plants to improve the energy efficiency. The system can be used for treatment of all volatile organic compounds usually arising from coating or printing activities. Typical volume flows range from 1 000 m^3/h to 200 000 m^3/h.

Economics

Investment and operational costs depend on the waste gas volume and the level of concentration of organic compounds to be treated:

- waste gas volume: 2 000 m^3/h at STP (standard temperature and pressure);
- TOC concentration in waste gas: > 100 % LEL;
- investment costs: about EUR 50 000 (2018 data);
- energy savings: about 8 m^3 of natural gas per operating hour;
- maintenance frequency: 1 h per month

Specific operational cost: Natural gas: EUR 0.45/m^3 (2018 data).

The operational cost of the end-of-pipe system is reduced. Depending on the application, a return on investment in ~ 2 years is reasonable.

Driving force for implementation

The main reason for implementation of the molecular sieve buffer for VOC peak removal is reduction of the running cost and the size of any downstream exhaust treatment system. Further explosion risks become manageable.

Example plants

Flexography and lamination: Plant #159.
Coating of metal surfaces: Plant #176 in [155, TWG 2016].

Reference literature

[155, TWG 2016] [212, TWG 2018] [259, COM 2017]

17.10.3.4 Plenum technique to reduce waste gas volume

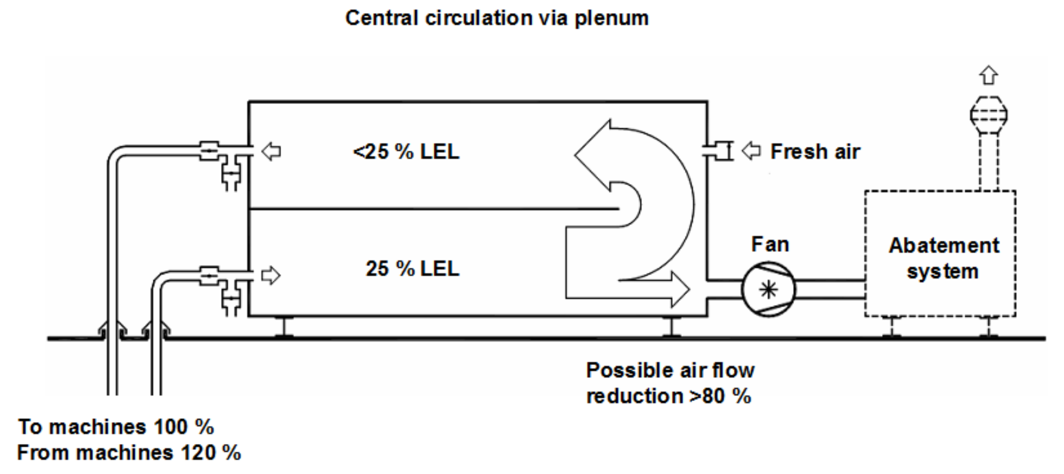
Description

Off-gases from curing ovens/dryers are sent to a large chamber (plenum) and partly recirculated as inlet air in the curing ovens/dryers. The surplus air from the plenum is sent to the off-gas treatment system. This cycle increases the VOC content of the curing ovens/dryers' air and decreases the waste gas volume.

Technical description

Plenum is defined as an air-filled space in a structure that receives air from a blower for distribution (as in a ventilation system). In this technique, it is the key part of a system for the external recirculation of air from dryers in order to increase the solvent concentration and reduce the net air volume to be treated by an abatement technique. See Figure 17.22.

Exhaust air from several dryers, often from several different coating machines, is sent to one large chamber – the plenum. The dryers take a large percentage of their inlet air from this chamber. The dryers supplement their inlet air from the surroundings of the coating machine. Thus, more air will be sent to the plenum than will be taken from it by the dryers. The excess air from the plenum is sent to an end-of-pipe abatement technique.



Source: [115, Verspoor et al. 2005]

Figure 17.22: Plenum chamber

The solvent concentration in the plenum is constantly measured. The concentration in the air extracted from the plenum by the dryers is allowed to rise to close to 25 % of the LEL according to EN 1539. The dryers take sufficient fresh air from their surroundings that in their exhaust the concentration will not exceed 25 % of the LEL. When the concentration in the plenum gets too high for this purpose, more air is extracted from it and the air in the plenum is supplemented with fresh air.

The plenum is an alternative to internal air recirculation in dryers (see Section 17.10.3.2).

Achieved environmental benefits
The net air volume to be treated by the abatement technique is very much reduced. Autothermal operation of the abatement technique becomes possible. Energy recovery from oxidation becomes possible.

Energy is also saved because the net amount of air to be heated in the dryers is reduced to the amount taken from their surroundings.

Environmental performance and operational data
Where dryers are applied without any internal recirculation and otherwise the outlet solvent concentration would be no more than one or two grams per m^3, the net airflow to be treated by the abatement technique may be reduced by up to 80 %.

Technical considerations relevant to applicability
Generally applicable.

The technique is applicable in situations where low solvent concentrations in outlet dryer air occur and internal recirculation of dryer air is not technically possible or disproportionately expensive due to the large number of dryers in the plant. Such situations may, for instance, occur where several older flexographic or rotogravure presses are used with eight or more dryers each.

The inlet temperature of all the dryers will be the same. This may cause difficulties when some dryers require high temperatures and others do not.

Economics

The plenum is not a cheap technique. Where internal recirculation in the dryers is possible and the number of dryers is limited, the net cost of internal recirculation combined with a larger oxidiser may be lower than that of the plenum.

Driving force for implementation

Where applicable (see above), the driving force is when it is economically advantageous compared with alternatives.

Example plants

LPF, Leeuwarden, the Netherlands,
Heatset web offset printing: Plant #002 in [155, TWG 2016].

Reference literature

[115, Verspoor et al. 2005] [155, TWG 2016]

17.10.4 Dust abatement

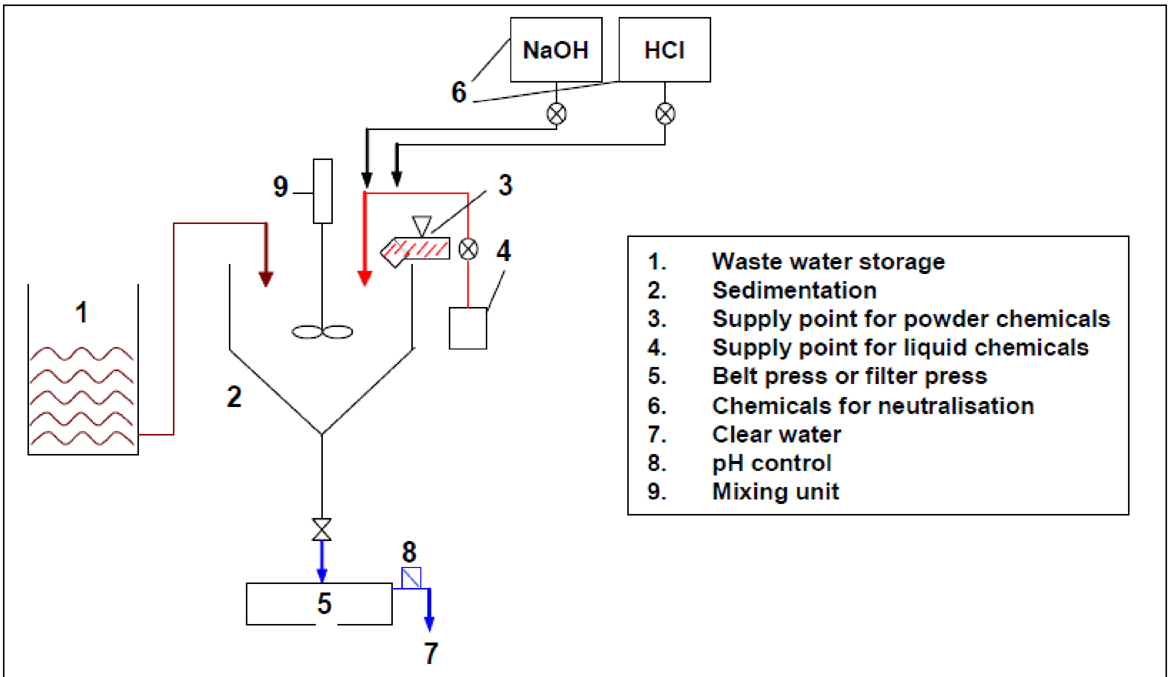
17.10.4.1 Wet separation spray booth (flushed impact panel)

Description

A water curtain cascading vertically down the spray cabin rear panel captures paint particles from overspray. The water-paint mixture is captured in a reservoir and the water is recirculated.

Technical description

Overspray in a spray booth where surfaces are sprayed with paint materials can be intercepted by applying a water curtain. The water-paint mixture is captured and treated in a reservoir below the spray booth.
Waste water is normally treated.



Source: [27, VITO 2003] with reference to Kluthe Benelux BV

Figure 17.23: Scheme of waste water treatment applied in a wet separation spray booth

Achieved environmental benefits

Reduced dust emissions to air.

Environmental performance and operational data

Removal of dust. Efficiencies of 98-99 % can be achieved. Sometimes the collected paint can be reused.

Cross-media effects

Although water is recirculated multiple times, there is generation of residual waste water (which will require treatment and disposal during periodic cleaning of the system) and of contaminated sludge that can be recycled but may need to be disposed of [ACEA comment #337 in [212, TWG 2018]].

Technical considerations relevant to applicability

Generally applicable.

Wet separation spray booths are applicable to water- and solvent-based paints. They are common practice in:

- wood and furniture painting;
- the automotive industry; in this industry for the serial coating of vehicles, a specific type of wet separation (venturi scrubber, see Section 17.10.4.2) is commonly applied;
- coating of aircraft components;
- coating of metal and plastic surfaces;

Economics

Estimated costs for an installation with the capacity to withhold 2-5 m^3/h waste water and covering a floor surface area of about 4 m^2 is about EUR 20 000 or EUR 1-2 per Nm^3 (2006 data). This size of the installation is suitable for large spraying zones with several water curtains.

Reference literature

[5, DFIU et al. 2002] [27, VITO 2003] [38, TWG 2004] [212, TWG 2018]

17.10.4.2 Wet scrubbing

Description

Paint particles and other dust in the off-gas are separated in scrubber systems by intensive mixing of waste air with water.

For VOC removal, see Section 17.10.6.3.

Technical description

Paint particles in the off-gas are separated in scrubber systems by intensive mixing of off-gas with a suitable liquid (usually water). Water scrubbers may also be used to remove other contaminants such as NO_X.

In the automobile industry, a special type of scrubber called a venturi scrubber (based on the venturi principle) is used, see Section 17.10.4.2.1 below.

Achieved environmental benefits

Reduced dust emissions to air. In an airflow scrubber, the paint particles are separated to around 95 %.

Environmental performance and operational data
With the spraying of paint, normally an overspray arises which might need to be captured and treated. The remaining particle content depends on whether the cleaned waste gas of the spray booth is supplied directly to a treatment system. For post-separation of paint particles after wet scrubber (venturi washers), additional paint particle separators can be necessary. In particular, if a circulating airflow aimed at solvent recovery exists or the protection of subsequent installation parts (rotor, heat exchanger) is required, secondary separation methods are applied.

Cross-media effects
Filtering requires energy and might generate noise, waste and waste water.

Technical considerations relevant to applicability
Generally applicable to both water-based and solvent-based paints.

Economics
Capital cost: EUR 2 000 up to EUR 30 000 per 1 000 Nm^3/h (scrubber with recirculation pump) (2006 data); the cost is strongly dependent on the application, e.g. type of impurities in the gases.

Example plants
Widely used in various coating sectors.

Reference literature
[5, DFIU et al. 2002] [38, TWG 2004] [78, TWG 2005] [94, VITO 2004]
[155, TWG 2016]

17.10.4.2.1 Venturi scrubber particle separation

Description
Separation of paint particles (overspray) from paint booth exhaust air using a venturi system with circulating water.

Technical description
The waste gas from the application zone contains paint particles. This air is carried into a venturi scrubber below the spray booth. A venturi scrubber consists of three sections: a converging section, a throat section, and a diverging section. The inlet gas stream enters the converging section and, as the area decreases, the gas velocity increases. Liquid is introduced either at the throat or at the entrance to the converging section. In the venturi scrubber, water droplets are separated from a water curtain. The water droplets combine with the paint particles, so that these heavier particles are deposited in the water.

Water and thin sludge are continuously drawn off from the circulation and are coagulated.

Achieved environmental benefits
Reduced particulate emissions to air. In a venturi scrubber, the paint particles are separated to around 99 % and a remaining particle concentration of < 3 mg/m^3 is usually achieved. Some older designs may achieve emission concentrations up to 5 mg/Nm^3.

Environmental performance and operational data
With spraying of paint, an overspray normally arises which may need to be captured and treated. This separation is necessary in order to ensure the safe operation of the entire plant, to allow air circulation and to meet working and environmental legal requirements.

Due to the energy expenditure for air conditioning, air recirculation of 80 %, for example, is uneconomical and has not been established for health reasons.

Also, wet systems require less space than dry systems which include large filter ducts, and there is a reduction in waste compared to the use of dry systems which require disposal of the solid filter medium.

Cross-media effects

Filtering requires energy and might generate noise, waste (paint sludge) and waste water. Although water is recirculated multiple times, there is residual waste water which will require treatment and disposal during periodic cleaning of the system, and contaminated sludge that can be recycled but may need to be disposed of [ACEA comment #337 in [212, TWG 2018]].

Technical considerations relevant to applicability

Generally applicable.

It is commonly applied in high-throughput paint shops, such as in vehicle coating.

Example plants

In all VW paint shops in Europe built before 2008.

Reference literature

[5, DFIU et al. 2002] , [38, TWG 2004] [78, TWG 2005]
[94, VITO 2004] [169, VDI 2013] [190, ESVOC 2017] [212, TWG 2018]
[265, TWG 2019]

17.10.4.3 Dry overspray separation with pre-coated filter (material)

[183, ACEA 2017]

Description

A dry paint overspray separation process using membrane filters combined with limestone as pre-coating material to prevent fouling of the membranes.

Technical description

Waterless overspray removal in industrial spray booths using membrane filters coated with limestone. This prevents direct contact of the sticky wet overspray particles with the filter surface and the inside of the filter module.

At the beginning of a filtration cycle, fresh limestone (pre-coat material) is introduced into the hopper. Air nozzles blow the dry material up into the airflow coming from the spray cabin. The limestone passes through the filter modules in circular channels and ensures circulation across all filter elements. Pre-coat (limestone) particles in the air stick to the filter surface and module as a closed, thin protection layer. This prevents direct contact of the sticky wet overspray particles with the filter surface and inside the filter module.

The filter cleaning process is fully automated:

During paint application, separation of the paint particles takes place on the filter via the air circulation. The paint particles accumulate on the pre-coat material and build up a filter cake. This results in an increase in air resistance over the filter. At pre-set intervals, automatic blowing-off of the filter cake is triggered. A jet of compressed air from the clean gas side of the filter element is shot for approximately 0.25 seconds, resulting in cleaning. Cleaning of the filter module takes place approximately every 25 minutes. The mixture of pre-coat and paint material falls to the bottom of the hopper and stays there until a certain saturation point is reached. Once this saturation point has been reached, the used pre-coat material is removed and replaced by new material.

The pre-coated material used is a natural limestone.

Achieved environmental benefits

Reduced dust emissions to air.

Environmental performance and operational data

The process-optimised, automatically regenerated filter, covered by a membrane layer, provides particle filtration of below 0.1 mg/m^3. This close to 100 % filtration process permits direct recirculation to spray booths without the requirement of additional filter levels. This filtration process takes place on the surface of the filter element, allowing direct recirculation of the clean air in the circulation process, as no pre-coat material or paint particles get through the filter membrane.

The following advantages can be mentioned:

- reduction of water consumption and no generation of waste water;
- significant reduction of energy consumption and CO_2 emission (no need for conditioning of the air used);
- significant reduction of particulate emissions;
- no dependence on weather conditions.

This is caused by:

- direct recirculation of process air;
- reduction of the air supply unit due to reduced air treatment;
- heat recovery.

Other resource considerations are as follows:

- Clean process (see below, no waste water, reduction of dust emission):
  - reduction of water consumption and waste water: no water required for overspray separation;
  - reduction of water consumption for air conditioning.
- Reduction in hazardous chemicals usage:
  - no use of detackifier chemicals or biocides to stabilise wet scrubber water systems.
- Waste management:
  - waste generation directly proportional to production;
  - waste generated validated as non-hazardous waste.
  - no disposal of paint sludge with solvent residues.
  - collected waste reused in cement clinker or lime plants.

Cross-media effects

- Consumption of natural raw materials (limestone).
- Generation of a new type of waste, in industrial quantities.
- Increase of truck road traffic due to delivering bulky new limestone and removal of used one.
- Increase of plastic foils waste (to protect inner surfaces of the spray booth and baffle plates.

Technical considerations relevant to applicability

Generally applicable.

The technique may be implemented in existing installations, either using solvent- or water-based paints, depending on the installation layout. No significant process modification is required but the dry separation system requires higher roof [256, COM 2018]. Installation in

existing plants is not possible if the paint booth does not have enough height under the spray zone. A complete replacement of the booth would be required.
Some parameters that need to be taken into consideration are:

- Very reliable process but it needs skilled operators.
- Outdoor capacity to implement $CaCO_3$ storage must be available next to the paint booth.
- Only limestone with approved qualities can be used; any derogation might have negative effects on the filtration efficiency and the lifetime of the filter material.
- Quality and cost of filter used.

It is also applied in several plastic parts paint shops (e.g. automotive bumpers).

Economics
The difference in investment with the water scrubber is compensated after less than 1 year, depending on the installation (similar investment and maintenance costs for both solutions, but the running costs are lower).

Driving force for implementation

- Lower maintenance effort.
- Simple, fully automated system.
- Long filter replacement cycle (lifetime proven beyond 3 years).

Example plants
This system is widely used in more than 30 new vehicle paint shops worldwide.
Europe: 2008 onwards, at least 10 passenger car plants and 4 commercial vehicle plants. Example plant #047 in [155, TWG 2016].
USA: 2011 onwards, at least 6 passenger car plants.
China: Since 2011, at least 18 passenger car plants.
It is also applied in several plastic parts paint shops (e.g. automotive bumpers).

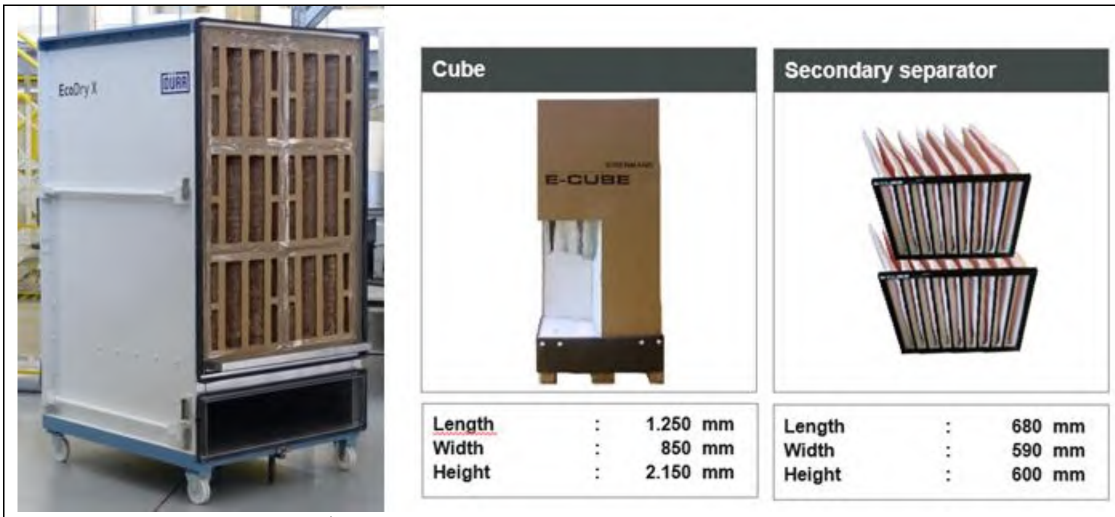
Reference literature
[183, ACEA 2017] [256, COM 2018] [265, TWG 2019]

17.10.4.4 Dry overspray separation using filters (cardboard, fabric or sinter)

Description
Mechanical separation system, e.g. using cardboard, fabric or sinter.

Technical description
Dry separation using cardboard, fabric or sinter is a mechanical separation system located below the grid level of the spray booth. The waste air (contaminated with paint particles) will be sucked through the cardboard filter. As it passes through the filters, the paint particles will be removed from the air. A second filter after the cardboard filter increases the separation rate. When the filters are completely loaded with paint, they will be exchanged manually with new, unloaded filter boxes. The change can be done during production. The condition of the filter box loading with paint is indicated by weight or pressure drop and can be used to determine the right time for filter exchange.

It is possible to recirculate air or utilise a supply and exhaust air system.



Source: [ACEA comment #234 in [212, TWG 2018]]

Figure 17.24: a) Filter trolley with 6 cardboard filter boxes (source Dürr) and b) E-Cube Filter concept (source Eisenmann)

Achieved environmental benefit

- Particle concentration after second bag filter stage and in exhaust air < 0.1 mg/m3.
- Compact layout and up to 35 % reduced cross-section.
- Suitable for all systems of all sizes.
- No need for chemicals, water or other additives.

Environmental performance and operational data

Lower energy use:

- Direct recirculation of process air.
- Reduction of air supply housing due to reduced air treatment.
- No heat recovery necessary.
- Smaller spray booth dimensions and reduced air volume flow.
- Reduction of 60 % of energy costs.

Lower raw material use:

- No water required for overspray separation.
- No usage of detackifier solvents or other coagulation chemistry.
- No disposal of sludge.
- 80 % reduced water consumption for air conditioning.

Lower maintenance:

- Simple, semi-automated system.
- No cabin grate to clean.

Process advantages:

- Carefree, reliable and hygienic air recirculation system.
- Low booth climate impact from outside air conditions (fresh air resupply of only 5-20 %).
- Well-balanced booth conditions (constant pressure) guaranteed by the automated filter regeneration.
- Avoidance of paint particle emissions caused by paint agglomerations.

The filters can be made mostly from recycled materials and be folded during storage and delivery. No chemicals, water or additives are required.

Spent modules can be used as a fuel source via incineration.

Cross-media effects

- Waste generation (spent filter materials).
- Increase in transportation due to moving bulky new cartridges and removal of contaminated ones.

Technical considerations relevant to applicability
Generally applicable.

The technique is applied in coating in the following sectors:
passengers cars, vans, trucks and buses;

- trains;
- two-wheelers;
- plastic parts; and
- parts of the general industry.

The filters are easy to assemble and replace – this can be undertaken by unskilled staff.

Economics
There is an investment cost for retrofitting but cost reduction due to material and energy savings.

Driving force for implementation
The filters result in low particle emissions into the exhaust air. This means that the exhaust air can be used as circulating air. The treatment of circulating air requires less energy and saves resources.

Example plants
Widely applied. Several paint shops in Europe, the US and China.

Reference literature
[183, ACEA 2017] [212, TWG 2018] [265, TWG 2019]

17.10.4.5 Electrostatic precipitator

Description
In electrostatic precipitators, particles are charged and separated under the influence of an electrical field. In a dry electrostatic precipitator (ESP), the collected material is mechanically removed (e.g. by shaking, vibration, compressed air). In a wet ESP, it is flushed with a suitable liquid, usually a water-based separation agent, see Section 2.4.7.3.

Achieved environmental benefits
Electrostatic precipitator systems have high overspray abatement efficiency (more than 99 %) and therefore very low remaining particle concentration (less than 1 mg/m^3), see also Section 2.4.7.3.

Environmental performance and operational data
Electrostatic filters can also be applied as a secondary separation step after the scrubbing system (described in Section 17.10.4.2). The electrostatic filter might serve as pretreatment for solvent adsorption/desorption techniques or solvent abatement techniques (see Section 17.10.3.3).

Cross-media effects
With wet electrostatic filters, there is the production of a wet waste, and waste water which may require treatment.

Technical considerations relevant to applicability
Generally applicable. Applied in the automotive industry (see Section 2.4.7.3).

Economics
In general, there is a higher installation cost associated with electrostatic precipitators than for dry filters, but the operating cost is lower.

Example plants
See Section 2.4.7.3.

Reference literature
[5, DFIU et al. 2002] [38, TWG 2004] [95, CEI-BOIS 2006] [94, VITO 2004]
[212, TWG 2018]

17.10.5 Oxidation techniques

Techniques for the thermal treatment of off-gases are discussed in this section. Oxidation techniques may be divided into two main categories: those combined with energy recovery and those without.

If the solvent mixture contains elements other than H, C or O, hazardous, toxic and/or corrosive by-products may be formed. Solvents containing halogenated compounds form aggressive flue-gases. When these flue-gases contain nitrogen, they form NO_X and when they contain sulphur, they form SO_X. Oxidation of ducting and vents may occur.

17.10.5.1 Sending off-gases to a combustion plant

Description
Off-gases are sent (partly or totally) as combustion air and supplementary fuel to a combustion plant (including CHP plants) used for steam and/or electricity production.

Technical description
Process off-gases may have a high calorific value due to the presence of organic solvents, unreacted organic raw materials, by-products or flammable diluents. The process off-gas is channelled to a gas engine or boiler where it is burnt to produce electricity and/or steam. The boiler may also use a conventional fuel, in which case the off-gases may require separate burners to ensure efficient combustion. The capacity to vent the off-gases or burn them in a flare may be required to cover process start-ups, shutdowns and other than normal operating conditions (OTNOC) of the process and the combustion unit.

Achieved environmental benefits

- Solvent emissions are treated and the emissions of the boiler will not change because solvents are used instead of fuel.
- Improved energy efficiency - lower energy consumption for steam production or electricity generation on site.

Environmental performance and operational data
The prerequisite for using an existing boiler is that it must be operational and able to receive vapours at all times when vapours are produced. Boilers usually work continuously, but the solvent load can be discontinuous. Lower VOC levels may require additional fuel.

The concentration range of the inlet gas is only limited because of the maximum LEL values and the airflow range that can be treated depends on the capacity of the existing boiler.
This technique can treat all types of solvents and solvent mixtures (special care is needed if CMR substances are included) and no specific pre- or post-treatment is needed; however, it is common practice to apply proper CO control.

Formaldehyde emissions from a plant using two CHP engine units were in the range of 4.5-5.5 mg/Nm^3 [Plant #176 in [155, TWG 2016]] [259, COM 2017].

Technical considerations relevant to applicability
This technique is easy to apply and is most appropriate for existing boilers with sufficient capacity and for production processes with a high energy demand.

For existing plants, the introduction of the technique will be restricted to major plant upgrades. It is only applicable if there is an on-site demand for the steam or electricity.

The substances in the process off-gas must be readily combustible. This technique may not be applicable for off-gases containing substances referred to in IED Article 59(5) or its applicability may be restricted due to safety considerations. The technique is not applicable for halogenated solvents containing sulphur or nitrogen or other hazardous solvents which will increase releases of acid gases and PCDD/F and might cause corrosion of the gas engine or boiler.

Sending process off-gas streams to a combustion unit may be restricted due to safety considerations depending on the hydrogen content of the off-gases.

Economics
There are significant benefits from steam and/or electricity generation. One plant reported that by sending the concentrated VOC exhaust flow to two CHPs it has achieved electricity independence combined with no additional gas consumption [Plant #176 in [155, TWG 2016]] [259, COM 2017].

The cost increases with the distance of the process to the boiler; however, in general this is a low-cost technique.

Driving force for implementation
Cost reduction for steam or electricity generation.

Example plants
Used in some plants that participated in the data collection (see also [259, COM 2017]).

Reference literature
[24, ESIG 2000] [37, Jansen 2005] [38, TWG 2004] [78, TWG 2005] [155, TWG 2016] [212, TWG 2018] [214, COM 2017] [259, COM 2017]

17.10.5.2 Thermal oxidation

Description
Oxidation of VOCs by heating off-gases with air or oxygen to above their auto-ignition point in a combustion chamber and maintaining a high temperature long enough to complete the combustion of VOCs to carbon dioxide and water.

Achieved environmental benefits
In general, a removal efficiency of > 99 % (24-hour average) can be achieved; however, this depends on the inlet concentration. Commonly achieved concentration levels after treatment do not generally exceed 20-30 mg C/m^3, and even lower levels can be achieved (see also Table

17.8 below). Lower levels can also be achieved where required; however, lower VOC levels may require additional fuel (see relevant sections for emissions in waste gases in the sector-specific chapters). Data from 50 thermal oxidation systems show an average abatement efficiency of 96.94 % with a maximum-minimum range of 99.99-93.93 % and a 50 % mid-range (75th – 25th percentile) of 99.94-96.98 % (see Table 21.29).

Thermal oxidation is also used for the abatement of odour.

Environmental performance and operational data

Solvents in the waste gas are normally destroyed by temperatures of 680-750 °C and this ensures almost complete combustion of the solvent load. The oxidisers normally operate with parameters adjusted for balanced minimum total emissions.

The concentration range of the inlet gas is only limited because of the maximum LEL values. The start-up time of the system is only 5 minutes. There are no limits to the inlet temperature.

The oxidiser should operate continuously when it is fitted with a lining system, because the lining system has to be kept warm. The amount of fuel required to keep it warm during idling is an important consideration for systems not operating continuously.

The dust concentration should generally be < 3 mg/Nm^3, but can be higher when incinerating organic dust particles.

The units can be integrated in the dryer (e.g. in heatset web offset printing, see Section 11.4.3.2) or applied as a central system for several dryers.

In the following table, some basic statistical data of reported emission levels for thermal oxidation systems for all STS sectors are presented [155, TWG 2016].

Table 17.8: Statistical parameters of VOC emissions in waste gases from thermal oxidation systems

Parameter	Value
Number of data	111
Average of VOC concentration values	9.3 mg C/Nm^3
Maximum of VOC concentration values	180.0 mg C/Nm^3
Minimum of VOC concentration values	0.2 mg C/Nm^3
95th percentile of VOC concentration values	33.5 mg C/Nm^3
75th percentile of VOC concentration values	7.4 mg C/Nm^3
25th percentile of VOC concentration values	1.7 mg C/Nm^3

NB: Data for the period 2013-2015.
Source: [155, TWG 2016]

Cross-media effects

A significant amount of additional fuel is needed to achieve the required burning temperatures: the energy consumption is higher than recuperative and regenerative oxidation. Emissions of NO_X, CO and CO_2 occur; the maximum level for each of these substances is normally below 100-150 mg/m^3. The achievable NO_X/CO emission levels are presented in the relevant sections for emissions in waste gases in the sector-specific chapters. See also Section 17.10.1 and Figure 17.18.

Technical considerations relevant to applicability

Generally applicable.

Thermal oxidation is especially suitable for high VOC concentrations (5-16 g/Nm^3) and for batch processes with all types of non-halogenated solvents (and their mixtures). In the case of halogenated compounds, a post-treatment of the waste gases will generally be required.

Small to medium flow rates < 25 000 Nm^3/h can be treated. This technique is most economically applied to flow rates in the range of 5-1 000 Nm^3/h and is most appropriate for batch processes, e.g. for some hours a day or week or some weeks a year. It can treat all types of solvents and solvent mixtures and no specific pre- or post-treatment is needed except perhaps in the case of halogenated compounds.

It is commonly applied in the manufacturing of abrasives especially in situations where recovered heat cannot be utilised. The technique is not applied in the automotive industry due to its low energy efficiency.

It was also commonly applied in the heatset web offset printing processes; however, nowadays regenerative oxidation is preferred instead.

Economics
As an investment, this technique is the most economical type of oxidiser. However, operational costs are high because a lot of additional fuel is needed, and there are increased plant running costs.

Driving force for implementation
Control of odour nuisance.

Example plants
Widely used (see also Table 17.8 above).

Reference literature
[4, Germany 2002] [5, DFIU et al. 2002] [14, Aminal et al. 2002] [19, Austria 2003] [24, ESIG 2000] [37, Jansen 2005] [38, TWG 2004] [78, TWG 2005] [94, VITO 2004] [155, TWG 2016]

17.10.5.3 Recuperative thermal oxidation

Description
Thermal oxidation using the heat of the waste gases, e.g. to preheat the incoming off-gases.

Technical description
The principle of destroying the solvents by burning is the same as described in thermal oxidation (see Section 17.10.5.2). However, energy is saved because the waste hot air is utilised for heating the incoming cold solvent-laden air or routed back to the drying process. Although heat exchangers are applied, additional fuel might still be necessary.

Achieved environmental benefits
More than 99 % destruction of VOCs can be achieved and commonly achieved emission levels are in general lower than 10 mg C/m^3 (daily average or average over the sampling period) (see relevant sections for emissions in waste gases in the sector-specific chapters). Data from 43 recuperative thermal oxidation systems show an average abatement efficiency of 98.31 % with a maximum-minimum range of 99.9-89.4 % and a 50 % mid-range (75th – 25th percentile) of 99.55-97.85 % (see Table 21.29).

Compared to thermal oxidation, 50-70 % energy can be recuperated as total heat in the heat exchanger.

Environmental performance and operational data

Usually, input solvent concentrations are between 2 g/Nm^3 and 12 g/Nm^3. The concentration range of the inlet gas is only limited because of the maximum LEL values and with low VOC levels more fuel has to be added. The maximum inlet temperature is 400 °C. Temperature control is needed. The VOC concentration after treatment can also be controlled continuously. However, in most conventional industries such as car manufacturing, only the combustion temperature is controlled.

Reported abatement efficiencies vary from 92 % to 99.5 %, values based on recent simultaneous measurements of inlet and clean TVOC concentrations for the vehicle coating sector [155, TWG 2016], see also 'Achieved environmental benefits' above and Table 21.29.

In the following table, some basic statistical data of reported emission levels for recuperative thermal oxidation systems for all STS sectors are presented [155, TWG 2016].

Table 17.9: Statistical parameters of VOC emissions in waste gases from recuperative thermal oxidation systems

Parameter	Value
Number of data	47
Average of VOC concentration values	9.7 mg C/Nm^3
Maximum of VOC concentration values	54.3 mg C/Nm^3
Minimum of VOC concentration values	0.6 mg C/Nm^3
95th percentile of VOC concentration values	43.8 mg C/Nm^3
75th percentile of VOC concentration values	10.2 mg C/Nm^3
25th percentile of VOC concentration values	2.1 mg C/Nm^3
NB: Data for the period 2013-2015. *Source*: [155, TWG 2016]	

The energy released by the oxidiser comes from both gas and solvent burning. Because of the high temperature of oxidated fumes, a large part of the energy can be recovered in exchangers for use in:

- preheating of the fumes before oxidation at around 600 °C (to reduce the gas consumption in the oxidiser);
- preheating of the air injection in the oven at a maximum of 400 °C, especially in the case of ‘hot air convection’ ovens (to reduce or eliminate the gas consumption in the ovens);
- water heating (for process and/or sanitary use).

In the case of technologies such as ‘infrared’ or ‘induction’ drying, there is not enough data available to determine the effect on prime energy requirements. However, it is known that the same opportunities for energy recovery do not exist.

Cross-media effects

NO_X, CO_2 and CO emissions occur. Reported data for emissions from recuperative thermal oxidation systems show an average (from 70 datasets) of 66.6 mg/Nm^3 for NO_X and 108.9 mg/Nm^3 for CO [155, TWG 2016] (see also Section 17.10.1 and Figure 17.18). Noise levels might increase.

Although this technique uses less energy than a thermal oxidiser (see Section 17.10.5.2), it still consumes a considerable amount of energy if the inlet VOC concentration is below the autothermal limit, which is about 2-3 g/m^3. The burner always needs a pilot flame (consuming energy).

Technical considerations relevant to applicability
Generally applicable.

Small to medium flow rates of < 40 000 Nm^3/h can be treated. This technique is most economically applied in this flow rate range and it is most appropriate for continuous processes and waste gas with a solvent concentration of 2-12 g/m^3. For low solvent concentrations (e.g. < 6 g/Nm^3) it can be used if subsequent heat recovery of the clean gas is made (e.g. dryers in the automotive industry). In addition to the high internal preheating, an additional heat recovery step is very common and of economic value. It can treat all types of solvents and solvent mixtures and no specific pre- or post-treatment is needed. This technique can operate both continuously and discontinuously because it has a relatively short start-up time of less than 1 hour.

As recuperative thermal oxidisers are easier and faster at abating VOCs compared to regenerative thermal oxidisers, they provide particular benefits in view of clogging through SiO_2 deposits created by siloxanes or other silicon compounds in the exhaust air.

This technique is commonly applied in the:

- printing industry, always with additional fuel;
- coil coating industry;
- automotive industry, always with additional fuel;
- metal packaging industry; however, high VOC concentrations can cause quality problems for colour coatings, e.g. whites can be discoloured.

Economics
At operating temperatures in excess of 750 °C, the lifetime of the plants is typically 15-20 years although temperature-induced material fatigue may reduce the lifetime of some heat exchangers to 8-12 years. In that case, investment costs are between EUR 150 000 and EUR 250 000 for installations with 10 000 m^3/h throughput (data from 2006).

For a new installation, costs for insulated ducts can be very important depending on the layout, due to the high temperature of the air.

Driving force for implementation
Recuperative thermal oxidation is applied for energy-saving purposes.

Example plants
Widely used in vehicle coating, coating and printing of metal packaging, coil coating, flexography and non-publication rotogravure printing and heatset web offset printing.

Reference literature
[4, Germany 2002] [5, DFIU et al. 2002] [14, Aminal et al. 2002] [22, ECCA 2004] [24, ESIG 2000] [27, VITO 2003] [37, Jansen 2005] [38, TWG 2004] [39, SEFEL 2004] [78, TWG 2005] [155, TWG 2016] [190, ESVOC 2017] [212, TWG 2018]

17.10.5.4 Regenerative thermal oxidation (multiple bed)

Description
An oxidiser with multiple beds (three or five) filled with ceramic packing. The beds are heat exchangers, alternately heated by flue-waste gases from oxidation, then the flow is reversed to heat the inlet air to the oxidiser. The flow is reversed on a regular basis. In the valveless rotating air distributor (see Section 17.10.5.5), the ceramic medium is held in a single rotating vessel divided into multiple wedges.

Technical description

The first generation of regenerative thermal oxidisers is the dual bed system in which each bed is filled with ceramic packing. One bed is used to preheat the gas stream to be treated; the other is heated by the flue-gases that arise from the oxidation. The flow is reversed on a regular basis to switch the preheat and the heat recovery beds. Some unburnt VOCs are emitted during switchover. There are also dual bed oxidisers with a buffer system, to reduce unburnt VOCs during bed switching.

Due to elevated emissions during bed switching, instead of dual bed oxidisers, three beds are now installed. The third bed is called the ‘purge bed’. Oxidisers with more than three beds (five or seven) are also available. In this case, several beds are used at the same time to preheat the gas stream to be treated, and several are heated by the outgoing airflow. One bed is used as a purge as in the three-bed system.

Regenerative oxidisers that receive an inlet gas with a VOC concentration above the autothermal level are called ‘flameless oxidisers’. Flameless operation can also be reached by using a direct fuel injection (only with gaseous fuel) and a sufficient concentration of oxygen in the crude gas.

Achieved environmental benefits

This system can achieve emission levels of < 5 –20 mg C/Nm^3 as a daily average or average over the sampling period (see relevant sections for emissions in waste gases in the sector-specific chapters) and abatement efficiencies in the range of 95-99.5 % as a 24-hour average. Data from 25 regenerative (three- or five-bed) thermal oxidation systems show an average abatement efficiency of 98.27 % with a maximum-minimum range of 99.8-87.8 % and a 50 % mid-range (75th – 25th percentile) of 99.4-98.5 % (see Table 21.29). However, in the case of low VOC concentrations in the inlet gas (< 100 mg/Nm^3) the efficiency can be lower than 95 %. As already stated, the overall efficiency is higher in the case of three or more bed systems because, compared to a dual bed system, no untreated VOC emissions occur due to switching the direction of the gas flow. The surplus energy generated may be reused and can result in significant overall energy savings.

Environmental performance and operational data

When the solvent concentration in the air to be treated is in the range of 1.5-3 g/m^3, the system is autothermal and no additional fuel needs to be added. The thermal energy of the outgoing air of the off-gas treatment system is utilised for the warming up of the raw gas by alternating the heat transfer beds. The excess heat can be recovered and, for example, used in production processes.

All but one reported abatement efficiency values based on recent simultaneous measurements of inlet and clean TVOC concentrations vary from 95.8 % to 99.5 %, for a number of sectors: flexography and non-publication rotogravure printing, vehicle coating, coating of other metal and plastic surfaces, coil coating, coating of textiles, foils and paper [155, TWG 2016].

The off-gas treatment removal efficiency for a three-bed regenerative thermal oxidiser can be calculated through the difference between inlet and downstream gas temperature [PT comment #5 in [212, TWG 2018]]. For that calculation, continuous pre- (in) and post- (out) off-gas temperature measurements are needed as well as knowledge of the type of solvents used.

The inlet VOC concentration (g VOCs/m^3) is a ratio between the in and out temperature difference of the RTO and the increase in temperature of each gram of solvents present in one cubic metre of off-gases ($\frac{°C * m^3}{gvoc}$)

Inlet solvent concentration: $$gvoc/_{m^3} = \frac{T_{out} - T_{in}}{\frac{\Delta T(°C) \cdot m^3}{gvoc}}$$

The ‘increase in the temperature for each gram of solvents’ can be obtained by the ratio between the solvent mixture heating value (kCal/g) and the specific heat of air (kCal/(m^3*°C):

$$\Delta T\,{}^{\circ}C * m^3 / g_{VOC} = \frac{\text{Solvent mixture heating value } (kCal/g)}{\text{specific heat of air } (kCal/m^3 * {}^{\circ}C)}$$

In the following table, some basic statistical data of reported emission levels for regenerative (three- or five-bed) thermal oxidation systems for all STS sectors are presented [155, TWG 2016].

Table 17.10: Statistical parameters of VOC emissions in waste gases from regenerative thermal oxidation (three- or five-bed) systems

Parameter	Value
Number of data	47
Average of VOC concentration values	14.4 mg C/Nm^3
Maximum of VOC concentration values	157.7 mg C/Nm^3
Minimum of VOC concentration values	0.4 mg C/Nm^3
95th percentile of VOC concentration values	42.7 mg C/Nm^3
75th percentile of VOC concentration values	14.1 mg C/Nm^3
25th percentile of VOC concentration values	4.0 mg C/Nm^3

NB: Data for the period 2013-2015.
Source: [155, TWG 2016]

The system is sensitive to the presence of dust in the off-gas because it will plug the ceramic packaging; however, some level of combustible dust can be accepted. The temperature is controlled before and after treatment, and the VOC concentration can also be controlled continuously. However, only the temperature is usually controlled continuously.

In the average flexography and non-publication rotogravure printing plant, the amount of excess heat is greater than can be utilised. The main heat consumers are the dryers on the presses. Oxidising one gram of solvents can heat one m^3 of air by approximately 25 °C. There are approximately 3-4 g/m^3 available: enough energy to heat each m^3 by 75-100 °C. The required temperature rise for the drying air is, however, on average only some 30 °C. This means that, for more than half the recovered heat, other possibilities have to be found. Sometimes the surplus energy is sold to neighbouring plants. The recovered heat then needs to be transported. For this purpose, steam or thermal oil is suitable. Most dryers however operate with an open gas flame or electricity. Using the excess heat from the oxidiser for the dryers would imply replacement of all the dryers: an investment that could never be recovered with the decrease of the energy costs alone.

In the coating and printing of DWI cans, the excess heat may be used for certain operations, e.g. in the cleaning process and for heating the incoming air to the dryers.

In coil coating, the fumes are oxidised in twin chambers which are preheated alternately. The chambers are preheated by the fumes from the other chamber in operation. A gas burner is used for starting the installation but normally not in steady conditions. It can process a very low VOC concentration in the fumes. The energy released by the oxidation only comes from the burning solvent. Due to the energy efficiency of the regenerative oxidiser, exhaust temperatures are low, reducing the opportunity for energy recovery. Because of the process, the main part of the energy is recovered for the oxidisation itself; the rest of the energy can be recovered in exchangers for preheating the air injection in the oven (at a low temperature) and for water heating (for process and/or sanitary use).

Cross-media effects

Compared to a conventional oxidiser, energy is needed to power larger fans used to drive the exhaust air through the heat exchangers. NO_X, CO_2 and CO emissions occur. Reported data for emissions from regenerative thermal oxidation systems (three or five beds) show an average (from 62 datasets) of 59.2 mg/Nm^3 for NO_X and 18.5 mg/Nm^3 for CO [155, TWG 2016] (see also Section 17.10.1 and Figure 17.18).

Oxidation requires energy (gas), mainly during the start-up operations.

Noise levels might increase.

Technical considerations relevant for applicability

Generally applicable.

This technique is commonly applied to an airflow in the range of > 1 500-120 000 Nm^3/h for one dual bed unit. For flows > 100 000 Nm^3/h, multibed systems are more economical. The maximum inlet temperature is 400 °C. The combustion temperature must be > 750 °C with a residence time in the combustion chamber > 1 s. For safety reasons, the maximum input concentration is limited to 25% of the LEL for predominantly aliphatic and 20% of the LEL for aromatic hydrocarbons (according to EN 12753). Typically 8 g/m^3 for aromatic solvents such as toluene, xylene with typical LEL values of about 40 g/m^3 and 15 g/m^3 for aliphatic solvents such as ethyl acetate or ethanol with typical LEL values of about more than 60 g/m^3. The safety margin is necessary to prevent explosions in the ceramic beds.

This technique can treat all types of non-halogenated solvents and solvent mixtures. However, with sticky substances, a regular ‘burn-out’ is required. With silicon hydrocarbons, regular cleaning is needed and therefore this type of substances should be avoided.

This technique is most commonly applied to continuous processes. When it is applied to discontinuous processes, it is normally on standby mode and at a certain temperature. The start-up time is 1 to 4 hours.

Regenerative oxidisers also allow more flexibility than recuperative oxidisers because their operation is not directly linked to the production.

Regenerative oxidisers of this type are commonly applied in:

- flexography and non-publication rotogravure printing plants;
- heatset web offset printing plants;
- the manufacturing of abrasives;
- the coating and printing of metal packaging (except in drum manufacturing);
- coil coating;
- the automotive industry.

Economics

The investment for a regenerative oxidiser is higher than that of a recuperative oxidiser. The investment and operational costs of end-of-pipe abatement equipment are largely determined by the maximum airflow that needs to be treated.

The investment can be estimated as minimum EUR 200 000 for a capacity of up to 10 000 m^3/h, plus EUR 10-15 for each additional m^3/h (2006 data). This includes a simple centralised collection duct, but not the cost of optimisation of the airflow. The fuel demand is low, so the electric fan mainly determines the running costs. The operating costs are some EUR 15 000 per year for treating 10 000 m^3/h (2006 data).

The recovery and transportation of excess heat requires additional investment. This investment is such that it can only be recovered with lower energy costs if all the excess heat can actually be used and if no additional investments are necessary to be able to use this heat.

Driving force for implementation
Energy efficiency.

Example plants
Widely used in most of the sectors; see also Achieved environmental benefits above.

Reference literature
[1, INTERGRAF and EGF 1999] [4, Germany 2002] [5, DFIU et al. 2002]
[14, Aminal et al. 2002] [22, ECCA 2004] [24, ESIG 2000] [27, VITO 2003]
[37, Jansen 2005] [38, TWG 2004] [39, SEFEL 2004] [78, TWG 2005] [155, TWG 2016]
[190, ESVOC 2017] [212, TWG 2018] [260, VDI 2014]

17.10.5.5 Regenerative thermal oxidation – valveless rotating air distributor

Technical description
Instead of RTO with multibed systems (see Section 17.10.5.4), this technique consist of the use of a one-vessel system with a rotating air distributor. The ceramic media is held in a single rotating vessel divided into multiple wedges. The waste stream is collected and directed through the valveless RTO (VRTO) by a variable speed fan. The rotary distributor is the only moving part in the system, and controls flow through the VRTO inlet, purge and outlet wedges in the heat exchanger section. The untreated stream is first directed up through the inlet wedge of the rotary distributor and the corresponding heat exchanger sections. This preheats the stream almost to the combustion chamber temperature as it travels up through the ceramic media. The stream is then oxidised in the combustion chamber using a modulating burner that provides additional heat only when required to maintain the combustion chamber temperature. The exhaust or outlet wedge of the rotary distributor allows clean oxidised air to flow downward through the exchanger. The exhaust gas heats up the ceramic media. The clean air exits the VRTO vessel and is sent to the exhaust stack. The purge wedge of the rotary distributor follows behind the inlet wedge, continually flushing the exchanger media with clean oxidised air.

Achieved environmental benefits
This system can achieve removal efficiencies in the range of 95-99.5 % as a 24-hour average. Data from 16 regenerative (valveless rotating air distributor) thermal oxidation systems show an average abatement efficiency of 93.34 % with a maximum-minimum range of 99.3-90 % and a 50 % mid-range (75th – 25th percentile) of 97.25-90 % (see also Table 21.29).

Compared to a conventional thermal oxidiser, a significant energy saving is achieved. The surplus energy generated may be reused.

Environmental performance and operational data
This technique is commonly applied for airflows in the range of 10 000–120 000 Nm^3/h. The maximum inlet temperature is 400 °C. The maximum VOC inlet concentration will be limited by the maximum LEL value, theoretically 12 g/m^3.

The system works autothermally with VOC concentrations in the range of 1.5-3 g/m^3, but the system is also applicable with concentrations of $> 3\ g/m^3$. Excess heat can be recovered and reused.

Reported abatement efficiencies vary from 90 % to 99.8 %, values based on recent simultaneous measurements of inlet and clean TVOC concentrations in the vehicle coating and coating of plastic surfaces sectors [155, TWG 2016].

In the following table, some basic statistical data of reported emission levels for regenerative (valveless rotating air distributor) thermal oxidation systems for all STS sectors are presented [155, TWG 2016].

Table 17.11: Statistical parameters of VOC emissions in waste gases from regenerative thermal oxidation systems

Parameter	Value
Number of data	31
Average of VOC concentration values	10.5 mg C/Nm^3
Maximum of VOC concentration values	31.1 mg C/Nm^3
Minimum of VOC concentration values	0.4 mg C/Nm^3
95th percentile of VOC concentration values	26.5 mg C/Nm^3
75th percentile of VOC concentration values	16.5 mg C/Nm^3
25th percentile of VOC concentration values	2.0 mg C/Nm^3

NB: Data for the period 2013-2015.
Source: [155, TWG 2016]

This technique is most commonly applied to continuous processes. When it is applied to discontinuous processes, it is normally in standby mode and at a certain temperature. The start-up time is 1 to 4 hours.

It can treat all types of non-halogenated solvents and solvent mixtures; however, with sticky substances a regular ‘burn-out’ is required. With silicon hydrocarbons, regular cleaning is needed and, therefore, these types of substances should be avoided.

The system is sensitive to the presence of dust in the off-gas; however, some level of combustible dust can be accepted.

This type of system is also sensitive to mechanical problems of the rotative part and has lower overall reliability than multibed systems.

Due to its ‘single reactor’ design, this system needs less space to implement than multibed systems.

Cross-media effects

Compared to a conventional oxidiser, energy is needed to power larger fans needed to drive the exhaust air through the heat exchangers.

CO, CO_2 and NO_X emissions occur. Reported data for emissions from regenerative (valveless rotating air distributor) thermal oxidation systems show an average (from 25 datasets) of 33.4 mg/Nm^3 for NO_X (34 datasets) and 69.9 mg/Nm^3 for CO [155, TWG 2016] (see also Section 17.10.1 and Figure 17.18). Low NO_X formation can be achieved by applying low combustion temperatures in the range of 750-820 ºC.

Noise levels might increase.

Technical considerations relevant to applicability

Generally applicable.

Regenerative oxidisers of this type are commonly applied in:

- flexography and non-publication rotogravure printing plants;
- heatset web offset printing plants;
- the manufacturing of adhesive tapes;
- the coating and printing of metal packaging;
- coil coating;
- coating of plastic surfaces;
- the automotive industry.

Economics
Due to the movement of the rotative system, maintenance costs are higher compared to multibed systems.

Driving force for implementation
Energy efficiency.

Example plants
Widely used in various sectors (see Technical considerations relevant to applicability above).

Reference literature
[24, ESIG 2000] [27, VITO 2003] [37, Jansen 2005] [38, TWG 2004] [78, TWG 2005] [155, TWG 2016] [190, ESVOC 2017] [212, TWG 2018]

17.10.5.6 Catalytic oxidation

Description
Oxidation of VOCs assisted by a catalyst to reduce the oxidation temperature and reduce the fuel consumption. Exhaust heat can be recovered with recuperative or regenerative types of heat exchangers. Higher oxidation temperatures (500-750 °C) are used for the treatment of off-gas from the manufacturing of winding wire.

Achieved environmental benefits
Removal efficiencies depend on several parameters, but with an optimal choice of the catalytic system efficiencies of 95-99 % are achieved.

Reported abatement efficiencies vary from 97 % to 99 %, values based on recent simultaneous measurements of inlet and clean TVOC concentrations for systems operated in plants for flexography and non-publication rotogravure plants and coating of textiles, foils and paper [155, TWG 2016] (see also Table 21.29).

The typically achieved concentration range is < 10-20 mg C/Nm^3. Compared to thermal oxidation (see Section 17.10.5.2), less additional fuel is needed, typically the required temperature range is 250-400 °C. Applying a catalyst in combination with recuperation of the exhaust heat requires less energy than recuperative oxidation without a catalyst (see Section 17.10.5.3).

Environmental performance and operational data
VOC concentrations of up to 5 g/Nm^3 can be treated. This technique can be applied for airflows in the range of 10-30 000 Nm^3/h. However, it is most suitable for discontinuous airflows of up to 10 000 Nm^3/h.

At inlet temperatures above 400 °C, no preheating is required to reach the start temperature of the catalyst. Normally oil is not used as a fuel, due to the sulphur content and related toxicity to the catalyst.

In the following table, some basic statistical data of reported emission levels for catalytic oxidation systems for all STS sectors are presented [155, TWG 2016].

Table 17.12: Statistical parameters of VOC emissions in waste gases from catalytic oxidation systems

Parameter	Value
Number of data	16
Average of VOC concentration values	26.5 mg C/Nm^3
Maximum of VOC concentration values	134.2 mg C/Nm^3
Minimum of VOC concentration values	2.7 mg C/Nm^3
95th percentile of VOC concentration values	64.0 mg C/Nm^3
75th percentile of VOC concentration values	37.1 mg C/Nm^3
25th percentile of VOC concentration values	8.3 mg C/Nm^3
NB: Data for the period 2013-2015. *Source*: [155, TWG 2016]	

This technique can be operated continuously or discontinuously; however, when continuously operated, the lifetime of the catalyst is limited to about 15 000-25 000 hours.

Most types of non-halogenated solvents and solvent mixtures can be treated. However, the presence of contaminants which could poison the catalyst must be checked. If the inlet concentration is too high, it may lead to overheating and damage to the catalyst. This technique is also very sensitive to the presence of dust or droplets in the feed and therefore pretreatment of the airflow is required. It is also sensitive to changes in the inlet concentration. Silicon hydrocarbons and silicons may also cause problems.

Cross-media effects

- Catalysts must be replaced/recharged periodically.
- Additional fuel is needed, although less than in thermal oxidation.
- Noise levels might increase.

Typically achieved emission levels of CO and NO_X are < 50 mg/m^3.

Reported data for emissions from catalytic oxidation systems show an average of 147.4 mg/Nm^3 for NO_X (five datasets) and 8.5 mg/Nm^3 for CO (four datasets) [155, TWG 2016] (see also Section 17.10.1 and Figure 17.18).

In the winding wire industry, reported emission levels for NO_X are in the range of 115-470 mg/Nm^3. However, this is dependent on the quantity of N-containing solvent in use.

Technical considerations relevant to applicability

Applicability may be restricted by the presence of catalyst poisons.

This technique, including the recuperation of the exhaust heat, is commonly applied in the winding wire industry. It is rarely used in the coil coating industry. The automotive industry has tested this technique, but it has not been generally applied. This technique was also reported by one flexography and non-publication rotogravure printing plant.

Economics

The usual cost issue of this technique is the catalyst that needs to be replaced at the end of its lifetime and this can only be checked by regular measurements. However, in general the costs are comparable to those for a regenerative oxidiser.

The prices below are representative for the Flemish wood industry and based on realistic theoretical working parameters. Equipment suppliers that provided the information stressed that it is impossible to extrapolate the costs of the examples on the basis of flows and VOC loads, so the numbers are purely indicative and valid at the time the estimations were made (November 2004).

Price quoted by supplier A:

1) Flow: 15 000 Nm^3/h.
    - VOC inlet concentration: 1500 mg/Nm^3, VOC emission: <20 mg/Nm^3.
    - Price: EUR 325 000.
2) Flow: 59 000 Nm^3/h.
    - VOC inlet concentration: 300 mg/Nm^3, VOC emission: <50 mg/Nm^3.
    - Price: EUR 628 000 to EUR 770 000.

Price quoted by supplier B:

1) Maximum flow: 15 000 Nm^3/h.
    - VOC inlet concentration: 1500 mg/Nm^3, VOC emission: <90 mg/Nm^3.
    - Price: EUR 300 000.

Driving force for implementation
Energy efficiency.

Example plants
Plants #010 (flexography), #098 (coil coating), #049 (vehicle coating) and #138 (coating of textiles) in [155, TWG 2016].

Reference literature
[4, Germany 2002] [14, Aminal et al. 2002] [22, ECCA 2004] [24, ESIG 2000] [27, VITO 2003] [28, EWWG 2004] [37, Jansen 2005] [38, TWG 2004] [78, TWG 2005] [95, CEI-BOIS 2006] [155, TWG 2016]

17.10.5.7 Oxidiser integrated into the dryer

See Section 11.4.3.2.

17.10.6 Techniques for the capture of solvents in off-gases

17.10.6.1 Condensation

Description
A technique for removing organic compounds by reducing the temperature below their dew points so that the vapours liquefy. Depending on the operating temperature range required, different refrigerants are used, e.g. cooling water, chilled water (temperature typically around 5 °C), ammonia or propane.

Technical description
[31, COM 2016]

Generally there are different methods of condensation, depending on the operating temperature range and include:

- coolant condensation, for a condensation temperature down to about 25 °C;
- refrigerant condensation, for a condensation temperature down to about 2 °C;
- brine condensation, for a condensation temperature down to about -10 °C;
- ammonia brine condensation, for a condensation temperature down to about -40 °C (one-stage) or -60 °C (two-stage);

- cryogenic condensation, for a condensation temperature down to about -120 °C, in practice often operated between -40 °C and -80 °C in the condensation device;
- closed-cycle inert gas condensation.

Condensation is carried out by means of direct cooling (i.e. contact between gas and cooling liquid) or indirect cooling (i.e. cooling via a heat exchanger). Indirect condensation is preferred because direct condensation needs an additional separation stage. Recovery systems vary from simple, single condensers to more complex, multi-condenser systems designed to maximise energy and vapour recovery.

Condensation is considered a very economical method and ideally suited for treatment of process gases with a high or medium solvent concentration (usually 50 g/m^3 to 1 000 g/m^3) and low flow rates (10 Nm^3/h to 2 000 Nm^3/h). However, it was reported by a plant with a significantly higher flow rate (see Example plants below). The liquid nitrogen required for the process is not consumed in the system, only its cooling effect is utilised and after evaporation in the condenser the gas is often reused by the customer (e.g. for inerting).

Achieved environmental benefits

- Reduction of VOC emissions.
- Collected solvents may be reused or recycled.

Environmental performance and operational data

The VOC-rich off-gas is cooled to the point where a significant portion of the vapours condenses. Heavy, low-volatile solvents can be recovered at room temperature; highly volatile solvents need to be cooled well below 0 °C to recover about 95 % or more. Cooling this low has the important disadvantages of high energy costs and water freezing the cooling elements. Cooling just above 0 °C avoids ice formation, but condenses water, and this may end up in the recovered solvent, necessitating expensive dehydration.

Typically in condensation processes, the solvents can be reused. It is also generally applied as a pretreatment stage.

A reported abatement efficiency of 95 % based on simultaneous measurements of inlet and clean TVOC concentrations was reported for an installation for the coating of textiles, foils and paper (see also Table 21.29). Emission data for two plants show achieved TVOC emission levels lower than 10 mg/Nm^3 [155, TWG 2016].

Cross-media effects

Energy consumption.

Technical considerations relevant to applicability

This technique is mainly applied to relatively small gas flows (up to 5 000 m^3/h) and on batch emissions. Continuous systems with a flow rate of 250 m^3/h or more are less frequently applied.

This technique is applied for the treatment of off-gases from paint application and dryers. Gases with a high water vapour content are less suitable because this may lead to the formation of ice.

It may not be applicable to low-VOC-concentration off-gas streams. Some standard input pollutant concentrations are up to 1 000 g/Nm^3 for acetone, methyl ethyl ketone (MEK), methanol, toluene, VOCs.

Economics

See relevant information in [31, COM 2016].

Driving forces for implementation

Workplace health and safety.

Example plants
Plant #024 (flexographic installation with a flow rate of 45 000 m^3/h) and Plant #138 in [155, TWG 2016]. It was also reported that it is applied in two heatset web offset plants in Germany [262, ESVOC et al. 2019].

Reference literature
[31, COM 2016] [155, TWG 2016] [262, ESVOC et al. 2019]

17.10.6.2 Adsorption using activated carbon or zeolites

Description
VOCs are adsorbed on the surface of activated carbon, zeolites or carbon fibre paper. The adsorbate is subsequently desorbed, e.g. with steam (often on site), for reuse or disposal and the adsorbent is reused. For continuous operation, typically more than two adsorbers are operated in parallel, one of them in desorption mode. It is also commonly applied as a concentration step to increase the subsequent oxidation efficiency.

Technical description
The technique is used to adsorb VOCs on the surface of activated carbon or zeolite. It is also commonly applied as a ‘concentrating up’ pretreatment to achieve a more concentrated waste stream that can be subsequently oxidised more economically (see Section 17.10.3.3).

During operation of the activated carbon (or zeolite) bed in the adsorption column or rotor adsorber, more and more solvent will build up in the bed. At a certain time, the efficiency of the adsorption bed will decrease and the outlet concentration will start to increase. At this point, the adsorption needs to be reactivated and the solvents may be recovered or destroyed. Desorption is often performed by sweeping with a hot gas stream (nitrogen, air or steam), but can also be done by vacuum (pressure swing adsorption). In cases where the waste gas flow is small (e.g. to solvent washing machines), the adsorbent may be regenerated off site (see Section 17.10.6.2.2).

After a longer period, the adsorbent cannot be fully reactivated by removing the solvent and requires a different type of reactivation (usually by heat treatment). This can be done on or off site (see Section 17.10.6.2.2). If activated carbon or other adsorbents are used which cannot be regenerated, the activated carbon is disposed of.

Continuous monitoring of the outlet concentration is helpful to check if the adsorption efficiency of the activated carbon is still sufficient (see Section 17.10.6.2.1).

Beds can be used in parallel and/or in sequence. In the case of a two-bed system, one is in adsorption mode and the other in desorption mode, or in the case of a three-bed system, two are used in adsorption mode and one in desorption mode.

An alternative continuous system is the rotor adsorber where the VOC-containing off-gases are fed to the adsorption wheel to be purified.

The adsorption wheel (rotor adsorber or rotor concentrator) consists of three areas:

1) the adsorption region, where the release of the solvents takes place;
2) the desorption region, characterised by the inclusion of the solvents (hot segment);
3) the cooling segment.

Ceramic carrier material with impregnated zeolites is used in the adsorption wheel where the concentration takes place. The cabin exhaust air is divided into the adsorption and desorption volumetric flow. The majority of the exhaust air is passed through the adsorption area and delivers the solvents to the carrier material. Due to the continuous rotational movement of the wheel, the adsorbed solvents are transported from the zeolite segments into the desorption zone and discharged there from the volumetrically smaller but hot desorption stream. The desorption air, however, serves initially to cool the wheel. The concentrated desorption air is treated in a thermal oxidiser. See also Section 17.10.3.3 where techniques for the external solvent concentration are discussed.

Achieved environmental benefits

Adsorbers can achieve a removal efficiency of > 99 % with an inlet concentration of > 7 g/m^3; however, this is related to various parameters such as the adsorbent type, the airflow volume, the inlet humidity and the regeneration type (hot air desorption, steam, etc.). For example, with an inlet concentration of > 7 g/m^3, removal efficiencies of > 99 % can be achieved. VOC concentrations of < 50 mg C/m^3 (24-hour average) can be achieved, with levels of < 20 mg C/m^3 being possible.

Data from 35 adsorption systems show an average abatement efficiency of 96.89 % with a maximum-minimum range of 99.9-80 % and a 50 % mid-range (75th – 25th percentile) of 98.92-98 % (see Table 21.24).

In the automotive industry, adsorption materials such as carbon fibre paper, zeolites and activated carbon are used. A transmission of the solvent load into an external hot air stream in the ratio of 1:6 to 1:40 (depending upon raw gas concentration) is achieved.

In adhesive tape manufacturing, emission concentrations of less than 50 mg C/m^3 were reported in the cleaned gas (see Section 7.3.2.2). Low concentrations can be achieved; however, they may require a reduction in adsorption periods and are, hence, correlated to increased steam production. The recovery process normally uses 2-3 kg steam per kg of recovered solvent.

In publication rotogravure printing, achieved levels are lower than 20 mg C/m^3 (see Section 13.3.3.3).

Environmental performance and operational data

Adsorption is not applicable to reactive compounds such as aldehydes and ketones because they may polymerise on the activated carbon, leading to overheating. The polymers will not desorb, therefore MEK and similar compounds are not suitable. However, this problem can be overcome if proper safety measures are implemented, such as always desorbing the system before weekends and holidays, and installing automatic sprinkler systems.

It is also not applicable to gases with a relative humidity of > 60 %, because water vapours will also adsorb on the activated carbon, reducing the adsorption capacity available for VOCs. Hydrophobic zeolites are available which do not have this problem. The system is sensitive to the presence of dust in the off-gas, because it will plug the adsorbent bed.

Adsorption systems can be applied as a pretreatment (concentration step) to thermal or catalytic oxidation (see Section 17.10.3.3). This leads to a reduction in the energy requirements of thermal oxidation (see Section 17.10.5.2). It also reduces the physical size of a thermal oxidiser when used together.

Desorption and regeneration reduce activated carbon consumption. The condensed steam can be reused for cleaning the adsorber and as boiler water. The drying air can also be recycled after the desorption process.

Cross-media effects

- In processes for the recovery of the solvents, steam is used and thus water and energy are used. The condensed steam contains traces of solvents.
- Noise levels might increase.
- Waste water arises from recovering the activated carbon.

Finding an optimum adsorption/desorption cycle means finding a balance between an acceptable emission concentration and the resources needed (i.e. energy, adsorbent which needs replacing periodically, water), and the waste water generated for cleaning the carbon bed when using steam.

It requires a careful balance of the gas flows as unpredictable exothermic reactions are possible (see Environmental performance and operational data above).

Technical considerations relevant to applicability
Applicability may be restricted where the energy demand for recovery is excessive due to the low VOC content.

This technique can be applied to off-gases with solvent concentrations of > 0.8 g/m^3. LELs do not play a role. The system can be applied to single solvents and mixtures. When single solvents that are not miscible with water are adsorbed, regeneration can be done with steam. When mixtures of solvents are adsorbed, regeneration has to be done with heated nitrogen and temperatures in the range of 150-300 °C.

In the automotive industry, there are some applications used for the cleaning of air from spray booths; typical inlet concentrations are between 300 mg/m^3 and 1 200 mg/m^3.

Airflows in the range of 1 000 m^3/h to 1 million m^3/h can be treated. For the upper end of the range, a 14-bed unit would be needed. The capacity of one bed depends only on the transportation of the system. The system can work continuously and discontinuously, and technically has a lifetime of more than 30 years. However, during this time it is likely to need to be adapted or renewed for environmental requirements, changes to process equipment and/or solvent types, etc., making the economic life shorter.

This technique is applied in all publication rotogravure printing plants for the toluene recovery (see below) and is also applied in the automotive industry, the coating of trucks and commercial vehicles and in adhesive tape manufacturing (also as the concentration step prior to solvent oxidation). It is also commonly applied in flexography and non-publication rotogravure printing (see Section 12.3.2.3).

Adsorption is especially suitable when concentrations of up to 4 g/m^3 have to be removed from the off-gas. However, it is also applied to concentrations of 10 g/m^3 or 12 g/m^3. In general, it is applicable for gases containing medium to low concentrations of VOCs. Only small molecules can be adsorbed and desorbed.
Some low-volatility solvents may adhere to the activated carbon permanently and quickly reduce the adsorption capacity with early replacement of the activated carbon as a result.

Adsorption and recovery of toluene used in the publication rotogravure printing processes is common practice. Toluene adsorbs well to activated carbon and is easily retrieved by heating the carbon with steam. The steam and solvent vapours are condensed to remove the toluene. The condensed steam can have a toluene concentration of between 380 mg/l and 540 mg/l and a stream of air bubbles is used to strip the toluene from the water. With stripping, this stream can have a concentration of toluene in the range of 1-10 mg/l. After being treated, the waste water is discharged or reused as, for example, cooling water or steam. The recovered toluene is in part reused and in part sold back to the ink manufacturers. This recovery process normally uses some 3-6 kg of steam per kg of recovered toluene. For a standard four-press plant, about 7 000 tonnes of toluene per year are recovered by using 20 000-30 000 tonnes of water.

In processes where solvent mixtures are applied, such as in flexography and non-publication rotogravure printing, adsorption and recovery may both be more difficult. Ethanol and ethyl acetate do not adsorb to carbon as well as toluene and subsequently larger carbon beds are required. Steam cannot be utilised for the recovery because these solvents dissolve in water.

Therefore, usually a hot inert gas such as N_2 is used. To separate the recovered solvent mixture, a distillation process is necessary.

In adhesive tape manufacturing, the recovery process normally uses 2-3 kg steam per kg of recovered solvent. Achieved emission concentrations lower than 50 mg C/Nm^3 were reported (see Section 7.3.2.2).

Economics

In general, this technique is twice as expensive as oxidation. The investment in solvent recovery will be EUR 0.5-1 million more than the investment in an oxidiser (2006 data). However, there is a payback from the recovered solvent. Zeolite as the adsorption medium is about 10 times more expensive than activated carbon, and is commonly applied for concentrating-up purposes.

It should be noted that adsorption units can be designed for achieving very low emission values by increasing the total surface of the activated carbon or by applying shorter adsorption cycles. However, it has to be considered that both options result in higher investment and operational costs and higher energy consumption.

The capital costs of adsorption equipment in an adhesive tape manufacturing example plant with a capacity of 800 kg/h were about EUR 2.7 million in 1992. Operating costs for adsorption and condensation together were about EUR 0.51 million/yr. Variable costs were about EUR 1.12 million/yr and fixed costs about EUR 1.38 million/yr.

In the case of flexography and non-publication rotogravure printing, investment and running costs for adsorption and subsequent solvent recovery are higher than those of any thermal treatment. The running costs are between EUR 0.15 and EUR 0.25 per recovered kg of solvent. The costs for recovery are EUR 0.10/kg solvent and savings are EUR 0.60-0.70/kg of solvent recovered, if the solvent is reused on site. Where the solvent consumption is less than 500 tonnes per year, it is very unlikely that solvent recovery will be an economically attractive alternative to oxidation.

In packaging rotogravure printing processes, if ethyl acetate generally makes up over 90 % of the total solvent used, the reusable amount may be such that the plant becomes almost self-sufficient and no longer needs to buy ethyl acetate for dilution purposes.

The prices below for activated carbon adsorption are representative for the Flemish wood industry and based on realistic theoretical working parameters. Equipment suppliers that provided the information stressed that it is impossible to extrapolate the costs of the examples on the basis of flows and VOC loads., so the numbers are purely indicative and valid at the time the estimations were made (November 2004).

- installation rental: EUR 6 052-8 544/year;
- purchase of the installation: EUR 22 355-23 740/unit;
- price quoted for 10 000 Nm^3/h and 500 mg VOCs/Nm^3 (220 working days/year, 8 hours/day, VOC emission standard 90 mg/m^3 and time load of 50 %):
  - activated carbon: EUR 8 316 for 5 400 kg (lasting 82 working days) = EUR 22 311/year;
- price quoted for 1 000 Nm/h and 500 mg VOCs/Nm^3 (other working conditions equal):
  - activated carbon EUR 8 316 for 5 400 kg (lasting 823 working days) = EUR 2 230/year.

Driving force for implementation

May be more economical than oxidation techniques.

Example plants
Widely used, reported by numerous plants for various sectors (see Environmental performance and operational data as well as Technical considerations relevant to applicability above).

Reference literature
[1, INTERGRAF and EGF 1999] [5, DFIU et al. 2002] [14, Aminal et al. 2002] [24, ESIG 2000] [26, CITEPA 2003] [27, VITO 2003] [37, Jansen 2005] [38, TWG 2004] [78, TWG 2005] [78, TWG 2005] [95, CEI-BOIS 2006] [96, Presti 2005] [155, TWG 2016] [212, TWG 2018]

17.10.6.2.1 Continuous monitoring of the adsorber performance

Description
Monitoring equipment is available to continuously control the performance of the adsorber, e.g. continuously comparing the level of VOCs in the raw gas and those in the treated waste gas.

Achieved environmental benefits
Reduction of untreated emissions because a poorly functioning adsorber can rapidly be detected and corrective action can be taken.

Environmental performance and operational data
In the event that the system consists of two or more parallel adsorption units, the monitoring can be used to switch from one to the next. It is reported that, in the automotive industry where concentration variations are small, measurements once a week or even less frequently are normally carried out by portable equipment.

It is common practice in publication rotogravure printing plants, where control of the carbon bed recovery cycle is carried out by concentration measurements and at fixed time intervals. This helps to decide when the carbon bed in the toluene adsorption systems has to be cleaned. Since the solvent content of the drying air is variable, these two methods of controlling the carbon bed recovery cycle may switch the adsorbers either too soon or too late. Too soon leads to excessive energy consumption, too late increases emissions disproportionately.

Technical considerations relevant to applicability
This technique is applicable to new and existing adsorbers, independent of the type of industry. Continuous monitoring is only required if concentrations are high or in the event that parallel adsorption equipment is used. It is not needed where the adsorber is an integral part of an abatement system and there are no releases to the air.

Economics
It is reported that the cost of the installation of four continuous measuring VOC devices including the software and access platforms was EUR 2 million in 2004.

Example plants
Plant #046 (treatment of cabin air from solvent-based filler application) in [155, TWG 2016].

Reference literature
[7, Germany 2003] [78, TWG 2005] [155, TWG 2016]

17.10.6.2.2 Regeneration of used activated carbon

When the surface of the adsorbent has adsorbed nearly as much as it can, the efficiency of adsorption decreases. The adsorbent is then usually regenerated by desorbing the retained solvents (and other materials). This may be carried out on or off site. The adsorbent also collects materials that are not desorbed, and these occupy increasing proportions of the surface area, leading to a decrease in the removal efficiency of target pollutants. The adsorbent may be regenerated by heat treatment. If the activated carbon or other adsorbents cannot be regenerated, they are usually disposed of (e.g. by incineration).

17.10.6.3 Absorption using a suitable liquid (wet scrubbing)

Description

Use of a suitable liquid to remove pollutants from the off-gas by absorption, in particular soluble compounds and solids (dust). Solvent recovery is possible using, for example, distillation or thermal desorption (see also Section 17.10.6.3.1). For dust removal, see Section 17.10.4.2.

Technical description

Wet scrubbing is a mass transfer between a soluble gas or dust and a solvent – often water – in contact with each other. Physical scrubbing is preferred for chemical recovery, whereas chemical scrubbing is restricted to removing and abating gaseous compounds. Physico-chemical scrubbing takes an intermediate position. The component is dissolved in the absorbing liquid and involved in a reversible chemical reaction, which enables the recovery of the gaseous component.

A full description of the wet scrubbing process and the types of wet scrubbing equipment available is given in the CWW BREF [31, COM 2016]. The abatement efficiency of wet scrubbers is dependent on the residence time of the gas in the absorption section, the type of scrubber used, e.g. the column internals (random packing, structured packing, etc.), the scrubbing liquid used and the liquid to gas ratio. If the scrubbing liquid is recirculated, the refreshment rate of the liquid and the addition rate of any chemicals can also be important.
Absorbed solvents may be recovered for reuse (e.g. DMF in PU coating of textiles).

Achieved environmental benefits

- Recovery of VOCs for reuse.
- Reduced emissions to air.
- Removal of gaseous pollutants, such as NO_X, hydrogen halides, SO_2, ammonia, hydrogen sulphide or VOCs (if water-soluble, such as IPA, ethanol, DMF).

Environmental performance and operational data

Data from five wet scrubbing systems show an average abatement efficiency of 79.2 % with a maximum-minimum range of 96-75 % (see Table 21.29).

Cross-media effects

Generation of waste water. See also the CWW BREF [31, COM 2016].

Technical considerations relevant to applicability

Generally applicable.

Water-based scrubbing is applicable to polar VOCs. However, desorption might be difficult and energy-intensive.

It is used in textile coating to recover water-soluble solvents such as DMF.

It is not applied in printing. In vehicle coating, it is applied as an overspray capture technique (see Section 17.10.4.2), mainly for the spray booth off-gases.

Economics

See the CWW BREF [31, COM 2016].

Example plants

Widely used in vehicle coating (as an overspray control technique). Textile coating: Plants #134 and #166 in [155, TWG 2016].

Reference literature

[31, COM 2016] [78, TWG 2005] [155, TWG 2016] [178, COM 2017] [179, COM 2017]

17.10.6.3.1 Absorption in liquid followed by solvent recovery (condensation) or thermal oxidation

Description

Absorptive off-gas treatment systems are used to concentrate VOCs for recovery or for combustion. The system consists of:

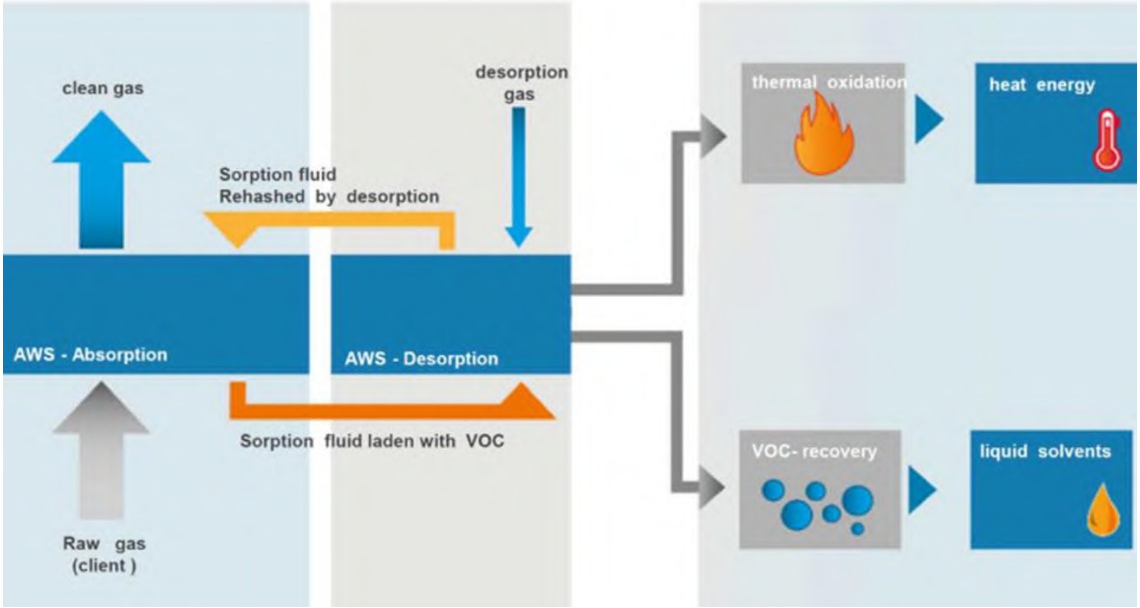
- filter unit (absorption system);
- desorber (desorption system); and
    a. condensation (solvent recovery); or
    b. thermal oxidation (energetic use).

The decision regarding which of the two options to choose depends on local conditions and is determined by economics and quality requirements. It depends on the need for heat versus the possibilities to reuse recovered solvents.

Volatile organic compounds originating from the vehicle coating process are collected in the absorption system, which reduces VOC emissions to air. Subsequently, the sorption fluid laden with organic solvents is directed to the desorption unit where solvents are removed from sorption fluid. This is achieved with hot air, which passes through the heated absorbent in a countercurrent flow.

The hot air laden with solvents is conducted to the condensation plant or to thermal oxidation.

Figure 17.25 illustrates the absorption of volatile organic compounds in the sorption fluid, the desorption by hot air in the desorption unit and the subsequent options for using the concentrated solvents.

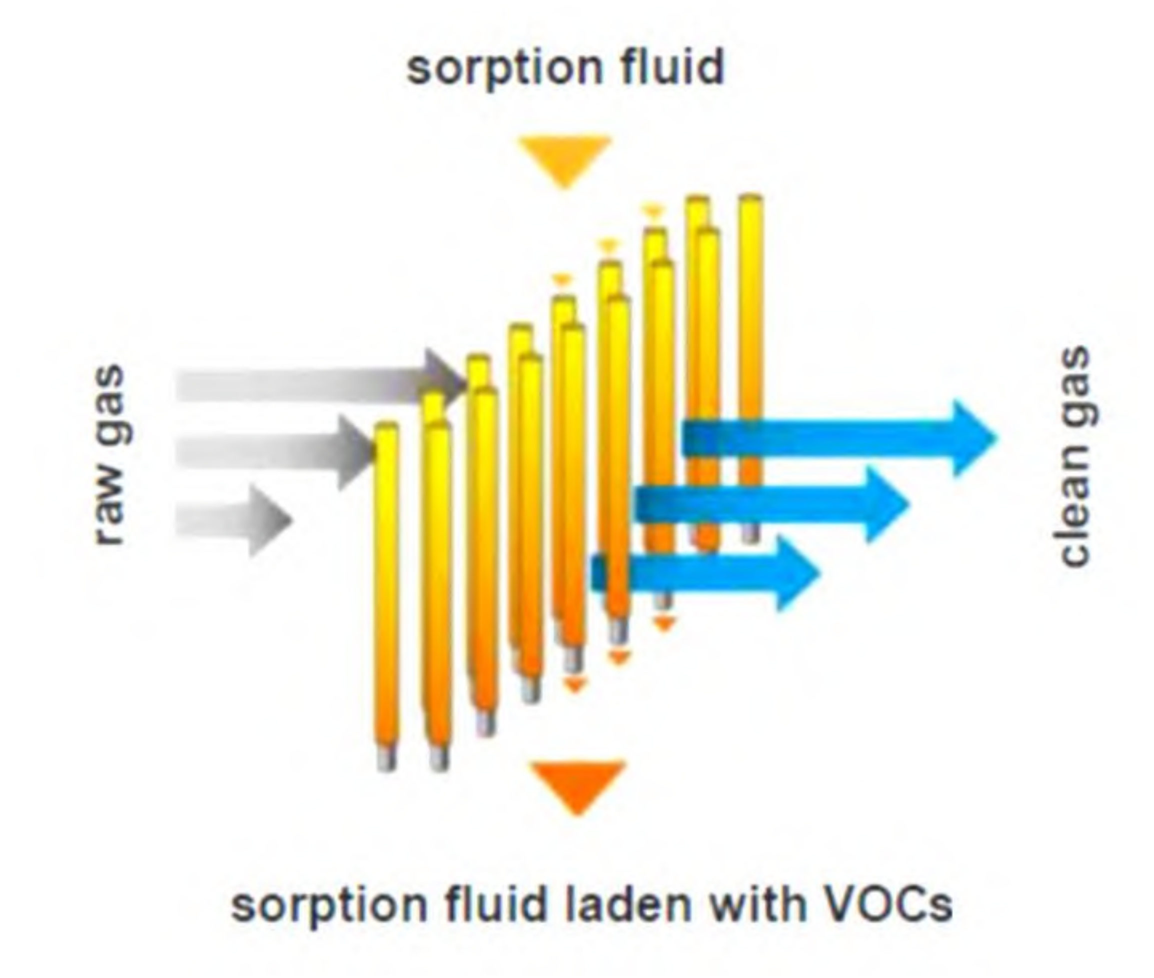


Source: [211, Germany 2017]

Figure 17.25: Scheme of the absorption off-gas treatment system

The absorption process takes place in a module that produces a film curtain by means of porous so-called Keder tubes. The curtain offers a large surface for the cross-counter flow of the off-gas. Alternatively, instead of the Keder tubes, random packing is possible.

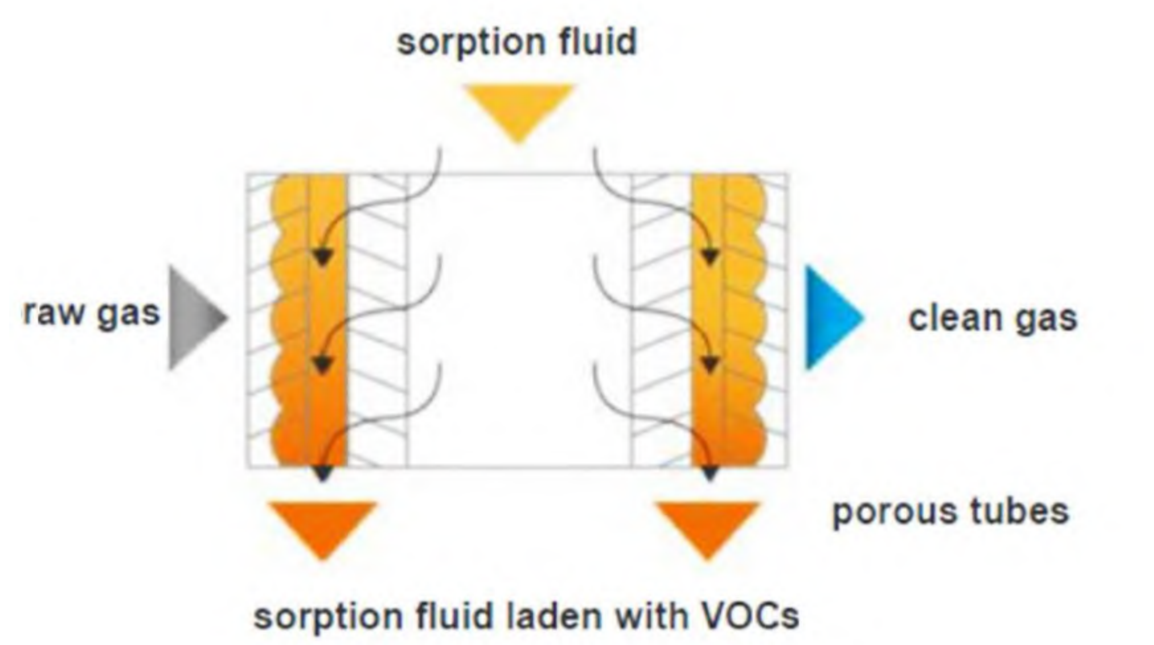
The modules are characterised by a low pressure loss on the exhaust side. Several modules can be combined in series, depending on the concentration of the off-gas and on the composition of the substances to be absorbed. Absorbent and off-gas are conducted in a cross-counter flow.



Source: [211, Germany 2017]

Figure 17.26: Cross-counter flow in the absorption unit

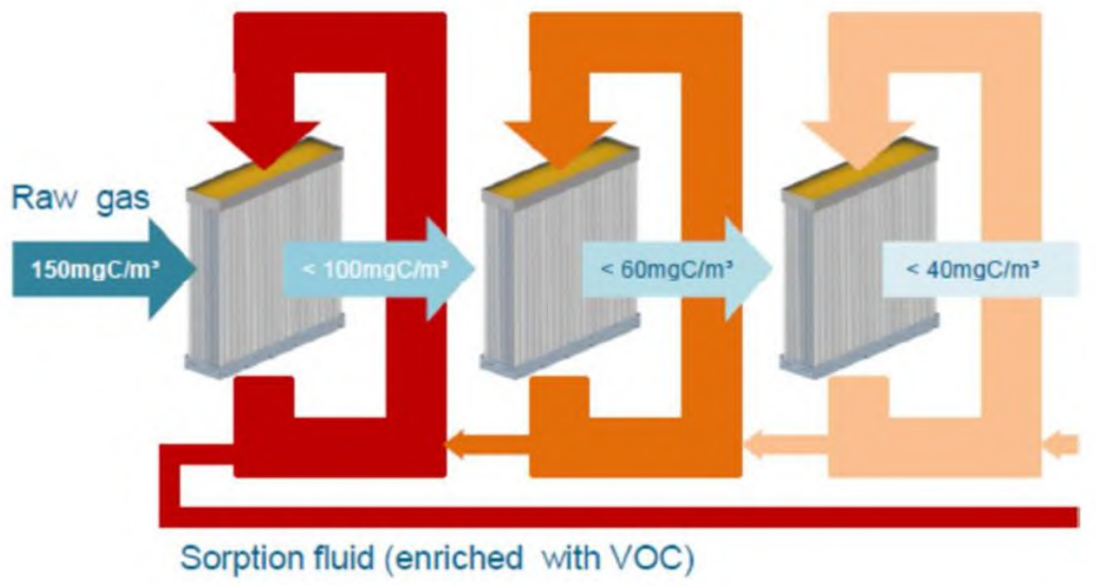
Figure 17.27 illustrates the flow in the Keder tube of the absorption unit.



Source: [211, Germany 2017]

Figure 17.27: Keder tube in the absorption unit

Figure 17.28 illustrates a filter cascade of absorption units.



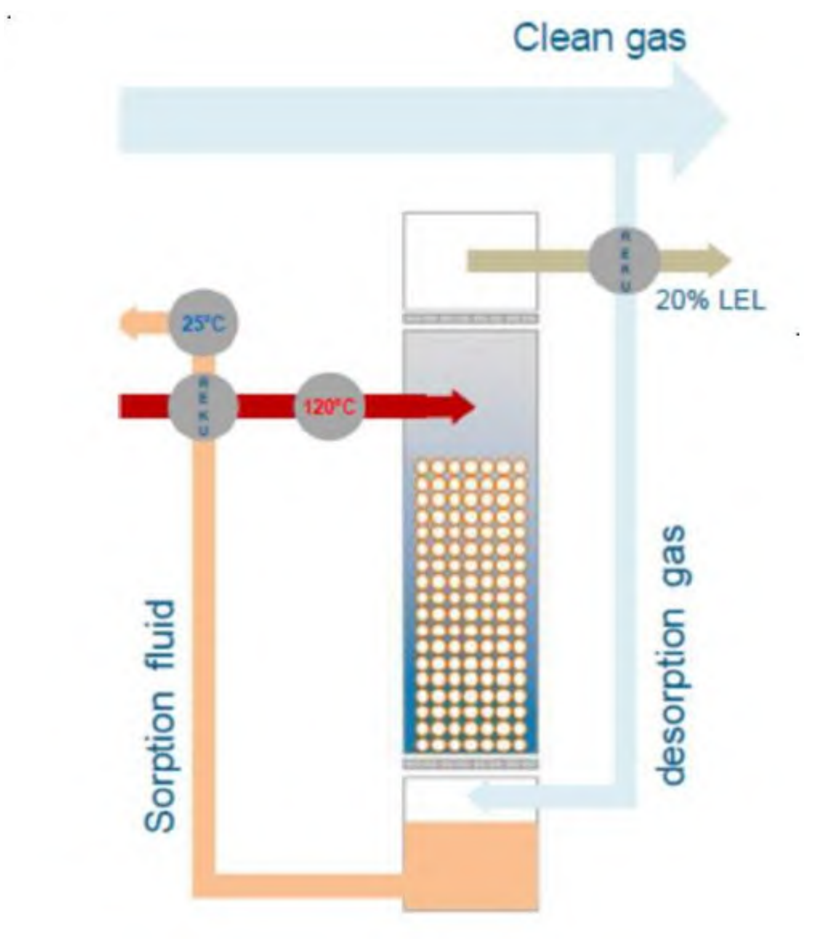
Source: [211, Germany 2017]

Figure 17.28: Filter cascade of absorption units

Figure 17.29 shows details of the desorption unit. The dark red arrow indicates the inlet of laden fluid originating from the absorption; the light red line shows the return of the fluid to the absorption unit.

Before returning to the absorption unit, the outlet of the hot fluid passes a heat exchange unit to heat up the incoming fluid. For desorption, the incoming fluid is heated to 130 °C.

A small volumetric flow of clean gas / fresh airflows countercurrently to the liquid through the column. The clean gas takes the VOCs out of the liquid and is enriched with them. The highly concentrated desorption gas can be used for VOC recovery (condensation) or be burnt in a thermal oxidiser.



Source: [211, Germany 2017]

Figure 17.29: Characteristics of the desorption unit

An absorption plant is used by an automotive manufacturer in Germany to clean the solvent-contaminated off-gas from spray booths. In these spray booths, car components are painted (mainly plastic parts with a topcoat in series). Also, manual coating of parts takes place in the spray booths.

The absorption and desorption in this plant are connected with condensation (recovery) of the solvents.

- Dimensions of the entire filter system: 20.2 m x 9.7 m x 4.7 (L x W x H).
- Exhausted airflow: 220 000 m^3/h (two lines with 110 000 m^3/h each).
- Absorber: 128 absorption modules.
- Quantity of absorbents: ~12 700 litres.
- Automatic control of fill level and temperature.
- Constant refill of the absorbents.

- Temperatures: absorption 25 °C, desorption 130 °C, condensation – 52 °C.
- Raw gas concentration: max. 130 mg C/Nm^3.
- Separation efficiency: (depending on the raw gas load) ~17.8 kg VOCs/h.
- Dimensions of the desorber: 7.3 m x 7.8 m x 6.5 m (L x W x H).
- Volume of packed bed: ~ 7.9 m^3.
- Dimensions of the condensation: 11 m x 1.5 m x 3.8 m (L x W x H).

Achieved environmental benefits

The off-gas treatment system reduces emissions of volatile organic compounds. Solvents that are concentrated in the absorbent can be recovered in liquid form through the desorption system in the plant. The desorbed solvents can alternatively be led to thermal oxidation.

Environmental performance and operational data

- TVOC concentration in waste gas: generally < 50 mg C/Nm^3.
- The maximum inlet concentration of the system is up to the lower explosive limit (LEL).
- Concentration ratio range between ~ 30:1 and ~ 150:1, depending on the raw gas concentration.

Cross-media effects

Energy consumption: The system leads to an additional energy consumption of natural gas and electricity. The increase of the exhaust fan electricity consumption is calculated separately from the electricity consumption of the exhaust fan operating without an off-gas treatment system. The figures below refer to the example plant indicated previously.

Natural gas:	
Thermal oxidiser:	~ 130 kW$_{th}$.

Electricity:

Exhaust air purification:	~ 46 kWel.
Cooling of sorption fluid:	~ 24 kWel.
Exhaust air fan (additional):	~ 120 kWel.

Furthermore, per operation hour a loss of 0.5-0.75 kg sorption fluid must be refilled.

Technical considerations relevant for applicability

The off-gas treatment system can be applied in new plants and for upgrading of existing plants. The absorption unit can be implemented in existing ventilation ducts. If not applicable because of restricted space, the separate location of absorption and desorption units is possible.

In the event of varying VOC concentrations in the raw gas, the storage capacity of the absorbent can be used to temporally decouple absorption and desorption.

Driving force for implementation

The main reason for implementation of the absorption off-gas treatment system are legal requirements. The system can be applied for concentration of VOCs where coating substances hinder the application of a zeolite absorption rotor (e.g. UV varnishes, high-boiling agents).

The system may be applied where solvent recovery is an objective.

The system is applied where combined heat and power systems are economically viable.

Example plants

Porsche Zuffenhausen.

Porsche Leipzig.
BMW Group Werk Landshut.

Reference literature
[211, Germany 2017] [ACEA comment #236 in [212, TWG 2018]]

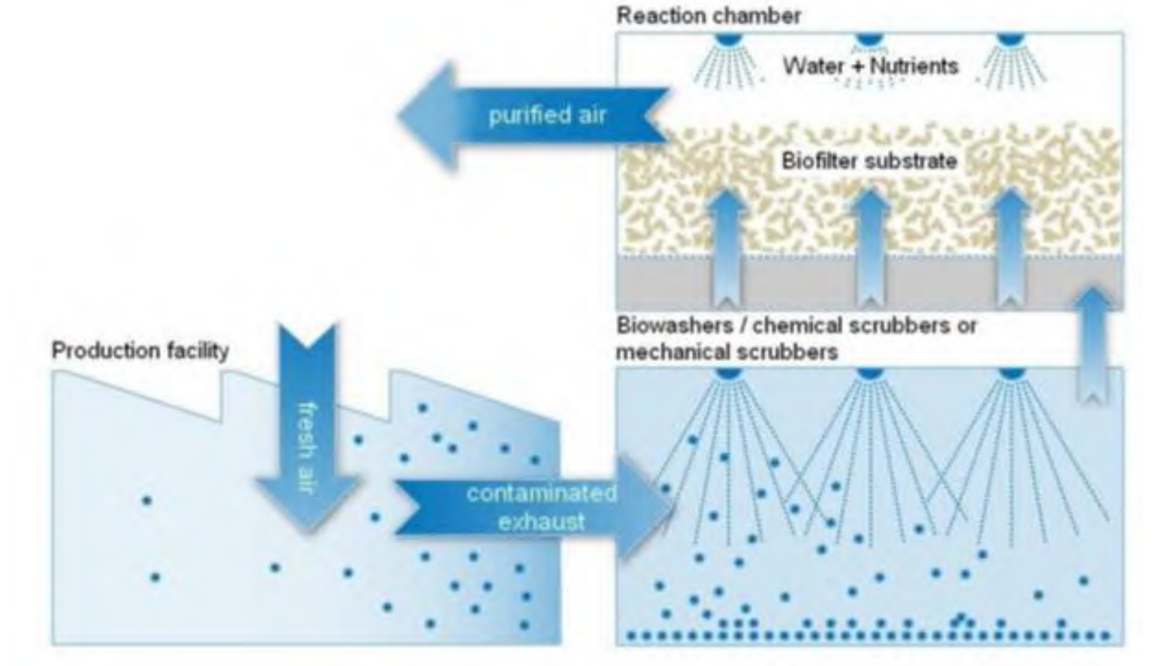
17.10.7 Biological off-gas treatment

Description
Off-gas is dedusted and sent to a reactor with biofilter substrate. The biofilter consists of a bed of organic material (such as peat, heather, compost, root, tree bark, softwood and different combinations) or some inert material (such as clay, activated carbon, and polyurethane), where the off-gas stream is biologically oxidised by naturally occurring microorganisms into carbon dioxide, water, inorganic salts and biomass. The biofilter is sensitive to dust, high temperatures or high variations in the off-gas, e.g. of the inlet temperature or the VOC concentration. Supplementary nutrient feeding may be needed.

Technical description
The biological off-gas treatment system consists of:

- scrubber for dedusting and humidification of the waste gas;
- reactor with biofilter substrate for pollutant destruction;
- automatic humidification supplying the microorganisms in the reactor with water and nutrients;
- heat exchanger for heating up fresh air for the production hall.

Figure 17.30 illustrates the production hall, the scrubber, the reactor and the heat exchanger.



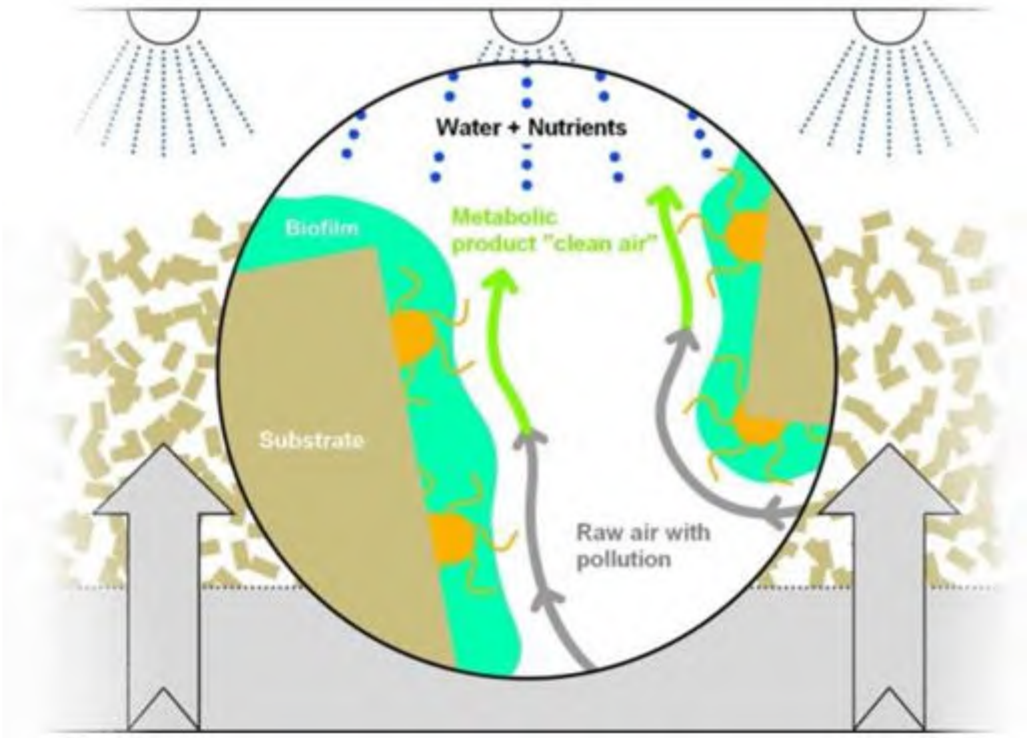
Source: [211, Germany 2017]

Figure 17.30: Scheme of the biological off-gas treatment system

The scrubber is operated with a countercurrent gas flow. The majority of the scrubber water is recirculated. If necessary, a waste water treatment system is installed. It minimises water consumption and ensures compliance with the local discharge limitations of the sewage system. The biological off-gas treatment system is based on the activity of microorganisms. The organisms biochemically oxidise organic pollutants as well as a part of the inorganic gaseous waste gas compounds. They are converted into non-toxic substances and substances that cannot be smelled.

In the reactor, microorganisms are situated on a solid supporting material. Pollutants contained in the off-gas will be absorbed by the surface of the supporting material (conversion into liquid phase). By this, they are accessible for the microorganisms. For building up their own biomass, the microorganisms use pollutants as nutrition and energy source.

The reactor contains several layers of packing material. The lower layers consist of coarse-grained material forming the reactor structure. The function of these layers is drainage and air distribution.



Source: [211, Germany 2017]

Figure 17.31: Reactor for biological off-gas treatment

The supporting material is the essential part of the off-gas treatment system. It is adapted to each specific case and consists of organic substances (Figure 17.32). The material is developed and specified by the supplier; it is produced under quality-controlled process conditions.

Source: [211, Germany 2017]

Figure 17.32: Biofilter material

For the upper layer, a specific active mix is used which has shown good results regarding the decomposition of hydrocarbons and odour. The material is highly resistant against biological destruction. This leads to a long lifetime. The large pores ensure a high biological abatement performance. The activity of the microorganisms and hence the function of the biofilter system are only ensured if the supporting material and the biomass are adapted to the process. Adaptation includes the adaptation of the pore volume and the absorption capacity (buffer capacity). This ensures a high total surface of the biofilter and sufficient retention time.

When the system starts operation, the supporting material will be inoculated with a specific bacteria culture adapted to the relevant off-gas composition. By this, the full performance is achieved in a short time.

After adaptation to the organic content of the off-gas, a specific biocoenosis is established and kept in balance in the filter material which is specific for the concentration and type of off-gas composition.

The metabolism of the bacteria produces water, CO_2 and biomass. As organic compounds are decomposed, no pollutants are accumulated in the biofilter material. Microorganisms grow rapidly if the nutrient supply is optimised. They adapt quickly to changing living conditions. Depending on the type of nutrients, a certain population is developed over time while other microorganisms will not survive.

Load peaks in the off-gas can be stored in the biofilter due to the high buffer capacity of the material. Stored organic compounds will later be decomposed by the microorganisms.

If the TOC load (from off-gases) is not sufficient, microorganisms may need to be fed with a mixture of nutrients to ensure a continuous decomposition process and a stable off-gas treatment performance.

Achieved environmental benefits

The biological off-gas treatment system reduces emissions of VOCs and minimises odour and dust emissions.

Only two datasets for the abatement efficiency of the biological off-gas treatment technique were submitted with efficiencies varying from 83 % to 94.3 % [155, TWG 2016].

Environmental performance and operational data

Example plant for metal surface coating [211, Germany 2017]:

- Measurements method for TOC: FID (EN 12619:2013-04).
- Measurement period: 30 minutes.
- Raw gas TOC concentration varies between 50 mg C/Nm3 and 300 mg C/Nm3.
- Waste gas concentration limits: TOC 50 mg/Nm3, dust 3 mg/Nm3,
- Measurement (7/8/2013): TOC 18.3/27.3/34.9 mg/Nm3, dust max. < 0.32 mg/Nm3.
- Measurement (15/7/2015): TOC max. 41.1 mg/Nm3, dust max. 0.77 mg/Nm3.
- Measurement uncertainty (15/7/2015): TOC 6.5 mg/Nm3, dust 0.22 mg/Nm3.

Cross-media effects

Energy consumption: The biofilter causes low pressure drop in the waste gas stream and therefore requires only a small power increase of the waste gas ventilator. Additional consumption is about 30 kWh (without conventional electricity consumption for ventilation as this is needed anyway for workplace safety).

Due to the biological activity in the biofilter, the waste gas outlet temperature is 2 °C higher than the inlet temperature. This energy can be recovered in the subsequent heat exchanger for warming up fresh air needed in the production halls. In winter, depending on the outside temperature level, about 50-75 % of the heating energy can be substituted.

Waste water: Waste water originates from the operation of the scrubber and the biofilter. The characteristics of the waste water depend on the off-gas composition and the concentration of organic compounds in it. Usually, discharge to the public sewage system is permitted.

Typical characteristics of the waste water [211, Germany 2017]:

- Waste water temperature: 10-30 °C.
- pH about 6-8.
- Conductivity: about 500-2 000 µS/cm.
- COD: about 400-2 000 mg/l.

Waste: When the supporting material has reached the end of its lifetime, it can be disposed of in a biomass incinerator or in a composting plant, as contaminants are not contained because they have been decomposed.

Technical considerations relevant to applicability

The biological off-gas treatment system can be applied in new plants and for upgrading of existing plants. The system can be used for treatment of all biologically degradable volatile organic compounds (except methane) usually arising from coating activities. However, it is not used in vehicle coating.

Each biofilter systems has to be adapted to the specific (combination) of organic substances in the raw gas. A change of the raw gas composition can lead to unpredictable results with regards to the abatement efficiency of the filter system. Therefore, operators who often have to switch between different customer-specific coating systems may not be able to comply with emission limits under all circumstances.

In addition, biofilter systems are not able to treat off-gases with quick and frequent variation of the solvent inlet concentration and composition.

Economics

Investment and operational costs depend on the off-gas volume and the level of concentration of organic compounds to be treated.

Operational costs (electricity, water, nutrients, chemicals, biofilter material, waste water disposal) vary due to the heterogeneous off-gas composition, varying off-gas volumes and changing raw gas compositions. The following values are estimates. Costs for disposal of the biofilter material at the end of its lifetime are neglected because it is assumed that energy recovery in a biomass combustion plant can be done without extra costs [211, Germany, 2017].

- Waste gas volume:
    - 60 000 Nm^3 at full load (about 2 000 h/yr);
    - 30 000 Nm^3 at part load (about 2 000 h/yr).
- TVOC concentration in raw gas: about 250 mg C/Nm3.
- Investment costs: about EUR 400 000.
- Operational costs: about EUR 29 000/yr.
- Maintenance frequency: 1-3 h per week.
- Specific off-gas treatment costs: EUR 0.000016 /m3.

Example plants

Metal coating: Vallo & Vogler Oberflächenveredlung, GmbH.
Wood coating: Möbelwerkstätten Hunke GmbH.
Plants #117 (metal packaging) and #027 (flexography) in [155, TWG 2016].

Reference literature

[155, TWG 2016] [211, Germany 2017]

17.10.8 NOX abatement techniques

17.10.8.1 Optimisation of thermal treatment conditions

Description

The good design of the combustion chambers, burners and associated equipment/devices is combined with optimisation of combustion conditions (e.g. by controlling combustion parameters such as temperature and residence time) with or without the use of automatic systems and the regular planned maintenance of the combustion system according to suppliers' recommendations.

Achieved environmental benefits

Reduction of TVOC, NO_X and CO emissions to air in a balanced way.

Environmental performance and operational data

Reported data for NO_X emissions from thermal oxidation systems are presented in Section 17.10.1 and Figure 17.18 [155, TWG 2016].

Technical considerations relevant to applicability
Design applicability may be restricted for existing plants due to techno-economic limitations in the possibilities to improve the combustion chamber design.

17.10.8.2 Use of low-NO_X burners

Description
The peak flame temperature in the combustion chamber is reduced, delaying but completing the combustion and increasing the heat transfer (increased emissivity of the flame). It is combined with increased residence time in order to achieve the desired VOC destruction.

Achieved environmental benefits
Reduction of NO_X emissions to air.

Technical considerations relevant to applicability
The applicability may be restricted by design and/or operational constraints at existing plants.

It is not applied in winding wire manufacturing or in coating of textiles, foils and paper. For both sectors, emitted NO_X is mainly due to the nitrogen content of the solvents used [EWWG/ORGALIM comment #94 and BE comment #105 in [212, TWG 2018]]. Also, it is not considered state of the art for the wooden surfaces coating sector [262, ESVOC et al. 2019].

Reference literature
[212, TWG 2018] [262, ESVOC et al. 2019]

17.11 Waste water treatment techniques

Waste water treatment may be carried out on or off site. Off-site treatment requires the discharge of waste waters with low concentrations of pollutants. For the STS sector, solvent output to waste water is a parameter of the solvent mass balance (see Section 17.3.1) and its calculation is important for the accuracy of the SMB exercise. The treatment of waste water may become a problem when solvent-based products are replaced by water-based alternatives, e.g. when there are soluble solvents, polymers and plasticisers in the waste water. Waste water treatment is described extensively elsewhere, such as in the CWW BREF [31, COM 2016] and for this sector in [46, France 2002]. More information on waste water treatment techniques for water-based activities can be found in the STM BREF [23, COM 2006].

For information on example plants using waste water treatment techniques listed below, see the relevant sector sections for emissions to water in Chapters 2 to 15.

17.11.1 Preliminary, primary and general techniques

17.11.1.1 Neutralisation

Description
The adjustment of the pH of waste water to a neutral value (approximately 7). The targeted pollutants are acids and alkalis. More information is provided in the STM [23, COM 2006] and CWW [31, COM, 2016] BREFs.

17.11.1.2 Equalisation

Description
Balancing of flows and pollutant loads by using tanks or other management techniques. More information is provided in the STM [23, COM 2006] and CWW [31, COM, 2016] BREFs.

17.11.1.3 Physical separation

Description
Use of, for example, screens, sieves, grit separators, primary settlement tanks and magnetic separators to remove gross solids, suspended solids and/or metal particles from the waste water. More information is provided in the STM BREF [23, COM 2006].

17.11.2 Physico-chemical treatment techniques

17.11.2.1 Chemical reduction

Description
Chemical reduction is the conversion of pollutants by chemical reducing agents into similar but less harmful or hazardous compounds. The targeted pollutants are mainly reducible dissolved non-biodegradable or inhibitory pollutants, e.g. hexavalent chromium (Cr(VI)).

Cr(VI) is converted by a chemical reducing agent to Cr(III) to enable precipitation and removal. More information is provided in the STM [23, COM 2006] and CWW [31, COM 2016] BREFs.

Technical considerations relevant to applicability
Generally applicable, especially when Cr(VI) conversion coatings are used (see also Section 6.4.6.2).

17.11.2.2 Vacuum distillation

Description

The removal of pollutants by thermal waste water treatment under reduced pressure. Vacuum distillation is a technique that uses a vacuum to extract VOCs from the waste water. It is an evaporative recovery system where a vacuum is applied to lower the pressure, so the distillation can be carried out at a lower temperature. This saves heating costs and also prevents less stable substances from decomposing under the high temperatures that would be required at atmospheric pressure.

The targeted pollutants are dissolved non-biodegradable or inhibitory pollutants that can be distilled, e.g. some solvents.

More information is provided in the CWW BREF [31, COM 2016].

17.11.2.3 Adsorption

Description

The removal of soluble substances (solutes) from the waste water by transferring them to the surface of solid, highly porous particles (typically activated carbon). Targeted pollutants are adsorbable dissolved non-biodegradable or inhibitory pollutants, e.g. AOX. This technique is described in the CWW BREF [31, COM 2016].

17.11.2.4 Precipitation

Description

The conversion of dissolved pollutants into insoluble compounds by adding precipitants. The solid precipitates formed are subsequently separated by sedimentation, flotation or filtration. Targeted pollutants are precipitable dissolved non-biodegradable or inhibitory pollutants (e.g. metals). More information is provided in the CWW BREF [31, COM 2016].

17.11.2.5 Ion exchange

Description

The retention of ionic pollutants from waste water and their replacement by more acceptable ions using an ion exchange resin. The pollutants are temporarily retained and afterwards released into a regeneration or backwashing liquid. Targeted pollutants are ionic dissolved non-biodegradable or inhibitory pollutants, e.g. metals. More information is provided in the CWW BREF [31, COM 2016].

17.11.2.6 Stripping

Description

The removal of purgeable pollutants from the aqueous phase by a gaseous phase (e.g. steam, nitrogen or air) that is passed through the liquid. The removal efficiency may be enhanced by increasing the temperature or reducing the pressure. Targeted pollutants are purgeable pollutants, e.g. some adsorbable organically bound halogens (AOX). More information is provided in the CWW BREF [31, COM 2016].

17.11.3 Biological treatment

Description
Use of microorganisms for waste water treatment (e.g. anaerobic treatment, aerobic treatment). Targeted pollutants are biodegradable organic compounds. More information is provided in the STM [23, COM 2006] and CWW [31, COM 2016] BREFs.

17.11.4 Final solids removal techniques

17.11.4.1 Coagulation and flocculation

Description
Coagulation and flocculation are used to separate suspended solids from waste water and are often carried out in successive steps. Coagulation is carried out by adding coagulants with charges opposite to those of the suspended solids. Flocculation is a gentle mixing stage so that collisions of microfloc particles cause them to bond to produce larger flocs. It may be assisted by adding polymers. More information is provided in the STM [23, COM 2006] and CWW [31, COM 2016] BREFs.

17.11.4.1.1 Electroflocculation

Description
Electroflocculation is flotation using electrolytically generated bubbles of hydrogen and oxygen for separating suspended substances from aqueous phases. This is effective in separating waste waters that do not settle well by gravity, such as oily waste water or oil-water emulsions, etc. More information is provided in the STM BREF [23, COM 2006].

17.11.4.2 Sedimentation

Description
The separation of suspended particles by gravitational settling. After flocculation (see Section 17.11.4.1), sedimentation can be applied to separate the waste water to be discharged from flocculated particle sludges.

Sedimentation is based on the difference in density to achieve a phase separation; the sludge sinks to the bottom. The sedimentation process can be improved by the use of a parallel plate or lamella separator. The concentrated sludge is pumped from the separator.
More information is provided in the STM [23, COM 2006] and CWW [31, COM 2016] BREFs.

17.11.4.3 Filtration (Ultra and nanofiltration and reverse osmosis)

Description
The separation of solids from waste water by passing them through a porous medium, e.g. sand filtration, nano, micro and ultrafiltration.

Waste water passes along a semi-permeable diaphragm under high pressure, which lets through small molecules such as water but not larger particles. The concentration of the contamination increases as the waste water is repeatedly recycled through the filter. The difference in the techniques is the pore size of the filters and therefore the molecules that are filtered out. There are four available membrane methods. Microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). MF and UF are mainly used for separation of solids and oil. NF and RO are mainly used for separation of dissolved compounds and ions. Particles in the water will block NF and RO and membrane fouling occurs. Therefore an efficient mechanical pre-filter is required [DK comment #18 in [212, TWG 2018]].

More information is provided in the STM [23, COM 2006] and CWW [31, COM 2016] BREFs.

17.11.4.4 Flotation

Description

The separation of solid or liquid particles from waste water by attaching them to fine gas bubbles, usually air. The buoyant particles accumulate at the water surface and are collected with skimmers. More information is provided in the CWW BREF [31, COM 2016].

17.12 Waste management techniques

The following sections show techniques aiming for appropriate waste management and monitoring as well as techniques used to minimise waste quantities sent for disposal through recovery and reuse.

See also Section 17.2.4 on minimisation of raw material consumption and Section 17.12.3 for measures to reduce the loss of raw materials in process waters.

17.12.1 Waste management plan

Description
A waste management plan is part of the EMS (see Section 17.1.1) and is a set of measures aiming to 1) minimise the generation of waste, 2) optimise the reuse, regeneration, recycling and/or recovery of energy of waste, and 3) ensure the proper disposal of waste.

Achieved environmental benefits

- Reduction of total quantities of waste generated and of solvent output in wastes.
- Increased overall environmental performance of the installation.
- Raw material and resources savings.

Environmental performance and operational data
Determination of the solvent content of waste is part of the solvent mass balance (SMB) exercise for the calculation of solvent inputs and outputs (see Section 17.3.1).

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable

Economics
The staff time required for the preparation and updating of the waste management plan.

Example plants
Widely applied.

Reference literature
[31, COM 2016] [155, TWG 2016]

17.12.2 Monitoring of waste quantities

Description
Annual recording of waste quantities generated for each type of waste. The solvent content in the waste is determined periodically (at least annually) by analysis or calculation.

Technical description
It is common practise for STS plants to measure the quantities of generated waste and to keep relevant records. Information on the solvent content in waste is also available and derived either by measurement (analysis) or by calculation/estimation. More information and related data on the waste quantity monitoring as well as on the solvent content of waste streams generated can be found in the relevant sector sections for waste generation in Chapters 2 to 15.

Achieved environmental benefits
Reduction of solvent emissions in wastes due to better information.

Environmental performance and operational data
Determination of the solvent content of waste is part of the solvent mass balance (SMB) exercise for the calculation of solvent inputs and outputs (see Section 17.3.1).

Technical considerations relevant to applicability
Generally applicable.

Driving forces for implementation
The solvent content of waste is part of the solvent mass balance (SMB) exercise for the calculation of solvent inputs and outputs (see Section 17.3.1).

Example plants
Monitoring of waste quantities and of the solvent content in waste streams was reported by almost all plants participating in the data collection.

Reference literature
[155, TWG 2016]

17.12.3 Recovery/recycling of solvents

Techniques may include:

- recovering/recycling solvents from liquid waste by filtration (see Section 17.12.3.1.1) or distillation (see Section 17.12.3.1.2) on or off site;
- recovering/recycling the solvent content of wipes by gravitational draining, wringing or centrifugation (see Section 17.12.3.2).

17.12.3.1 Recovery of used solvents from the process and cleaning

Description
Solvents are recovered/recycled from liquid waste generated by the process and cleaning systems.

Technical description
Used solvents, e.g. used for cleaning, can be treated for reuse, e.g. by filtration or distillation (see Sections 17.12.3.1.1 and 17.12.3.1.2). Both recovery and reuse can be done on or off site. For example, where pig cleaning systems or purge systems are applied, solvents are used on site to clean the system after each change of colour – called the purges. Modern paint supply equipment includes recovery of the purge solvents. Solvents can also be disposed of as hazardous waste to an off-site solvent recovery installation. There, the clean solvents are reused, but not necessarily by the same user.

Cleaning can be carried out in washing machines, where the solvent is recovered and reused internally (see Section 17.8.6). Halogenated VOCs can be used for this technique, in conjunction with closed storage and waste disposal systems.

Achieved environmental benefits
Benefits include reduced amounts of hazardous waste and reduced consumption of fresh solvents. By reusing the hazardous waste (in this case solvent), its life cycle is extended.

In the automotive industry, typically 80-90 % of cleaning and purge solvents can be recovered, either on or off site, for reuse.

Environmental performance and operational data
For filtration and distillation in an economical manner, generally large quantities (several tonnes at a time) are required and are usually contracted out. This implies storage of large amounts of both clean and used solvents. There should be adequate storage for both receiving used solvents waiting to be removed and for the returned clean solvent: the amounts should be equal if usage remains unchanged.

In coil coating processes, solvents from waste paints are commonly recovered and reused in cleaning activities. The remaining solid waste is usually incinerated off site.

Cross-media effects

- Noise levels might increase.
- Storage risk increased for hazardous materials.

Technical considerations relevant to applicability
Generally applicable.

It is applicable especially in plants using large quantities of solvents. Recovery of cleaning agents is commonly applied in:

- publication rotogravure, heatset web offset, and flexography and non-publication rotogravure printing plants, although only in publication rotogravure and heatset web offset printing plants using more than 200 litres cleaning agents a week;
- the coating and printing of metal packaging;
- wood furniture painting, e.g. in the coating of wooden kitchen and bathroom furniture;
- the automotive industry.

The cleaning of purge solvents is applicable in all industries applying piping systems, e.g. paint or ink supply, and is commonly applied in the automotive industry.

Care must be taken to ensure that solvents recovered by distillation or filtration (or any other method) are only used where technical specifications are fulfilled. They can alternatively be used for other applications, or reworked to meet the specifications required (although this may be more expensive than buying fresh solvent).

Economics
A saving will be incurred because of reduced consumption of solvents and a reduced amount of hazardous waste. In large plants, the savings will approximately outweigh the investment. For example, the investment costs for the recovery of cleaning agents might be in the range of EUR 3 000-150 000 (2006 data), depending on, for example, size, tank capacity and automation.

Reusing hazardous solvents is a cost-effective activity. The utilisation of hazardous used solvents is productive for the company that generates used solvents, because the company does not have to pay for the disposal of hazardous waste. The company that processes the used solvents gets the necessary amount of input solvent cheaply, and the end user who needs processed used solvents in its manufacturing processes gets the raw material at a competitive price.

Driving force for implementation
Solvent recycling and VOC emission reduction.

Example plants
See example plants in filtration (Section 17.12.3.1.1) and distillation (Section 17.12.3.1.2).

Reference literature

[1, INTERGRAF and EGF 1999] [5, DFIU et al. 2002] [26, CITEPA 2003]
[38, TWG 2004] [78, TWG 2005] [155, TWG 2016]

17.12.3.1.1 Filtration

Description

Dirty cleaning solutions, e.g. of HBS or VCAs (see Section 17.9.5), can be filtered on or off site. The solvents can be reused and the water residue can normally be discharged to the municipal waste water treatment system. It is also applied for recovery of raw materials (e.g. electrocoat paint).

Achieved environmental benefits

- Less waste water and less use of fresh solvents.
- Reclaiming of valuable raw materials.

Environmental performance and operational data

Experiments are being carried out in the Netherlands with low-volatility cleaning agents in cleaning machines for flexible packaging. Filtration and reuse of these cleaning agents is an important part of these experiments.

Cross-media effects

Filtration requires energy and the water residue is discharged.

Noise levels might increase.

The impact upon the aquatic environment has not been considered sufficiently.

Any dissolved HBS or VCA will drastically affect the chemical oxygen demand and biological oxygen demands of the water being discharged to the municipal waste water system.

Example plants

Widely applied: Plant #059 (ultrafiltration to reclaim electrocoat paint and return it to process tanks), Plant #144 (filtration of used solvents), Plant #150 (reducing dampening waste water) and Plant #165 in [155, TWG 2016].

Reference literature

[7, Germany 2003] [38, TWG 2004] [155, TWG 2016]

17.12.3.1.2 Distillation

Description

Solvent-based waste such as inks, paints, and adhesives can be distilled on or off site to recover the solvent and to reduce the amount of hazardous waste. Special distillation equipment exists.

Achieved environmental benefits

The amount of hazardous waste is reduced and the solvent can be reused, e.g. for cleaning.

Environmental performance and operational data
A significant percentage of the used solvent may be recovered and reused. A plant (#126 in [155, TWG 2016]) reported that about 95 % of the used solvent is reused on site after distillation.

The distillation equipment must be installed and operated with care. Cleaning agents with a high flashpoint generally also have a high boiling point. For these solvents, only vacuum distillation equipment can be applied (see Section 17.12.3.1.2); in these situations, membrane filtration may be used (see Section 17.12.3.1.1). It is reported that relatively small vacuum distillation units (50 litres) are readily available. Furthermore, membrane filtration can be expensive and many of the solvents used can attack the membrane.

Cleaning machines that have distillation equipment attached are available.

In publication rotogravure printing plants (where toluene is the sole ink diluter), the equipment for the distillation of cleaning agents may, if suitable, also be used for waste ink. Distilling waste inks only may not be cost-effective because only four colours are used and there is little waste ink.

Cross-media effects
Distillation requires energy. However, compared to oxidation, which emits CO_2 and also uses energy, it is likely that distillation and reuse saves energy.

Noise levels might increase.

Technical considerations relevant to applicability
Applicable in new and existing installations. Applicable to solvent-based inks and adhesives.

In packaging rotogravure printing, distillation of waste inks is used less and less because there are less waste inks due to the application of automated mixing of inks (see Section 17.2.4.1).

Where on-site distillation is not cost-effective, external distillers can be used, e.g. in publication rotogravure printing.

It is used in the automobile industry if the recovered solvents can be used for processes with a lower quality requirement, such as general cleaning.

Economics
Investment costs start at EUR 10 000 (2006 data) for smaller vacuum distillation plants, depending on, for example, size, tank capacity and automation. There is an additional cost if the existing equipment for the distillation of cleaning agents can be used.

Example plants
On-site distillation of used solvents: Plants #056, #071, #078, #079, #091, #096, #097, #126, #134 and #135 in [155, TWG 2016].

Reference literature
[1, INTERGRAF and EGF 1999] [6, DFIU et al. 2002] [22, ECCA 2004] [38, TWG 2004] [78, TWG 2005] [155, TWG 2016]

17.12.3.2 Recovery of used solvents from wipes

Description
The majority of solvents in wipes are removed by gravitational draining, wringing, or centrifugation prior to transport.

This technique is an answer to the bad practice of using too much solvent and pouring the excess solvents from the used solvent containers over the wipes in order not to have to dispose of them separately.

Achieved environmental benefits

- The recovered solvents can be used again for cleaning, or, if too dirty, distilled and reused (see Section 17.12.3.1.2).
- Less weight has to be transported.
- Emissions during storage and transportation are reduced.

Environmental performance and operational data
Commonly applied in the printing industry in the US.

Cross-media effects

- Emissions on site from the handling required for removing the solvents from the wipes.
- Noise levels might increase.

Technical considerations relevant to applicability
Generally applicable. Applicable to all printing plants using solvent wipes. The wipes might be reusable (see Section 17.12.3.2.1) or disposable.

Example plants
Plants #030, #057 and #158 in [155, TWG 2016].

Reference literature
[18, US EPA et al. 2003] [38, TWG 2004] [155, TWG 2016]

17.12.3.2.1 Reusable cleaning wipes

Description
Cleaning can be done with disposable and reusable wipes. Reusable wipes are normally rented. Once dirty, they are returned to the rental company, where they are washed and put back into circulation.

In some cases, reusable wipes are first treated on site (e.g. by drying with extraction and subsequent thermal treatment of contained solvents) and then sent off site for washing (plant #137 in [155, TWG 2016]).

Reusable wipes are made of natural textile fibres. After use, they are washed with solvents and then dried. The contaminated solvent is distilled and the sludge is incinerated as hazardous waste. The washing, drying and distillation processes for reusable wipes give rise to solvent emissions.

Since reusable wipes are far less absorbent than disposables, a far greater weight and volume is needed. The amount of transportation involved is consequently larger for the same amount of cleaning. However, reusable wipes generate less waste than disposable wipes.

Achieved environmental benefits
There is no clear environmental difference between reusable and disposable wipes apart from the lower volume of generated waste.

Cross-media effects
Raw materials are consumed in the production of reusable cleaning wipes and, once they have reached the end of their life, the wipes are discarded as waste. Additional wastes may also be created and energy used during the washing and drying process.

Environmental performance and operational data
Reusable wipes are stronger and thicker than disposable wipes. This makes them fit for use in situations where manual force and repetitive movement are necessary to clean the object. This force may not be applicable on delicate surfaces.

Technical considerations relevant to applicability
Reusable wipes are commonly used in all types of industries, e.g. in the printing and coil coating industry.

Reusable cleaning wipes are too hard for the finishing of wooden workpieces.

As an alternative and when reusable wipes could not be used, disposable wipes may be used. A possible reason for the choice for disposable wipes is the damage that may be done to very sensitive surfaces such as offset plates and gravure cylinders by a reusable wipe that is not completely free of contamination from previous uses. Disposable wipes are generally made of synthetic fibres. Per unit of weight, they can contain many times more cleaning agent and dirt than reusable wipes. After use, they are incinerated together with their contamination. Since disposable wipes are light, the incineration of the sludge from the cleaning of reusable wipes offers little advantage over incineration of completely disposable wipes (example plants #024, #025 in [155, TWG 2016]).

Example plants
Widely used in all sectors. Plants: #003, #011, #015, #024, #045, #061, #064, #071, #097, #106, #112, #115, #125, #128, #137, #143, #149, #150, #159, #161 and #168 in [155, TWG 2016].

Reference literature
[1, INTERGRAF and EGF 1999] [7, Germany 2003] [22, ECCA 2004] [38, TWG 2004] [155, TWG 2016]

17.12.4 Waste-stream-specific techniques

Techniques may include:

- reducing the water content of the waste, e.g. by using a filter press for the sludge treatment (see Section 17.12.4.1);
- reducing the sludge and waste solvent generated, e.g. by reducing the number of cleaning cycles (see Section 17.9);
- using reusable containers, reusing the containers for other purposes, or recycling the container material (see Section 17.12.4.2);
- sending the spent limestone generated from dry scrubbing to a lime or cement kiln (see Section 17.12.4.3).

17.12.4.1 Dewatering of process sludges

Techniques for treating and managing waste water from sludges are described in more detail in the STM BREF [23, COM 2006] and in the CWW BREF [31, COM 2016], as well as in specialist texts such as [46, France 2002].

The following two techniques refer to processes for the dewatering of process sludges focusing on the reduction of the quantity of waste.

17.12.4.1.1 Centrifuges

Description
Centrifuges are used for enforced draining of paint sludge. Paint sludge is disposed of whereas the fluid is usually fed back into the waste water treatment process.

Achieved environmental benefits

- Easier handling of waste.
- Less solid or sludgy waste to dispose of.
- Reduction of waste (less water).
- Helps to prolong service life of wet scrubbing systems.

Environmental performance and operational data
Water contents of 50-70 % can be reached.

The desludging frequency is strongly interdependent with other bath maintenance operations and any continuous filtration. Usually, baths are cleaned two to three times a year, with possible additional cleaning during a shutdown period. A longer service life of venturi system baths can be achieved if continuous desludging is carried out. Therefore centrifuges are operated either continuously or for shorter intervals during the cleansing campaign [ACEA comment #342 in [212, TWG 2018]].

Cross-media effects
Energy consumption.

Technical considerations relevant to applicability
This technique is applied in the automotive industry if the water content after sedimentation or flotation is still too high. In the case of phosphate sludge, filter presses can be used instead.

Economics
Lower costs for transport and disposal of paint sludge.

Driving force for implementation
Cost reduction and legal requirements.

Example plants
Widely reported for all coating activities. Plants #040, #041, #045, #046, #048, #050, #053, #054, #055, #056, #057, #062, #067, #068, #117, #126, #145 and #158 in [155, TWG 2016].

Reference literature
[23, COM 2006] [38, TWG 2004] [155, TWG 2016] [212, TWG 2018]

17.12.4.1.2 Filter press

Description
Filter presses are used for dewatering of sludge derived from the waste water treatment processes. In vehicle coating plants, separated phosphate sludge from sedimentation (such as from a lamella separator) is often dewatered using filter presses with woven fabric filters.

Achieved environmental benefits

- Easier handling and disposal of the waste.

- Reduced waste volume and weight.

Environmental performance and operational data
In vehicle coating plants, dry matter (DM) is usually the base for dewatering. A total of 40-60 % dry matter (DM) can be achieved for zinc-phosphate sludge. For hydroxide sludge dewatering in physico-chemical waste water treatment, 30-35 % DM can be achieved. A chamber filter press is not applicable for paint sludge dewatering [DE comment #231 & ACEA comment #254 in [212, TWG 2018]].

Technical considerations relevant to applicability
These techniques are commonly applied in the automotive industry.

Economics
Lower costs for transport and disposal of paint sludge.

Driving force for implementation
Cost reduction and legal requirements.

Example plants
Commonly applied. Reported by the majority of vehicle coating and coil coating plants as well as from plants for the coating and printing of metal packaging (#112, #114, #117, #122 and #125), coating of metal and plastic surfaces (#129 and #165) and publication rotogravure printing (#143).

Reference literature
[23, COM 2006] [38, TWG 2004] [155, TWG 2016] [212, TWG 2018]

17.12.4.2 Reusable containers

Description
Many raw materials are supplied in reusable containers, such as IBCs (intermediate bulk containers) with a capacity of approximately 1 tonne, or standard 200-litre metal drums, etc. These containers can be returned for reuse or reused for containing solvents. Incorporation of a liner that is unreactive to the contents and can be disposed of can eliminate the damage to the 200-litre open-top drum and make reuse easier.

Achieved environmental benefits
Reduced quantities of waste generated.

Environmental performance and operational data
Large offset printing plants apply a direct supply of ink by piping systems. Solvents used as cleaning agents are also commonly contained in reusable containers. Less waste containers and large containers makes direct ink supply to the presses via piping systems possible.

A disadvantage might be that the reuse of empty ink and solvent containers require the return of these containers to the manufacturers. As the trade in inks is international, empty metal containers would have to be collected, stored and then shipped across Europe.

Cross-media effects
Before reuse, the containers need to be cleaned, normally off site.

Technical considerations relevant to applicability
Applicable to all plants using large quantities of materials.

In heatset web offset printing, the standard colours of offset inks are supplied in reusable containers.

In flexible packaging, the many different colours used restrict its applicability. The amount per colour does not warrant sending containers back to the supplier, with the possible exception of white ink, some paints and some adhesives. The containers in which the inks have been supplied are reused in house. They are used to mix colours, to dilute inks and to transport the inks to the presses. They are frequently cleaned and reused many times over.

Reusable bulk containers for paint are commonly applied in coil coating plants. They are also supplied in the winding wire industry and sent back to the supplier after use.

Economics
Ink and solvents supplied in large quantities in reusable bulk containers are often cheaper and less waste has to be disposed of.

Example plants
Widely reported for various sectors. Plants #001, #002, #003, #097, #098, #112, #116, #128, #143, #144, #145, #149, #154 and #159 in [155, TWG 2016].

Reference literature
[1, INTERGRAF and EGF 1999] [22, ECCA 2004] [38, TWG 2004] [78, TWG 2005] [155, TWG 2016]

17.12.4.3 Sending spent limestone to a lime or cement kiln

Description
Spent limestone generated from dry overspray (using limestone) separation systems is sent to a lime or cement kiln (see also Section 17.10.4.3).

Achieved environmental benefits
Reduced quantities of waste to dispose of.

17.13 Odour emissions

Many processes using solvent have odour impacts. However, in-process and end-of-pipe techniques to reduce solvent emissions as well as the installation of high stacks for waste gas emissions also resolve these (see Sections 17.6, raw material management (including substitution), and 17.10, off-gas extraction and treatment).

In principle, management of odour emissions should be based on the selection of substances/mixtures with low odours. In case of odour-intense ingredients, the recipes are checked for possibilities of substitution.

17.13.1 Odour management plan

Description
An odour management plan (OMP) is part of the environmental management system (EMS) of the installation (see Section 17.1.1) and includes elements to prevent or reduce odorous nuisances.

Technical description
The OMP includes:

- a protocol containing actions and timelines;
- a protocol for response to identified odour incidents;
- an odour prevention and reduction programme designed to identify the source(s), to characterise the contributions of the sources, and to implement prevention and/or reduction measures.

Achieved environmental benefits
Prevention or reduction of the emissions of those odorous releases that may be offensive and detectable beyond the boundaries of the site.

Cross-media effects
None.

Technical considerations related to applicability
The technique is applicable to new and existing plants where an odour nuisance at sensitive receptors is expected and/or has been substantiated.

Economics
The staff time required for the preparation and updating of the odour management plan.

Driving force for implementation
Reduction of number of complaints from the neighbourhood.

Example plants
Plant #139 in [155, TWG 2016].

Reference literature
[31, COM 2016] [155, TWG 2016]

18 BEST AVAILABLE TECHNIQUES (BAT) CONCLUSIONS FOR SURFACE TREATMENT USING ORGANIC SOLVENTS INCLUDING PRESERVATION OF WOOD AND WOOD PRODUCTS WITH CHEMICALS

SCOPE

These BAT conclusions concern the following activities specified in Annex I to Directive 2010/75/EU:

6.7: Surface treatment of substances, objects or products using organic solvents, in particular for dressing, printing, coating, degreasing, waterproofing, sizing, painting, cleaning or impregnating, with an organic solvent consumption capacity of more than 150 kg per hour or more than 200 tonnes per year.

6.10: Preservation of wood and wood products with chemicals with a production capacity exceeding 75 m^3 per day other than exclusively treating against sapstain.

6.11: Independently operated treatment of waste water not covered by Directive 91/271/EEC provided that the main pollutant load originates from activities specified in point 6.7 or 6.10 of Annex I to Directive 2010/75/EU.

These BAT conclusions also cover the combined treatment of waste water from different origins provided that the main pollutant load originates from the activities specified in point 6.7 or 6.10 of Annex I to Directive 2010/75/EU and that the waste water treatment is not covered by Directive 91/271/EEC.

These BAT conclusions do not address the following:

For surface treatment of substances, objects or products using organic solvents:

- Waterproofing of textiles by means other than the use of a solvent-based continuous film. This may be covered by the BAT conclusions for the textiles industry (TXT).
- Printing, sizing and impregnation of textiles. This may be covered by the BAT conclusions for the textiles industry (TXT).
- Lamination of wood-based panels.
- Conversion of rubber.
- Manufacturing of coating mixtures, varnishes, paints, inks, semiconductors, adhesives or pharmaceutical products.
- On-site combustion plants unless the hot gases generated are used for direct contact heating, drying or any other treatment of objects or materials. These may be covered by the BAT conclusions for large combustion plants (LCP) or by Directive 2015/2193/EU.

For preservation of wood and wood products with chemicals:

- Chemical modification and hydrophobisation (e.g. using resins) of wood and wood products.
- Sapstain treatment of wood and wood products.
- Ammonia treatment of wood and wood products.
- On-site combustion plants. These may be covered by the BAT conclusions for large combustion plants (LCP) or by Directive 2015/2193/EU.

Other BAT conclusions and reference documents which may be of relevance for the activities covered by these BAT conclusions are the following:

- Economics and Cross-Media Effects (ECM).
- Emissions from Storage (EFS).
- Energy Efficiency (ENE).
- Waste Treatment (WT).
- Large Combustion Plants (LCP).
- Surface Treatment of Metals and Plastics (STM).
- Monitoring of Emissions to Air and Water from IED Installations (ROM).

DEFINITIONS

For the purposes of these BAT conclusions, the following definitions apply:

General terms	
Term used	**Definition**
Base coat	Paint which, when applied to a substrate, determines the colour and the effect (e.g. metallic, pearlescent).
Batch discharge	Discharge of a discrete, contained volume of water.
Clear coat	Coating material which, when applied to a substrate, forms a solid transparent film with protective, decorative or specific technical properties.
Combiline	Combination of hot-dip galvanising and coil coating in the same process line.
Continuous measurement	Measurement using an automated measuring system permanently installed on site for continuous monitoring of emissions, according to EN 14181.
Direct discharge	Discharge to a receiving water body without further downstream waste water treatment.
Emission factors	Coefficients that can be multiplied by known data such as plant/process data or throughput data to estimate emissions.
Existing plant	A plant that is not a new plant.
Fugitive emissions	Fugitive emissions as defined in Article 57(3) of Directive 2010/75/EU.
Grade B or C creosote	Types of creosote for which specifications are given in EN 13991.
Indirect discharge	Discharge which is not a direct discharge.
Major plant upgrade	A major change in the design or technology of a plant with major adjustments or replacements of the process and/or abatement technique(s) and associated equipment.
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 following the publication of these BAT conclusions.
Off-gas	The gas extracted from a process, piece of equipment or area which is either directed to treatment or discharged directly to air through a stack.
Organic compound	Organic compound as defined in Article 3(44) of Directive 2010/75/EU.
Organic solvent	Organic solvent as defined in Article 3(46) of Directive 2010/75/EU.
Plant	All parts of an installation that carry out an activity listed in point 6.7 or 6.10 of Annex I to Directive 2010/75/EU and any other directly associated activities which have an effect on consumption and/or emissions. Plants may be new plants or existing plants.
Primer coat	Paint formulated for use as a layer on a prepared surface, to provide good adhesion, protection of any layers below and filling of surface irregularities.
Sector	Any of the surface treatment activities that are part of activities listed in point 6.7 of Annex I to Directive 2010/75/EU and are referred to in Section 18.1 of these BAT conclusions.
Sensitive receptor	Area which needs special protection, such as: - residential areas, - areas where human activities are carried out (e.g. neighbouring workplaces, schools, day-care centres, recreational areas, hospitals or nursing homes).
Solid mass input	The total mass of solids used as defined in Part 5, 3(a)(i) of Annex VII to Directive 2010/75/EU.
Solvent	'Solvent' refers to 'organic solvent'.
Solvent input	The total quantity of organic solvents used as defined in Part 7, 3(b) of Annex VII to Directive 2010/75/EU.
Solvent-based (SB)	Type of paint, ink or other coating material using solvent(s) as the carrier. For the preservation of wood and wood products, it refers to the type of treatment chemicals.
Solvent-based-mix (SB-mix)	Solvent-based coating where one of the coating layers is water-based (WB).
Solvent mass balance (SMB)	A mass balance exercise conducted at least once every year according to Part 7 of Annex VII to Directive 2010/75/EU.

Surface run-off water	Water from precipitation that flows over land or impervious surfaces, such as paved streets and storage areas, rooftops, etc. and does not soak into the ground.
Total emissions	The sum of fugitive emissions and emissions in waste gases as defined in Article 57(4) of Directive 2010/75/EU.
Treatment chemicals	Chemicals used in wood and wood products preservation such as biocides, chemicals used for waterproofing (e.g. oils, emulsions) and flame retardants. This also includes the carrier of active substances (e.g. water, solvent).
Valid hourly/half-hourly average	An hourly/half-hourly average is considered valid when there is no maintenance or malfunction of the automated measuring system.
Waste gases	Waste gases as defined in Article 57(2) of Directive 2010/75/EU.
Water-based (WB)	Type of paint, ink or other coating material in which water replaces all or part of the solvent content. For the preservation of wood and wood products, it refers to the type of treatment chemicals.
Wood preservation	Activities whose purpose is to protect wood and wood products from the damaging effects of fungi, bacteria, insects, water, weather or fire; to provide long-term conservation of structural integrity; and to improve the resistance of wood and wood products.

Pollutants and parameters	
Term used	**Definition**
AOX	Adsorbable organically bound halogens, expressed as Cl, include adsorbable organically bound chlorine, bromine and iodine.
CO	Carbon monoxide.
COD	Chemical oxygen demand. Amount of oxygen needed for the total chemical oxidation of the organic matter to carbon dioxide using dichromate. COD is an indicator for the mass concentration of organic compounds.
Chromium	Chromium, expressed as Cr, includes all inorganic and organic chromium compounds, dissolved or bound to particles.
DMF	*N*,*N*-Dimethylformamide.
Dust	Total particulate matter (in air).
F^-	Fluoride.
Hexavalent chromium	Hexavalent chromium, expressed as Cr(VI), includes all chromium compounds where the chromium is in the oxidation state +6 (dissolved or bound to particles).
HOI	Hydrocarbon oil index. The sum of compounds extractable with a hydrocarbon solvent (including long-chain or branched aliphatic, alicyclic, aromatic or alkyl-substituted aromatic hydrocarbons).
IPA	Isopropyl alcohol: propan-2-ol (also called isopropanol).
Nickel	Nickel, expressed as Ni, includes all inorganic and organic nickel compounds, dissolved or bound to particles.
NO_X	The sum of nitrogen monoxide (NO) and nitrogen dioxide (NO_2), expressed as NO_2.
PAHs	Polycyclic aromatic hydrocarbons.
TOC	Total organic carbon, expressed as C (in water).
TVOC	Total volatile organic carbon, expressed as C (in air).
TSS	Total suspended solids. Mass concentration of all suspended solids (in water), measured via filtration through glass fibre filters and gravimetry.
VOC	Volatile organic compound as defined in Article 3(45) of Directive 2010/75/EU.
Zinc	Zinc, expressed as Zn, includes all inorganic and organic zinc compounds, dissolved or bound to particles.

ACRONYMS

For the purposes of these BAT conclusions, the following acronyms apply:

Acronym	Definition
BPR	Biocidal Products Regulation (Regulation (EU) No 528/2012 of the European Parliament and of the Council of 22 May 2012 concerning the making available on the market and use of biocidal products).
DWI	Draw and wall ironed (a type of can in the metal packaging industry).
EMS	Environmental management system.
IED	Industrial Emissions Directive (2010/75/EU).
IR	Infrared.
LEL	Lower explosive limit – the lowest concentration (percentage) of a gas or vapour in air capable of producing a flash of fire in the presence of an ignition source. Concentrations lower than LEL are 'too lean' to burn. Also called lower flammable limit (LFL).
OTNOC	Other than normal operating conditions.
STS	Surface treatment using organic solvents.
UV	Ultraviolet.
WPC	Preservation of wood and wood products with chemicals.

GENERAL CONSIDERATIONS

Best Available Techniques

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, these BAT conclusions are generally applicable.

Emission levels associated with the best available techniques (BAT-AELs)

BAT-AELs for total and fugitive VOC emissions

For total VOC emissions, the emission levels associated with the best available techniques (BAT-AELs) are given in these BAT conclusions:

- as a specific emission load calculated as yearly averages by dividing the total emissions of VOCs (as calculated by the solvent mass balance) by a sector-dependent production input (or throughput) parameter; or
- as a percentage of the solvent input, calculated as yearly averages as per Part 7, 3(b)(i) of Annex VII to Directive 2010/75/EU.

For fugitive VOC emissions, the emission levels associated with the best available techniques (BAT-AELs) are given in these BAT conclusions as a percentage of the solvent input, calculated as yearly averages as per Part 7, 3(b)(i) of Annex VII to Directive 2010/75/EU.

BAT-AELs and indicative emission levels for emissions in waste gases

Emission levels associated with the best available techniques (BAT-AELs) and indicative emission levels for emissions in waste gases given in these BAT conclusions refer to concentrations, expressed as mass of emitted substance per volume of waste gas under the following standard conditions: dry gas at a temperature of 273.15 K and a pressure of 101.3 kPa, without correction for oxygen content and expressed in mg/Nm^3.

For averaging periods of BAT-AELs and indicative emission levels for emissions in waste gases, the following definitions apply.

Type of measurement	Averaging period	Definition
Continuous	Daily average	Average over a period of one day based on valid hourly or half-hourly averages.
Periodic	Average over the sampling period	Average value of three consecutive measurements of at least 30 minutes each (1).
(1) For any parameter where, due to sampling or analytical limitations and/or due to operational conditions, a 30-minute sampling/measurement and/or an average of three consecutive measurements is inappropriate, a more representative sampling/measurement procedure may be employed.		

BAT-AELs for emissions to water

Emission levels associated with the best available techniques (BAT-AELs) for emissions to water given in these BAT conclusions refer to concentrations (mass of emitted substance per volume of water), expressed in mg/l.

Averaging periods associated with the BAT-AELs refer to either of the following two cases:

- in the case of continuous discharge, daily average values, i.e. 24-hour flow-proportional composite samples;
- in the case of batch discharge, average values over the release duration taken as flow-proportional composite samples.

Time-proportional composite samples can be used provided that sufficient flow stability is demonstrated. Alternatively, spot samples may be taken, provided that the effluent is appropriately mixed and homogeneous. Spot samples are taken if the sample is unstable with respect to the parameter to be measured. All BAT-AELs for emissions to water apply at the point where the emission leaves the plant.

Other environmental performance levels

Specific energy consumption (energy efficiency) levels associated with the best available techniques (BAT-AEPLs)

The environmental performance levels related to specific energy consumption refer to yearly averages calculated using the following equation:

$$\text{specific energy consumption} = \frac{\text{energy consumption}}{\text{activity rate}}$$

where:

energy consumption: the total amount of heat (generated by primary energy sources) and electricity consumed by the plant, as defined in the energy efficiency plan (see BAT 19 (a)), expressed in MWh/year;

activity rate: total amount of products processed by the plant or plant throughput, expressed in the appropriate unit depending on the sector (e.g. kg/year, m^2/year, vehicles coated/year).

Specific water consumption levels associated with the best available techniques (BAT-AEPLs)

The environmental performance levels related to specific water consumption refer to yearly averages calculated using the following equation:

$$\text{specific water consumption} = \frac{\text{water consumption}}{\text{activity rate}}$$

where:

water consumption: total amount of water consumed by the activities carried out in the plant excluding recycled and reused water, cooling water used in once-through cooling systems, as well as water for domestic-type usage, expressed in l/year or m^3/year;

activity rate: total amount of products processed by the plant or plant throughput expressed in the appropriate unit depending on the sector (e.g. m^2 of coated coil/year, vehicles coated/year, thousand cans/year).

Indicative levels for specific waste quantity sent off site

The indicative levels related to the specific quantity of waste sent off site refer to yearly averages calculated using the following equation:

$$\text{specific waste quantity sent off site} = \frac{\text{waste quantity sent off site}}{\text{activity rate}}$$

where:

waste quantity sent off site:	total amount of waste sent off site by the plant, expressed in kg/year;
activity rate:	total amount of products processed by the plant or plant throughput expressed in vehicles coated/year.

18.1 BAT conclusions for surface treatment using organic solvents

18.1.1 General BAT conclusions

18.1.1.1 Environmental Management Systems

BAT 1. In order to improve the overall environmental performance, BAT is to elaborate and implement an Environmental Management System (EMS) that incorporates all of the following features:

i. commitment, leadership, and accountability of the management, including senior management, for the implementation of an effective EMS;
ii. an analysis that includes the determination of the organisation's context, the identification of the needs and expectations of interested parties, the identification of characteristics of the installation that are associated with possible risks for the environment (or human health) as well as of the applicable legal requirements relating to the environment;
iii. development of an environmental policy that includes the continuous improvement of the environmental performance of the installation;
iv. establishing objectives and performance indicators in relation to significant environmental aspects, including safeguarding compliance with applicable legal requirements;
v. planning and implementing the necessary procedures and actions (including corrective and preventive actions where needed), to achieve the environmental objectives and avoid environmental risks;
vi. determination of structures, roles and responsibilities in relation to environmental aspects and objectives and provision of the financial and human resources needed;
vii. ensuring the necessary competence and awareness of staff whose work may affect the environmental performance of the installation (e.g. by providing information and training);
viii. internal and external communication;
ix. fostering employee involvement in good environmental management practices;
x. establishing and maintaining a management manual and written procedures to control activities with significant environmental impact as well as relevant records;
xi. effective operational planning and process control;
xii. implementation of appropriate maintenance programmes;
xiii. emergency preparedness and response protocols, including the prevention and/or mitigation of the adverse (environmental) impacts of emergency situations;
xiv. when (re)designing a (new) installation or a part thereof, consideration of its environmental impacts throughout its life, which includes construction, maintenance, operation and decommissioning;
xv. implementation of a monitoring and measurement programme; if necessary, information can be found in the Reference Report on Monitoring of Emissions to Air and Water from IED Installations;
xvi. application of sectoral benchmarking on a regular basis;
xvii. periodic independent (as far as practicable), internal auditing and periodic, independent external auditing in order to assess the environmental performance and to determine whether or not the EMS conforms to planned arrangements and has been properly implemented and maintained;
xviii. evaluation of causes of nonconformities, implementation of corrective actions in response to nonconformities, review of the effectiveness of corrective actions, and determination of whether similar nonconformities exist or could potentially occur;
xix. periodic review, by senior management, of the EMS and its continuing suitability, adequacy and effectiveness;
xx. following and taking into account the development of cleaner techniques.

Specifically for surface treatment using organic solvents, BAT is also to incorporate the following features in the EMS:

- i. Interaction with quality control and assurance as well as health and safety considerations.
- ii. Planning to reduce the environmental footprint of an installation. In particular, this involves the following:
  - a. assessing the overall environmental performance of the plant (see BAT 2);
  - b. taking into account cross-media considerations, especially the maintenance of a proper balance between solvent emissions reduction and consumption of energy (see BAT 19), water (see BAT 20) and raw materials (see BAT 6);
  - c. reducing VOC emissions from cleaning processes (see BAT 9).
- iii. The inclusion of:
  - a. a plan for the prevention and control of leaks and spillages (see BAT 5 (a));
  - b. a raw material evaluation system to use raw materials with low environmental impact and a plan to optimise the use of solvents in the process (see BAT 3);
  - c. a solvent mass balance (see BAT 10);
  - d. a maintenance programme to reduce the frequency and environmental consequences of OTNOC (see BAT 13);
  - e. an energy efficiency plan (see BAT 19 (a));
  - f. a water management plan (see BAT 20 (a));
  - g. a waste management plan (see BAT 22 (a));
  - h. an odour management plan (see BAT 23).

Note
Regulation (EC) No 1221/2009 establishes the European Union eco-management and audit scheme (EMAS), which is an example of an EMS consistent with this BAT.

Applicability
The level of detail and the degree of formalisation of the EMS will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

18.1.1.2 Overall environmental performance

BAT 2. In order to improve the overall environmental performance of the plant, in particular concerning VOC emissions and energy consumption, BAT is to:

- identify the process areas/sections/steps that represent the greatest contribution to the VOC emissions and energy consumption and the greatest potential for improvement (see also BAT 1);
- identify and implement actions to minimise VOC emissions and energy consumption;
- regularly (at least once every year) update the situation and follow up the implementation of the identified actions.

18.1.1.3 Selection of raw materials

BAT 3. In order to prevent or reduce the environmental impact of the raw materials used, BAT is to use both of the techniques given below.

	Technique	Description	Applicability
a.	Use of raw materials with a low environmental impact	As part of the EMS (see BAT 1), systematic evaluation of the adverse environmental impacts of the materials used (in particular substances that are carcinogenic, mutagenic and toxic to reproduction as well as substances of very high concern) and substitution by others with no or lower environmental and health impacts where possible, taking into consideration the product quality requirements or specifications.	Generally applicable. The scope (e.g. level of detail) and nature of the evaluation will generally be related to the nature, scale and complexity of the plant and the range of environmental impacts it may have, as well as to the type and quantity of materials used.
b.	Optimisation of the use of solvents in the process	Optimisation of the use of solvents in the process by a management plan (as part of the EMS (see BAT 1)) that aims to identify and implement necessary actions (e.g. colour batching, optimising spray pulverisation).	Generally applicable.

BAT 4. In order to reduce solvent consumption, VOC emissions and the overall environmental impact of the raw materials used, BAT is to use one or a combination of the techniques given below.

	Technique	Description	Applicability
a.	Use of high-solids solvent-based paints / coatings / varnishes / inks / adhesives	Use of paints, coatings, liquid inks, varnishes and adhesives containing a low amount of solvents and an increased solids content.	The selection of the surface treatment techniques may be restricted by the activity type, the substrate type and shape, product quality requirements as well as the need to ensure that the materials used, coating application techniques, drying / curing techniques and off-gas treatment systems are mutually compatible.
b.	Use of water-based paints / coatings / inks / varnishes / adhesives	Use of paints, coatings, liquid inks, varnishes and adhesives where organic solvent is partially replaced by water.	
c.	Use of radiation-cured inks / coatings / paints / varnishes / adhesives	Use of paints, coatings, liquid inks, varnishes and adhesives suitable to be cured by the activation of specific chemical groups by UV or IR radiation, or fast electrons, without heat and without emission of VOCs.	
d.	Use of solvent-free two-component adhesives	Use of solvent-free two-component adhesive materials consisting of a resin and a hardener.	
e.	Use of hot-melt adhesives	Use of coating with adhesives made from the hot extrusion of synthetic rubbers, hydrocarbon resins and various additives. No solvents are used.	
f.	Use of powder coatings	Use of solvent-free coating which is applied as a finely divided powder and cured in thermal ovens.	
g.	Use of laminate film for web or coil coatings	Use of polymer films applied onto a coil or web in order to give aesthetic or functional properties, which reduces the number of coating layers needed.	
h.	Use of substances which are not VOCs or are VOCs of a lower volatility	Substitution of high-volatility VOC substances with others containing organic compounds that are non-VOCs or VOCs of a lower volatility (e.g. esters)	

18.1.1.4 Storage and handling of raw materials

BAT 5. In order to prevent or reduce fugitive VOC emissions during storage and handling of solvent-containing materials and/or hazardous materials, BAT is to apply the principles of good housekeeping by using all of the techniques given below.

Technique		Description	Applicability
Management techniques			
a.	Preparation and implementation of a plan for the prevention and control of leaks and spillages	A plan for the prevention and control of leaks and spillages is part of the EMS (see BAT 1) and includes, but is not limited to: • site incident plans for small and large spillages; • identification of the roles and responsibilities of persons involved; • ensuring staff are environmentally aware and trained to prevent/deal with spillage incidents; • identification of areas at risk of spillage and/or leaks of hazardous materials and ranking them according to the risk; • in identified areas, ensuring suitable containment systems are in place, e.g. impervious floors; • identification of suitable spillage containment and clean-up equipment and regularly ensuring it is available, in good working order and close to points where these incidents may occur; • waste management guidelines for dealing with waste arising from spillage control; • regular (at least once every year) inspections of storage and operational areas, testing and calibration of leak detection equipment and prompt repair of leaks from valves, glands, flanges, etc. (see BAT 13).	Generally applicable. The scope (e.g. level of detail) of the plan will generally be related to the nature, scale and complexity of the installation, as well as to the type and quantity of materials used.
Storage techniques			
b.	Sealing or covering of containers and bunded storage area	Storage of solvents, hazardous materials, waste solvents and waste cleaning materials in sealed or covered containers, suitable for the associated risk and designed to minimise emissions. The containers' storage area is bunded and of adequate capacity.	Generally applicable.
c.	Minimisation of storage of hazardous materials in production areas	Hazardous materials are present in production areas only in amounts that are necessary for production; larger quantities are stored separately.	
Techniques for pumping and handling liquids			
d.	Techniques to prevent leaks and spillages during pumping	Leaks and spillages are prevented by using pumps and seals suitable for the material handled and which ensure proper tightness. This includes equipment such as canned motor pumps, magnetically coupled pumps, pumps with multiple mechanical seals and a quench or buffer system, pumps with multiple mechanical seals and seals dry to atmosphere, diaphragm pumps or bellow pumps.	Generally applicable.
e.	Techniques to prevent overflows during pumping	This includes ensuring for example that: • the pumping operation is supervised; • for larger quantities, bulk storage tanks are fitted with acoustic and/or optical high-level alarms, with shut-off systems if necessary.	
f.	Capture of VOC vapour during solvent-containing material	When delivering solvent-containing materials in bulk (e.g. loading or unloading of tanks), the vapour displaced from receiving tanks is captured, usually by back-venting.	May not be applicable for solvents with low vapour pressure or due

Technique		Description	Applicability
	delivery		to cost considerations.
g.	Containment for spills and/or rapid take-up when handling solvent-containing materials	When handling solvent-containing materials in containers, possible spills are avoided by providing containment, e.g. by using trolleys, pallets and/or stillages with built-in containment (e.g. 'catch pans') and/or rapid take-up by using absorbent materials.	Generally applicable.

18.1.1.5 Distribution of raw materials

BAT 6. In order to reduce raw material consumption and VOC emissions, BAT is to use one or a combination of the techniques given below.

Technique		Description	Applicability
a.	Centralised supply of VOC-containing materials (e.g. inks, coatings, adhesives, cleaning agents)	Supply of VOC-containing materials (e.g. inks, coatings, adhesives, cleaning agents) to the application area by direct piping with ring lines, including system cleaning such as pig cleaning or air flushing.	May not be applicable in the case of frequent changes of inks / paints / coatings / adhesives or solvents.
b.	Advanced mixing systems	Computer-controlled mixing equipment to achieve the desired paint / coating / ink /adhesive.	Generally applicable.
c.	Supply of VOC-containing materials (e.g. inks, coatings, adhesives, cleaning agents) at the point of application using a closed system	In the case of frequent changes of inks / paints / coatings / adhesives and solvents or for small-scale usage, supply of inks / paints / coatings / adhesives and solvents from small transport containers placed near the application area using a closed system.	
d.	Automation of colour change	Automated colour changing and ink / paint / coating line purging with solvent capture.	
e.	Colour grouping	Modification of the sequence of products to achieve large sequences with the same colour.	
f.	Soft purge in spraying	Refilling the spray gun with new paint without intermediate rinsing.	

18.1.1.6 Coating application

BAT 7. In order to reduce raw material consumption and the overall environmental impact of the coating application processes, BAT is to use one or a combination of the techniques given below.

	Technique	Description	Applicability
Techniques for non-spraying application			
a.	Roller coating	Application where rollers are used to transfer or meter the liquid coating onto a moving strip.	Only applicable to flat substrates (1).
b.	Doctor blade over roller	The coating is applied to the substrate through a gap between a blade and a roller. As the coating and substrate pass, the excess is scraped off.	Generally applicable (1).
c.	No-rinse (dry-in-place) application in the coating of coil	Application of conversion coatings which do not require a further water rinse using a roller coater (chemcoater) or squeegee rollers.	Generally applicable (1).
d.	Curtain coating (casting)	Workpieces are passed through a laminar film of coating discharged from a header tank.	Only applicable to flat substrates (1).
e.	Electrocoating (e-coat)	Paint particles dispersed in a water-based solution are deposited on immersed substrates under the influence of an electric field (electrophoretic deposition).	Only applicable to metal substrates (1).
f.	Flooding	The workpieces are transported via conveyor systems into a closed channel, which is then flooded with the coating material via injection tubes. The excess material is collected and reused.	Generally applicable (1).
g.	Co-extrusion	The printed substrate is coupled with a warm, liquefied plastic film and subsequently cooled down. This film replaces the necessary additional coating layer. It may be used between two different layers of different carriers acting as an adhesive.	Not applicable where high bond strength or resistance to sterilisation temperature is needed (1).
Spraying atomisation techniques			
h.	Air-assisted airless spraying	An airflow (shaping air) is used to modify the spray cone of an airless spray gun.	Generally applicable (1).
i.	Pneumatic atomisation with inert gases	Pneumatic paint application with pressurised inert gases (e.g. nitrogen, carbon dioxide).	May not be applicable to coating of wooden surfaces (1).
j.	High-volume low-pressure (HVLP) atomisation	Atomisation of paint in a spray nozzle by mixing paint with high volumes of air with a low pressure (max. 1.7 bar). HVLP guns have a paint transfer efficiency of > 50 %.	Generally applicable (1).
k.	Electrostatic atomisation (fully automated)	Atomisation by high-speed rotational discs and bells and shaping the spray jet with electrostatic fields and shaping air.	
l.	Electrostatically assisted air or airless spraying	Shaping the spray jet of pneumatic or airless atomisation with an electrostatic field. Electrostatic paint guns have a transfer efficiency of > 60 %. Fixed electrostatic methods have a transfer efficiency of up to 75 %.	
m.	Hot spraying	Pneumatic atomisation with hot air or heated paint.	May not be applicable for frequent colour changes (1).
n.	'Spray, squeegee and rinse' application in the coating of coil	Sprays are used for application of cleaners, pretreatments and for rinsing. After spraying, squeegees are used to minimise solution dragout, which is followed by rinsing.	Generally applicable (1).

Technique		Description	Applicability
Automation of spray application			
o.	Robot application	Robot application of coatings and sealants to internal and external surfaces.	Generally applicable (1).
p.	Machine application	Use of paint machines for the handling of the sprayhead / spray gun / nozzle.	

(1) The selection of the application techniques may be restricted at plants with low throughput and/or high product variety as well as by the substrate type and shape, product quality requirements and the need to ensure that the materials used, coating application techniques, drying/curing techniques and off-gas treatment systems are mutually compatible.

18.1.1.7 Drying/curing

BAT 8. In order to reduce energy consumption and the overall environmental impact from drying/curing processes, BAT is to use one or a combination of the techniques given below.

Technique		Description	Applicability
a.	Inert gas convection drying/curing	The inert gas (nitrogen) is heated in the oven, enabling solvent loading above the LEL. Solvent loads of > 1 200 g/m^3 nitrogen are possible.	Not applicable where dryers need to be opened regularly (1).
b.	Induction drying/curing	Online thermal curing or drying by electromagnetic inductors that generate heat inside the metallic workpiece by an oscillating magnetic field.	Only applicable to metal substrates (1).
c.	Microwave and high-frequency drying	Drying using microwave or high-frequency radiation.	Only applicable to water-based coatings and inks and non-metallic substrates (1).
d.	Radiation curing	Radiation curing is applied based on resins and reactive diluents (monomers) which react on exposure to radiation (infrared (IR), ultraviolet (UV)), or high-energy electron beams (EB).	Only applicable to specific coatings and inks (1).
e.	Combined convection / IR radiation drying	Drying of a wet surface with a combination of circulating hot air (convection) and an infrared radiator.	Generally applicable (1).
f.	Convection drying/curing combined with heat recovery	Heat from off-gases is recovered (see BAT 19(e)) and used to preheat the input air of the convection dryer / curing oven.	Generally applicable (1).

(1) The selection of the drying/curing techniques may be restricted by the substrate type and shape, product quality requirements and the need to ensure that the materials used, coating application techniques, drying/curing techniques and off-gas treatment systems are mutually compatible.

18.1.1.8 Cleaning

BAT 9. In order to reduce VOC emissions from cleaning processes, BAT is to minimise the use of solvent-based cleaning agents and to use a combination of the techniques given below.

Technique		Description	Applicability
a.	Protection of spraying areas and equipment	Application areas and equipment (e.g. spray booth walls and robots) susceptible to overspray and drips, etc. are covered with fabric covers or disposable foils where foils are not subject to tearing or wear.	The selection of cleaning techniques may be restricted by the type of process, the substrate or equipment to be cleaned and the type of contamination.
b.	Solids removal prior to complete cleaning	Solids are removed in a (dry) concentrated form, usually by hand, with or without the aid of small amounts of cleaning solvent. This reduces the amount of material to be removed by solvent and/or water in subsequent cleaning stages, and therefore the amount of solvent and/or water used.	
c.	Manual cleaning with pre-impregnated wipes	Wipes pre-impregnated with cleaning agents are used for manual cleaning. Cleaning agents may be solvent-based, low-volatility solvents or solvent-free.	
d.	Use of low-volatility cleaning agents	Application of low-volatility solvents as cleaning agents, for manual or automated cleaning, with high cleaning power.	
e.	Water-based cleaning	Water-based detergents or water-miscible solvents such as alcohols or glycols are used for cleaning.	
f.	Enclosed washing machines	Automatic batch cleaning/degreasing of press/machine parts in enclosed washing machines. This can be done using either: a) organic solvents (with air extraction followed by VOC abatement and/or recovery of the used solvents) (see BAT 15); or b) VOC-free solvents; or c) alkaline cleaners (with external or internal waste water treatment).	
g.	Purging with solvent recovery	Collection, storage and, if possible, reuse of the solvents used to purge the guns/applicators and lines between colour changes.	
h.	Cleaning with high-pressure water spray	High-pressure water spray and sodium bicarbonate systems or similar are used for automatic batch cleaning of press/machine parts.	
i.	Ultrasonic cleaning	Cleaning in a liquid using high-frequency vibrations to loosen the adhered contamination.	
j.	Dry ice (CO_2) cleaning	Cleaning of machinery parts and metallic or plastic substrates by blasting with CO_2 chips or snow.	
k.	Plastic shot-blast cleaning	Excess paint build-up is removed from panel jigs and body carriers by shot-blasting with plastic particles.	

18.1.1.9 Monitoring

18.1.1.9.1 Solvent mass balance

BAT 10. BAT is to monitor total and fugitive VOC emissions by compiling, at least once every year, a solvent mass balance of the solvent inputs and outputs of the plant, as defined in Part 7(2) of Annex VII to Directive 2010/75/EU and to minimise the uncertainty of the solvent mass balance data by using all of the techniques given below.

Technique		Description
a.	Full identification and quantification of the relevant solvent inputs and outputs, including the associated uncertainty	This includes: • identification and documentation of solvent inputs and outputs, (e.g. emissions in waste gases, emissions from each fugitive emission source, solvent output in waste); • substantiated quantification of each relevant solvent input and output and recording of the methodology used (e.g. measurement, calculation using emission factors, estimation based on operational parameters); • identification of the main sources of uncertainty of the aforementioned quantification, and implementation of corrective actions to reduce the uncertainty; • regular update of solvent input and output data.
b.	Implementation of a solvent tracking system	A solvent tracking system aims to keep control of both the used and unused quantities of solvents (e.g. by weighing unused quantities returned to storage from the application area).
c.	Monitoring of changes that may influence the uncertainty of the solvent mass balance data	Any change that could influence the uncertainty of the solvent mass balance data is recorded, such as: • malfunctions of the off-gas treatment system: the date and duration are recorded; • changes that may influence air/gas flow rates, e.g. replacement of fans, drive pulleys, motors; the date and type of change are recorded.

Applicability

The level of detail of the solvent mass balance will be proportionate to the nature, scale and complexity of the installation, and the range of environmental impacts it may have, as well as to the type and quantity of materials used.

18.1.1.9.2 Emissions in waste gases

BAT 11. BAT is to monitor emissions in waste gases with at least the frequency given below and in accordance with 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.

Substance/ Parameter	Sectors/Sources		Standard(s)	Minimum monitoring frequency	Monitoring associated with
Dust	Coating of vehicles – Spray coating		EN 13284-1	Once every year (1)	BAT 18
	Coating of other metal and plastic surfaces – Spray coating				
	Coating of aircraft – Preparation (e.g. sanding, blasting) and coating				
	Coating and printing of metal packaging – Spray application				
	Coating of wooden surfaces – Preparation and coating				
TVOC	All sectors	Any stack with a TVOC load < 10 kg C/h	EN 12619	Once every year (1)(2)(3)	BAT 14, BAT 15
		Any stack with a TVOC load ≥ 10 kg C/h	Generic EN standards (4)	Continuous	
DMF	Coating of textiles, foils and paper (5)		No EN standard available (6)	Once every three months (1)	BAT 15
NO_X	Thermal treatment of off-gases		EN 14792	Once every year (7)	BAT 17
CO	Thermal treatment of off-gases		EN 15058	Once every year (7)	BAT 17

(1) To the extent possible, the measurements are carried out at the highest expected emission state under normal operating conditions.

(2) In the case of a TVOC load of less than 0.1 kg C/h, or in the case of an unabated and stable TVOC load of less than 0.3 kg C/h, the monitoring frequency may be reduced to once every 3 years or the measurement may be replaced by calculation provided that it ensures the provision of data of an equivalent scientific quality.

(3) For the thermal treatment of off-gases, the temperature in the combustion chamber is continuously measured. This is combined with an alarm system for temperatures falling outside the optimised temperature window.

(4) Generic EN standards for continuous measurements are EN15267-1, EN15267-2, EN15267-3 and EN 14181.

(5) The monitoring only applies if DMF is used in the processes.

(6) In the absence of an EN standard, the measurement includes the DMF contained in the condensed phase.

(7) In the case of a stack with a TVOC load of less than 0.1 kg C/h, the monitoring frequency may be reduced to once every 3 years.

18.1.1.9.3 Emissions to water

BAT 12. BAT is to monitor emissions to water with at least the frequency given below and in accordance with 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.

Substance/ Parameter	Sector	Standard(s)	Minimum monitoring frequency	Monitoring associated with
TSS (1)	Coating of vehicles	EN 872	Once every month (2)(3)	BAT 21
	Coil coating			
	Coating and printing of metal packaging (only for DWI cans)			
COD (4)(1)	Coating of vehicles	No EN standard available		
	Coil coating			
	Coating and printing of metal packaging (only for DWI cans)			
TOC (4)(1)	Coating of vehicles	EN 1484		
	Coil coating			
	Coating and printing of metal packaging (only for DWI cans)			
Cr(VI) (5)(6)	Coating of aircraft	EN ISO 10304-3 or EN ISO 23913		
	Coil coating			
Cr (7)(6)	Coating of aircraft	Various EN standards available (e.g. EN ISO 11885, EN ISO 17294-2, EN ISO 15586)		
	Coil coating			
Ni (6)	Coating of vehicles			
	Coil coating			
Zn (6)	Coating of vehicles			
	Coil coating			
AOX (6)	Coating of vehicles	EN ISO 9562		
	Coil coating			
	Coating and printing of metal packaging (only for DWI cans)			
F^- (6)(8)	Coating of vehicles	EN ISO 10304-1		
	Coil coating			
	Coating and printing of metal packaging (only for DWI cans)			

(1) The monitoring only applies in the case of direct discharge to a receiving water body.
(2) The monitoring frequency may be reduced to once every 3 months if the emission levels are proven to be sufficiently stable.
(3) In the case of batch discharge that is less frequent than the minimum monitoring frequency, monitoring is carried out once per batch.
(4) TOC monitoring and COD monitoring are alternatives. TOC monitoring is the preferred option because it does not rely on the use of very toxic compounds.
(5) Monitoring of Cr(VI) only applies if chromium(VI) compounds are used in the processes.
(6) In the case of indirect discharge to a receiving water body, the monitoring frequency may be reduced if the downstream waste water treatment plant is designed and equipped appropriately to abate the pollutants concerned.
(7) Monitoring of Cr only applies if chromium compounds are used in the processes.
(8) Monitoring of F^- only applies if fluorine compounds are used in the processes.

18.1.1.10 Emissions during OTNOC

BAT 13. In order to reduce the frequency of the occurrence of OTNOC and to reduce emissions during OTNOC, BAT is to use both of the techniques given below.

Technique		Description
a.	Identification of critical equipment	Equipment critical to the protection of the environment (‘critical equipment’) is identified on the basis of a risk assessment. In principle, this concerns all equipment and systems handling VOCs (e.g. off-gas treatment system, leak detection system).
b.	Inspection, maintenance and monitoring	A structured programme to maximise critical equipment availability and performance which includes standard operating procedures, preventive maintenance, regular and unplanned maintenance. OTNOC periods, duration, causes and, if possible, emissions during their occurrence are monitored.

18.1.1.11 Emissions in waste gases

18.1.1.11.1 VOC emissions

BAT 14. In order to reduce VOC emissions from the production and storage areas, BAT is to use technique (a) and an appropriate combination of the other techniques given below.

	Technique	Description	Applicability
a.	System selection, design and optimisation	An off-gas system is selected, designed and optimised taking into account parameters such as: - amount of extracted air; - type and concentration of solvents in extracted air; - type of treatment system (dedicated/centralised); - health and safety; - energy efficiency. The following order of priority for the system selection may be considered: • segregation of off-gases with high and low VOC concentrations; • techniques to homogenise and increase the VOC concentration (see BAT 16 (b) and (c)); • techniques for the recovery of solvents in off-gases (see BAT 15); • VOC abatement techniques with heat recovery (see BAT 15); • VOC abatement techniques without heat recovery (see BAT 15).	Generally applicable.
b.	Air extraction as close as possible to the point of application of VOC-containing materials	Air extraction as close as possible to the point of application with full or partial enclosure of solvent application areas (e.g. coaters, application machines, spray booths). Extracted air may be treated by an off-gas treatment system.	May not be applicable where enclosure leads to difficult machinery access during operation. Applicability may be restricted by the shape and size of the area to be enclosed.
c.	Air extraction as close as possible to the point of preparing paints / coatings / adhesives / inks	Air extraction as close as possible to the point of preparing paints / coatings / adhesives / inks (e.g. mixing area). Extracted air may be treated by an off-gas treatment system.	Only applicable where paints / coatings / adhesives / inks are prepared.
d.	Extraction of air from the drying/curing processes	The curing ovens/dryers are equipped with an air extraction system. Extracted air may be treated by an off-gas treatment system.	Only applicable to drying/curing processes.

	Technique	Description	Applicability
e.	Minimisation of fugitive emissions and heat losses from the ovens/dryers either by sealing the entrance and the exit of the curing ovens/dryers or by applying subatmospheric pressure in drying	The entrance to and the exit from curing ovens/dryers are sealed to minimise fugitive VOC emissions and heat loss. The sealing may be ensured by air jets or air knives, doors, plastic or metallic curtains, doctor blades, etc. Alternatively, ovens/dryers are kept under subatmospheric pressure.	Only applicable when curing ovens/dryers are used.
f.	Extraction of air from the cooling zone	When substrate cooling takes place after drying/curing, the air from the cooling zone is extracted and may be treated by an off-gas treatment system.	Only applicable when substrate cooling takes place after drying/curing.
g.	Extraction of air from storage of raw materials, solvents and solvent-containing wastes	Air from raw material stores and/or individual containers for raw materials, solvents and solvent-containing wastes is extracted and may be treated by an off-gas treatment system.	May not be applicable for closed containers or for storage of raw materials, solvents and solvent-containing wastes with a low vapour pressure and low toxicity.
h.	Extraction of air from cleaning areas	Air from the areas where machine parts and equipment are cleaned with organic solvents, either by hand or automatically, is extracted and may be treated by an off-gas treatment system.	Only applicable to areas where machine parts and equipment are cleaned with organic solvents.

BAT 15. In order to reduce VOC emissions in waste gases and increase resource efficiency, BAT is to use one or a combination of the techniques given below.

	Technique	Description	Applicability
I. Capture and recovery of solvents in off-gases			
a.	Condensation	A technique for removing organic compounds by reducing the temperature below their dew points so that the vapours liquefy. Depending on the operating temperature range required, different refrigerants are used, e.g. cooling water, chilled water (temperature typically around 5 °C), ammonia or propane.	Applicability may be restricted where the energy demand for recovery is excessive due to the low VOC content.
b.	Adsorption using activated carbon or zeolites	VOCs are adsorbed on the surface of activated carbon, zeolites or carbon fibre paper. Adsorbate is subsequently desorbed, e.g. with steam (often on site), for reuse or disposal and the adsorbent is reused. For continuous operation, typically more than two adsorbers are operated in parallel, one of them in desorption mode. Adsorption is also commonly applied as a concentration step to increase the subsequent oxidation efficiency.	Applicability may be restricted where the energy demand for recovery is excessive due to the low VOC content.
c.	Absorption using a suitable liquid	Use of a suitable liquid to remove pollutants from the off-gas by absorption, in particular soluble compounds and solids (dust). Solvent recovery is possible, for example, using distillation or thermal desorption. (For dust removal, see BAT 18.)	Generally applicable.
II. Thermal treatment of solvents in off-gases with energy recovery			
d.	Sending off-gases to a combustion plant	Part or all of the off-gases are sent as combustion air and supplementary fuel to a combustion plant (including CHP (combined heat and power) plants) used for steam and/or electricity production.	Not applicable for off-gases containing substances referred to in IED Article 59(5). Applicability may be restricted due to safety considerations.
e.	Recuperative thermal oxidation	Thermal oxidation using the heat of the waste gases, e.g. to preheat the incoming off-gases.	Generally applicable.
f.	Regenerative thermal oxidation with multiple beds or with a valveless rotating air distributor	An oxidiser with multiple beds (three or five) filled with ceramic packing. The beds are heat exchangers, alternately heated by flue-waste gases from oxidation, then the flow is reversed to heat the inlet air to the oxidiser. The flow is reversed on a regular basis. In the valveless rotating air distributor, the ceramic medium is held in a single rotating vessel divided into multiple wedges.	Generally applicable.
g.	Catalytic oxidation	Oxidation of VOCs assisted by a catalyst to reduce the oxidation temperature and reduce the fuel consumption. Exhaust heat can be recovered with recuperative or regenerative types of heat exchangers. Higher oxidation temperatures (500–750 °C) are used for the treatment of off-gas from the manufacturing of winding wire.	Applicability may be restricted by the presence of catalyst poisons.

Technique		Description	Applicability
III. Treatment of solvents in off-gases without solvent or energy recovery			
h.	Biological off-gas treatment	Off-gas is dedusted and sent to a reactor with biofilter substrate. The biofilter consists of a bed of organic material (such as peat, heather, compost, root, tree bark, softwood and different combinations) or some inert material (such as clay, activated carbon, and polyurethane), where the off-gas stream is biologically oxidised by naturally occurring microorganisms into carbon dioxide, water, inorganic salts and biomass. The biofilter is sensitive to dust, high temperatures or high variations in the off-gas, e.g. of the inlet temperature or the VOC concentration. Supplementary nutrient feeding may be needed.	Only applicable to the treatment of biodegradable solvents.
i.	Thermal oxidation	Oxidation of VOCs by heating off-gases with air or oxygen to above their auto-ignition point in a combustion chamber and maintaining a high temperature long enough to complete the combustion of VOCs to carbon dioxide and water.	Generally applicable.

BAT-associated emission levels (BAT-AELs) are given in Tables 18.11, 18.15, 18.17, 18.19, 18.21, 18.24, 18.27, 18.30, 18.32 and 18.35 of these BAT conclusions.

BAT 16. In order to reduce the energy consumption of the VOC abatement system, BAT is to use one or a combination of the techniques given below.

Technique		Description	Applicability
a.	Maintaining the VOC concentration sent to the off-gas treatment system by using variable-frequency drive fans	Use of a variable-frequency drive fan with centralised off-gas treatment systems to modulate the airflow to match the exhaust from the equipment that may be in operation.	Only applicable to central thermal off-gas treatment systems in batch processes such as printing.
b.	Internal concentration of solvents in the off-gases	Off-gases are recirculated within the process (internally) in the curing ovens/dryers and/or in spray booths, so the VOC concentration in the off-gases increases and the abatement efficiency of the off-gas treatment system increases.	Applicability may be limited by health and safety factors such as the LEL, and product quality requirements or specifications.
c.	External concentration of solvents in the off-gases through adsorption	The concentration of solvent in off-gases is increased by a continuous circular flow of the spray booth process air, possibly combined with curing oven/dryer off-gases, through adsorption equipment. This equipment can include: - fixed bed adsorber with activated carbon or zeolite; - fluidised bed adsorber with activated carbon; - rotor adsorber with activated carbon or zeolite; - molecular sieve.	Applicability may be restricted where the energy demand is excessive due to the low VOC content.

d.	Plenum technique to reduce waste gas volume	Off-gases from curing ovens/dryers are sent to a large chamber (plenum), and partly recirculated as inlet air in the curing ovens/dryers. The surplus air from the plenum is sent to the off-gas treatment system. This cycle increases the VOC content of the curing ovens/dryers' air and decreases the waste gas volume.	Generally applicable.

18.1.1.11.2 NO_X and CO emissions

BAT 17. In order to reduce NO_X emissions in waste gases while limiting CO emissions from the thermal treatment of solvents in off-gases, BAT is to use technique (a) or both of the techniques given below.

Technique		Description	Applicability
a.	Optimisation of thermal treatment conditions (design and operation)	Good design of the combustion chambers, burners and associated equipment/devices is combined with optimisation of combustion conditions (e.g. by controlling combustion parameters such as temperature and residence time) with or without the use of automatic systems and the regular planned maintenance of the combustion system according to suppliers' recommendations.	Design applicability may be restricted for existing plants.
b.	Use of low-NO_X burners	The peak flame temperature in the combustion chamber is reduced, delaying but completing the combustion and increasing the heat transfer (increased emissivity of the flame). It is combined with increased residence time in order to achieve the desired VOC destruction.	Applicability may be restricted at existing plants by design and/or operational constraints.

Table 18.1: BAT-associated emission level (BAT-AEL) for NO_X emissions in waste gases and indicative emission level for CO emissions in waste gases from the thermal treatment of off-gases

Parameter	Unit	BAT-AEL (1) (Daily average or average over the sampling period)	Indicative emission level (1) (Daily average or average over the sampling period)
NO_X	mg/Nm^3	20–130 (2)	No indicative level
CO		No BAT-AEL	20–150

(1) The BAT-AEL and indicative level do not apply where off-gases are sent to a combustion plant.

(2) The BAT-AEL may not apply if nitrogen-containing compounds (e.g. DMF or NMP (*N*-methylpyrrolidone)) are present in the off-gas.

The associated monitoring is given in BAT 11.

18.1.1.11.3 Dust emissions

BAT 18. In order to reduce dust emissions in waste gases from substrate surface preparation, cutting, coating application and finishing processes for the sectors and processes listed in Table 18.2, BAT is to use one or a combination of the techniques given below.

Technique		**Description**
a.	Wet separation spray booth (flushed impact panel)	A water curtain cascading vertically down the spray cabin rear panel captures paint particles from overspray. The water-paint mixture is captured in a reservoir and the water is recirculated.
b.	Wet scrubbing	Paint particles and other dust in the off-gas are separated in scrubber systems by intensive mixing of the off-gas with water. (For VOC removal, see BAT 15(c).)
c.	Dry overspray separation with pre-coated material	A dry paint overspray separation process using membrane filters combined with limestone as pre-coating material to prevent fouling of the membranes.
d.	Dry overspray separation using filters	Mechanical separation system, e.g. using cardboard, fabric or sinter.
e.	Electrostatic precipitator	In electrostatic precipitators, particles are charged and separated under the influence of an electrical field. In a dry electrostatic precipitator (ESP), the collected material is mechanically removed (e.g. by shaking, vibration, compressed air). In a wet ESP, it is flushed with a suitable liquid, usually a water-based separation agent.

Table 18.2: BAT-associated emission levels (BAT-AELs) for dust emissions in waste gases

Parameter	**Sector**	**Process**	**Unit**	**BAT-AEL (Daily average or average over the sampling period)**
Dust	Coating of vehicles	Spray coating	mg/Nm^3	< 1–3
	Coating of other metal and plastic surfaces	Spray coating		
	Coating of aircraft	Preparation (e.g. sanding, blasting), coating		
	Coating and printing of metal packaging	Spray application		
	Coating of wooden surfaces	Preparation, coating		

The associated monitoring is given in BAT 11.

18.1.1.12 Energy efficiency

BAT 19. In order to use energy efficiently, BAT is to use techniques (a) and (b) and an appropriate combination of the techniques (c) to (h) given below.

Technique		Description	Applicability
Management techniques			
a.	Energy efficiency plan	An energy efficiency plan is part of the EMS (see BAT 1) and entails defining and calculating the specific energy consumption of the activity, setting key performance indicators on an annual basis (e.g. MWh/tonne of product) and planning the periodic improvement targets and related actions. The plan is adapted to the specificities of the plant in terms of process(es) carried out, materials, products, etc.	The level of detail and nature of the energy efficiency plan and of the energy balance record will generally be related to the nature, scale and complexity of the installation and types of energy sources used. It may not be applicable if the STS activity is carried out within a larger installation, provided that the energy efficiency plan and the energy balance record of the larger installation sufficiently cover the STS activity.
b.	Energy balance record	The drawing up once every year of an energy balance record which provides a breakdown of the energy consumption and generation (including energy export) by the type of source (e.g. electricity, fossil fuels, renewable energy, imported heat and/or cooling). This includes: (i) defining the energy boundary of the STS activity; (ii) information on energy consumption in terms of delivered energy; (iii) information on energy exported from the plant; (iv) energy flow information (e.g. Sankey diagrams or energy balances) showing how the energy is used throughout the process. The energy balance record is adapted to the specificities of the plant in terms of process(es) carried out, materials, etc.	
Process-related techniques			
c.	Thermal insulation of tanks and vats containing cooled or heated liquids, and of combustion and steam systems	This may be achieved for example by: • using double-skinned tanks; • using pre-insulated tanks; • applying insulation to combustion equipment, steam pipes and pipes containing cooled or heated liquids.	Generally applicable.
d.	Heat recovery by cogeneration – CHP (combined heat and power) or CCHP (combined cooling, heat and power)	Recovery of heat (mainly from the steam system) for producing hot water/steam to be used in industrial processes/activities. CCHP (also called trigeneration) is a cogeneration system with an absorption chiller that uses low-grade heat to produce chilled water.	Applicability may be restricted by the plant layout, the characteristics of the hot gas streams (e.g. flow rate, temperature) or the lack of a suitable heat demand.
e.	Heat recovery from hot gas streams	Energy recovery from hot gas streams (e.g. from dryers or cooling zones), e.g. by their recirculation as process air, through the use of heat exchangers, in processes, or externally.	
f.	Flow adjustment of process air and off-gases	Adjustment of the flow of process air and off-gases according to the need. This includes reduction of air ventilation during idle operation or maintenance.	Generally applicable.
g.	Spray booth off-gas recirculation	Capture and recirculation of the off-gas from the spray booth in combination with efficient paint overspray separation. Energy consumption is less than in the case of fresh air use.	Applicability may be restricted by health and safety considerations.

Technique		Description	Applicability
h.	Optimised circulation of warm air in a large-volume curing booth using an air turbulator	Air is blown into a single part of the curing booth and distributed using an air turbulator which turns the laminar airflow into the desired turbulent flow.	Only applicable to spray coating sectors.

Table 18.3: BAT-associated environmental performance levels (BAT-AEPLs) for specific energy consumption

Sector	Product type	Unit	BAT-AEPL (Yearly average)
Coating of vehicles	Passenger cars	MWh/vehicle coated	0.5–1.3
	Vans		0.8–2
	Truck cabins		1–2
	Trucks		0.3–0.5
Coil coating	Steel and/or aluminium coil	kWh/m^2 of coated coil	0.2–2.5 (1)
Coating of textiles, foils and paper	Coating of textiles with polyurethane and/or polyvinyl chloride	kWh/m^2 of coated surface	1–5
Manufacturing of winding wires	Wires with an average diameter > 0.1 mm	kWh/kg of coated wire	< 5
Coating and printing of metal packaging	All product types	kWh/m^2 of coated surface	0.3–1.5
Heatset web offset printing	All product types	Wh/m^2 of printed area	4–14
Flexography and non-publication rotogravure printing	All product types	Wh/m^2 of printed area	50–350
Publication rotogravure printing	All product types	Wh/m^2 of printed area	10–30

(1) The BAT-AEPL may not apply where the coil coating line is part of a larger manufacturing installation (e.g. steelworks) or for combilines.

The associated monitoring is given in BAT 19 (b).

18.1.1.13 Water use and waste water generation

BAT 20. In order to reduce water consumption and waste water generation from aqueous processes (e.g. degreasing, cleaning, surface treatment, wet scrubbing), BAT is to use technique (a) and an appropriate combination of the other techniques given below.

Technique		Description	Applicability
a.	Water management plan and water audits	A water management plan and water audits are part of the EMS (see BAT 1) and include: • flow diagrams and a water mass balance of the plant; • establishment of water efficiency objectives; • implementation of water optimisation techniques (e.g. control of water usage, water recycling, detection and repair of leaks). Water audits are carried out at least once every year.	The level of detail and nature of the water management plan and water audits will generally be related to the nature, scale and complexity of the plant. It may not be applicable if the STS activity is carried out within a larger installation, provided that the water management plan and the water audits of the larger installation sufficiently cover the STS activity.
b.	Reverse cascade rinsing	Multiple stage rinsing in which the water flows in the opposite direction to the workpieces/substrate. It allows a high degree of rinsing with a low water consumption.	Applicable where rinsing processes are used.
c.	Reuse and/or recycling of water	Water streams (e.g. spent rinse water, wet scrubber effluent) are reused and/or recycled, if necessary after treatment, using techniques such as ion exchange or filtration (see BAT 21). The degree of water reuse and/or recycling is limited by the water balance of the plant, the content of impurities and/or the characteristics of the water streams.	Generally applicable.

Table 18.4: BAT-associated environmental performance levels (BAT-AEPLs) for specific water consumption

Sector	Product type	Unit	BAT-AEPL (Yearly average)
Coating of vehicles	Passenger cars	m^3/vehicle coated	0.5–1.3
	Vans		1–2.5
	Truck cabins		0.7–3
	Trucks		1–5
Coil coating	Steel and/or aluminium coils	l/m^2 of coated coil	0.2–1.3 (1)
Coating and printing of metal packaging	Two-piece DWI beverage cans	l/1 000 cans	90–110
(1) The BAT-AEPL may not apply where the coil coating line is part of a larger manufacturing installation (e.g. steelworks) or for combilines.			

The associated monitoring is given in BAT 20 (a).

18.1.1.14 Emissions to water

BAT 21. In order to reduce emissions to water and/or to facilitate water reuse and recycling from aqueous processes (e.g. degreasing, cleaning, surface treatment, wet scrubbing), BAT is to use a combination of the techniques given below.

	Techniques	Description	Typical pollutants targeted
Preliminary, primary and general treatment			
a.	Equalisation	Balancing of flows and pollutant loads by using tanks or other management techniques.	All pollutants.
b.	Neutralisation	The adjustment of the pH of waste water to a neutral value (approximately 7).	Acids, alkalis.
c.	Physical separation, for example, by using screens, sieves, grit separators, primary settlement tanks and magnetic separation		Gross solids, suspended solids, metal particles.
Physico-chemical treatment			
d.	Adsorption	The removal of soluble substances (solutes) from the waste water by transferring them to the surface of solid, highly porous particles (typically activated carbon).	Adsorbable dissolved non-biodegradable or inhibitory pollutants, e.g. AOX.
e.	Vacuum distillation	The removal of pollutants by thermal waste water treatment under reduced pressure.	Dissolved non-biodegradable or inhibitory pollutants that can be distilled, e.g. some solvents.
f.	Precipitation	The conversion of dissolved pollutants into insoluble compounds by adding precipitants. The solid precipitates formed are subsequently separated by sedimentation, flotation or filtration.	Precipitable dissolved non-biodegradable or inhibitory pollutants, e.g. metals.
g.	Chemical reduction	Chemical reduction is the conversion of pollutants by chemical reducing agents into similar but less harmful or hazardous compounds.	Reducible dissolved non-biodegradable or inhibitory pollutants, e.g. hexavalent chromium (Cr(VI)).
h.	Ion exchange	The retention of ionic pollutants from waste water and their replacement by more acceptable ions using an ion exchange resin. The pollutants are temporarily retained and afterwards released into a regeneration or backwashing liquid.	Ionic dissolved non-biodegradable or inhibitory pollutants, e.g. metals.
i.	Stripping	The removal of purgeable pollutants from the aqueous phase by a gaseous phase (e.g. steam, nitrogen or air) that is passed through the liquid. The removal efficiency may be enhanced by increasing the temperature or reducing the pressure.	Purgeable pollutants, e.g. some adsorbable organically bound halogens (AOX).
Biological treatment			
j.	Biological treatment	Use of microorganisms for waste water treatment (e.g. anaerobic treatment, aerobic treatment).	Biodegradable organic compounds.

Final solids removal			
k.	Coagulation and flocculation	Coagulation and flocculation are used to separate suspended solids from waste water and are often carried out in successive steps. Coagulation is carried out by adding coagulants with charges opposite to those of the suspended solids. Flocculation is a gentle mixing stage so that collisions of microfloc particles cause them to bond to produce larger flocs. It may be assisted by adding polymers.	Suspended solids and particulate-bound metals.
l.	Sedimentation	The separation of suspended particles by gravitational settling.	
m.	Filtration	The separation of solids from waste water by passing them through a porous medium, e.g. sand filtration, nano-, micro- and ultrafiltration	
n.	Flotation	The separation of solid or liquid particles from waste water by attaching them to fine gas bubbles, usually air. The buoyant particles accumulate at the water surface and are collected with skimmers.	

Table 18.5: BAT-associated emission levels (BAT-AELs) for direct discharges to a receiving water body

Substance/Parameter	Sector	BAT-AEL (1)
Total suspended solids (TSS)	Coating of vehicles Coil coating Coating and printing of metal packaging (only for DWI cans)	5–30 mg/l
Chemical oxygen demand (COD) (2)		30–150 mg/l
Adsorbable organically bound halogens (AOX)		0.1–0.4 mg/l
Fluoride (F^-) (3)		2–25 mg/l
Nickel (expressed as Ni)	Coating of vehicles Coil coating	0.05–0.4 mg/l
Zinc (expressed as Zn)		0.05–0.6 mg/l (4)
Total chromium (expressed as Cr) (5)	Coating of aircraft Coil coating	0.01–0.15 mg/l
Hexavalent chromium (expressed as Cr(VI)) (6)		0.01–0.05 mg/l

(1) The averaging period is given in the general considerations.
(2) The BAT-AEL for COD may be replaced by a BAT-AEL for TOC. The correlation between COD and TOC is determined on a case-by-case basis. The BAT-AEL for TOC is the preferred option because TOC monitoring does not rely on the use of very toxic compounds.
(3) The BAT-AEL only applies if fluorine compounds are used in the processes.
(4) The upper end of the BAT-AEL range may be 1 mg/l in the case of zinc-containing substrates or of substrates pretreated using zinc.
(5) The BAT-AEL only applies if chromium compounds are used in the processes.
(6) The BAT-AEL only applies if chromium(VI) compounds are used in the processes.

The associated monitoring is given in BAT 12.

Table 18.6: BAT-associated emission levels (BAT-AELs) for indirect discharges to a receiving water body

Substance/Parameter	Sector	BAT-AEL (1)(2)
Adsorbable organically bound halogens (AOX)	Coating of vehicles Coil coating Coating and printing of metal packaging (only for DWI cans)	0.1–0.4 mg/l
Fluoride (F^-) (3)		2–25 mg/l
Nickel (expressed as Ni)	Coating of vehicles Coil coating	0.05–0.4 mg/l
Zinc (expressed as Zn)		0.05–0.6 mg/l (4)
Total chromium (expressed as Cr) (5)	Coating of aircraft Coil coating	0.01–0.15 mg/l
Hexavalent chromium (expressed as Cr(VI)) (6)		0.01–0.05 mg/l

(1) The BAT-AELs may not apply if the downstream waste water treatment plant is designed and equipped appropriately to abate the pollutants concerned, provided this does not lead to a higher level of pollution in the environment.
(2) The averaging period is given in the general considerations.
(3) The BAT-AEL only applies if fluorine compounds are used in the processes.
(4) The upper end of the BAT-AEL range may be 1 mg/l in the case of zinc-containing substrates or of substrates pretreated using zinc.
(5) The BAT-AEL only applies if chromium compounds are used in the processes.
(6) The BAT-AEL only applies if chromium(VI) compounds are used in the processes.

The associated monitoring is given in BAT 12.

18.1.1.15 Waste management

BAT 22. In order to reduce the quantity of waste sent for disposal, BAT is to use the techniques (a) and (b) and one or both of the techniques (c) and (d) given below.

Technique		Description
a.	Waste management plan	A waste management plan is part of the EMS (see BAT 1) and is a set of measures aiming to 1) minimise the generation of waste, 2) optimise the reuse, regeneration and/or recycling of waste and/or the recovery of energy from waste, and 3) ensure the proper disposal of waste.
b.	Monitoring of waste quantities	Annual recording of waste quantities generated for each type of waste. The solvent content in the waste is determined periodically (at least once every year) by analysis or calculation.
c.	Recovery/recycling of solvents	Techniques may include: • recovering/recycling solvents from liquid waste by filtration or distillation on site or off site; • recovering/recycling the solvent content of wipes by gravitational draining, wringing or centrifugation.
d.	Waste-stream-specific techniques	Techniques may include: • reducing the water content of the waste, e.g. by using a filter press for the sludge treatment; • reducing the sludge and waste solvent generated, e.g. by reducing the number of cleaning cycles (see BAT 9); • using reusable containers, reusing the containers for other purposes, or recycling the container material; • sending the spent limestone generated from dry scrubbing to a lime or cement kiln.

18.1.1.16 Odour emissions

BAT 23. In order to prevent or, where that is not practicable, to reduce odour emissions, BAT is to set up, implement and regularly review an odour management plan, as part of the environmental management system (see BAT 1), that includes all of the following elements:

- a protocol containing actions and timelines;
- a protocol for response to identified odour incidents, e.g. complaints;
- an odour prevention and reduction programme designed to identify the source(s), to characterise the contributions of the source(s), and to implement prevention and/or reduction measures.

Applicability
The applicability is restricted to cases where an odour nuisance at sensitive receptors is expected and/or has been substantiated.

18.1.2 BAT conclusions for the coating of vehicles

The BAT conclusion in this section applies to the coating of vehicles (passenger cars, vans, truck cabins, trucks and buses), and applies in addition to the general BAT conclusions given in Section 18.1.1.

18.1.2.1 VOC emissions and energy and raw material consumption

BAT 24. In order to reduce the consumption of solvents, other raw materials and energy, as well as to reduce VOC emissions, BAT is to use one or a combination of the coating systems given below.

	Coating system	Description	Applicability
a.	Mixed (SB-mix) coating	A coating system where one coating layer (primer or base coat) is water-based.	Only applicable to new plants or major plant upgrades.
b.	Water-based (WB) coating	A coating system where the primer and base coat layers are water-based.	
c.	Integrated coating process	A coating system which combines the functions of primer and base coat and is applied by spray coating in two steps.	
d.	Three-wet process	Coating system where the primer, base coat and clear coat layers are applied without intermediate drying. The primer and base coat may be solvent-based or water-based.	

Table 18.7: BAT-associated emission levels (BAT-AELs) for total emissions of VOCs from the coating of vehicles

Parameter	**Vehicle type**	**Unit**	**BAT-AEL (1) (Yearly average)**	
			New plant	**Existing plant**
Total VOC emissions as calculated by the solvent mass balance	Passenger cars	g VOCs per m^2 of surface area (2)	8–15	8–30
	Vans		10–20	10–40
	Truck cabins		8–20	8–40
	Trucks		10–40	10–50
	Buses		< 100	90–150

(1) The BAT-AELs refer to emissions from all process stages, carried out at the same installation from the electrophoretic coating or any other kind of coating process up to and including the final wax and polish of the topcoat, as well as solvents used in cleaning of production equipment, both during and outside the production period.

(2) The surface area is defined as set out in Part 3 of Annex VII to Directive 2010/75/EU.

The associated monitoring is given in BAT 10.

18.1.2.2 Waste quantity sent off site

Table 18.8: Indicative levels for specific waste quantity sent off site from the coating of vehicles

Parameter	Vehicle type	Relevant waste streams	Unit	Indicative level (Yearly average)
Waste quantity sent off site	Passenger cars	• Waste paint • Waste plastisols, sealers and adhesives • Used solvents • Paint sludge • Other paint-shop-related waste (e.g. absorbent and cleaning materials, filters, packaging materials, spent activated carbon)	kg/vehicle coated	3–9 (1)
	Vans			4–17 (1)
	Truck cabins			2–11 (1)
(1) The upper end of the range is higher if dry scrubbing with limestone is used.				

The associated monitoring is given in BAT 22 (b).

18.1.3 BAT conclusions for the coating of other metal and plastic surfaces

The emission levels given below for coating of other metal and plastic surfaces are associated with the general BAT conclusions described in Section 18.1.1. The emission levels given below may not apply where metal and/or plastic automotive components are coated in a vehicle coating plant and these emissions are included in the calculation of the total VOC emissions for the coating of vehicles (see Section 18.1.2).

Table 18.9: BAT-associated emission levels (BAT-AELs) for total emissions of VOCs from the coating of other metal and plastic surfaces

Parameter	Process	Unit	BAT-AEL (Yearly average)
Total VOC emissions as calculated by the solvent mass balance	Coating of metal surfaces	kg VOCs per kg of solid mass input	< 0.05–0.2
	Coating of plastic surfaces		< 0.05–0.3

The associated monitoring is given in BAT 10.

As an alternative to the BAT-AELs in Table 18.9, the BAT-AELs in both Table 18.10 and Table 18.11 may be used.

Table 18.10: BAT-associated emission level (BAT-AEL) for fugitive emissions of VOCs from the coating of other metal and plastic surfaces

Parameter	Unit	BAT-AEL (Yearly average)
Fugitive VOC emissions as calculated by the solvent mass balance	Percentage (%) of the solvent input	< 1–10

The associated monitoring is given in BAT 10.

Table 18.11: BAT-associated emission level (BAT-AEL) for VOC emissions in waste gases from the coating of other metal and plastic surfaces

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
TVOC	mg C/Nm^3	1–20 (1)(2)

(1) The upper end of the BAT-AEL range is 35 mg C/Nm^3 if techniques are used which allow the reuse/recycling of the recovered solvent.

(2) For plants using BAT 16 (c) in combination with an off-gas treatment technique, an additional BAT-AEL of less than 50 mg C/Nm^3 applies to the waste gas of the concentrator.

The associated monitoring is given in BAT 11.

18.1.4 BAT conclusions for the coating of ships and yachts

The BAT conclusion in this section applies to the coating of ships and yachts, and applies in addition to the general BAT conclusions given in Section 18.1.1.

BAT 25. In order to reduce total emissions of VOCs and dust emissions to air, to reduce emissions to water and to improve the overall environmental performance, BAT is to use the techniques (a) and (b) and a combination of the techniques (c) to (i) given below.

	Technique	Description	Applicability
Waste and waste water management			
a.	Segregation of waste and waste water streams	Docks and slipways are constructed with: • a system to collect and handle dry waste effectively and keep it separate from wet waste; • a system to separate waste water from storm water and run-off water.	Only applicable to new plants or major plant upgrades.
Techniques relating to preparation and coating processes			
b.	Restrictions for adverse weather conditions	Where the treatment areas are not fully enclosed, blasting and/or airless spray coating are not carried out if adverse weather conditions are observed or forecast.	Generally applicable.
c.	Partial enclosure of treatment areas	Fine nets and/or water spray curtains are used around areas where blasting and/or airless spray coating are carried out to prevent dust emissions. They may be permanent or temporary.	Applicability may be restricted by the shape and size of the area to be enclosed. Water spray curtains may not be applicable in cold climatic conditions.
d.	Full enclosure of treatment areas	Blasting and/or airless spray coating are carried out in halls, closed workshops, areas tented with textiles or areas fully enclosed with nets to prevent dust emissions. Air from the treatment areas is extracted and may be sent to off-gas treatment; see also BAT 14 (b).	Applicability may be restricted by the shape and size of the area to be enclosed.
e.	Dry blasting in a closed system	Dry blasting using steel grit or shot is carried out in closed blasting systems equipped with a suction head and centrifugal blasting wheels.	Generally applicable.

Technique		Description	Applicability
f.	Wet blasting	Blasting is carried out with water containing a fine abrasive material, such as a fine cinder (e.g. copper slag cinder) or silica.	May not be applicable in cold climatic conditions and/or in enclosed areas (cargo tanks, double bottom tanks) due to the heavy mist formation.
g.	(Ultra-)High-Pressure ((U)HP) water jetting or blasting	(U)HP blasting is a dustless surface treatment method using extremely high-pressure water. There are options with or without an abrasive.	May not be applicable in cold climatic conditions, or due to surface specifications (e.g. new surfaces, spot blasting).
h.	Stripping of coatings by induction heating	An inductor head is moved over the surface, causing localised fast heating of the steel to lift old coatings.	May not be applicable for surfaces with a thickness of less than 5 mm and/or for surfaces with components sensitive to induction heating (e.g. insulation, flammable).
i.	Underwater hull and propeller cleaning system	Underwater cleaning system using water pressure and rotating polypropylene brushes.	Not applicable for ships in full dry dock.

Table 18.12: BAT-associated emission level (BAT-AEL) for total emissions of VOCs from the coating of ships and yachts

Parameter	Unit	BAT-AEL (Yearly average)
Total VOC emissions as calculated by the solvent mass balance	kg VOCs per kg of solid mass input	< 0.375

The associated monitoring is given in BAT 10.

18.1.5 BAT conclusions for the coating of aircraft

The BAT conclusion in this section applies to the coating of aircraft, and applies in addition to the general BAT conclusions given in Section 18.1.1.

BAT 26: In order to reduce total emissions of VOCs and to improve the overall environmental performance of coating of aircraft, BAT is to use technique (a) or both of the techniques given below.

Technique		Description	Applicability
a.	Enclosure	Component parts are coated in enclosed spray booths (see BAT 14 (b)).	Generally applicable.
b.	Direct printing	Use of a printing device to directly print complex layouts on the aircraft parts.	Applicability may be restricted by technical considerations (e.g. accessibility of the applicator gantry, customised colours).

Table 18.13: BAT-associated emission level (BAT-AEL) for total emissions of VOCs from the coating of aircraft

Parameter	Unit	BAT-AEL (Yearly average)
Total VOC emissions as calculated by the solvent mass balance	kg VOCs per kg of solid mass input	0.2–0.58

The associated monitoring is given in BAT 10.

18.1.6 BAT conclusions for coil coating

The emission levels for coil coating given below are associated with the general BAT conclusions given in Section 18.1.1.

Table 18.14: BAT-associated emission level (BAT-AEL) for fugitive emissions of VOCs from coil coating

Parameter	Unit	BAT-AEL (Yearly average)
Fugitive VOC emissions as calculated by the solvent mass balance	Percentage (%) of the solvent input	< 1–3

The associated monitoring is given in BAT 10.

Table 18.15: BAT-associated emission level (BAT-AEL) for VOC emissions in waste gases from coil coating

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
TVOC	mg C/Nm^3	1–20 (1)(2)
(1) The upper end of the BAT-AEL range is 50 mg C/Nm^3 if techniques are used which allow the reuse/recycling of the recovered solvent. (2) For plants using BAT 16 (c) in combination with an off-gas treatment technique, an additional BAT-AEL of less than 50 mg C/Nm^3 applies to the waste gas of the concentrator.		

The associated monitoring is given in BAT 11.

18.1.7 BAT conclusions for the manufacturing of adhesive tapes

The emission levels for the manufacturing of adhesive tapes given below are associated with the general BAT conclusions given in Section 18.1.1.

Table 18.16: BAT-associated emission level (BAT-AEL) for total emissions of VOCs from the manufacturing of adhesive tapes

Parameter	Unit	BAT-AEL (Yearly average)
Total VOC emissions as calculated by the solvent mass balance	Percentage (%) of the solvent input	< 1–3 (1)
(1) This BAT-AEL may not apply to the manufacturing of plastic films used in temporary surface protection.		

The associated monitoring is given in BAT 10.

Table 18.17: BAT-associated emission level (BAT-AEL) for VOC emissions in waste gases from the manufacturing of adhesive tapes

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
TVOC	mg C/Nm^3	2–20 (1)(2)

(1) The upper end of the BAT-AEL range is 50 mg C/Nm^3 if techniques are used which allow the reuse/recycling of the recovered solvent.
(2) For plants using BAT 16 (c) in combination with an off-gas treatment technique, an additional BAT-AEL of less than 50 mg C/Nm^3 applies to the waste gas of the concentrator.

The associated monitoring is given in BAT 11.

18.1.8 BAT conclusions for the coating of textiles, foils and paper

The emission levels for the coating of textiles, foils and paper given below are associated with the general BAT conclusions given in Section 18.1.1.

Table 18.18: BAT-associated emission level (BAT-AEL) for fugitive emissions of VOCs from the coating of textiles, foils and paper

Parameter	Unit	BAT-AEL (Yearly average)
Fugitive VOC emissions as calculated by the solvent mass balance	Percentage (%) of the solvent input	< 1–5

The associated monitoring is given in BAT 10.

Table 18.19: BAT-associated emission level (BAT-AEL) for VOC emissions in waste gases from the coating of textiles, foils and paper

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
TVOC	mg C/Nm^3	5–20 (1)(2)

(1) The upper end of the BAT-AEL range is 50 mg C/Nm^3 if techniques are used which allow the reuse/recycling of the recovered solvent.
(2) For plants using BAT 16 (c) in combination with an off-gas treatment technique, an additional BAT-AEL of less than 50 mg C/Nm^3 applies to the waste gas of the concentrator.

The associated monitoring is given in BAT 11.

18.1.9 BAT conclusions for the manufacturing of winding wire

The BAT conclusion in this section applies to the manufacturing of winding wire, and applies in addition to the general BAT conclusions given in Section 18.1.1.

BAT 27. In order to reduce total emissions of VOCs and energy consumption, BAT is to use technique (a) and one or a combination of the techniques (b) to (d) given below.

Technique		Description	Applicability
a.	Process-integrated VOC oxidation	The air/solvent mix resulting from solvent evaporation during the repeated enamel curing process is treated in a catalytic oxidiser (see BAT 15 (g)) integrated in the curing oven/dryer. The waste heat from the catalytic oxidiser is used in the drying process to heat up the circulating airflow and/or as process heat for other purposes within the plant.	Generally applicable.
b.	Solvent-free lubricants	Solvent-free lubricants are applied as follows: • the wire is drawn through a lubricant-wetted felt; or • a lubricant-impregnated filament is run with the wire and the paraffin wax melts due to the residual heat of the wire and the frictional heat.	Applicability may be limited due to product quality requirements or specifications, e.g. diameter.
c.	Self-lubricating coatings	A solvent-containing lubrication step is avoided by using a coating system that also contains lubricant (a special wax).	Applicability may be limited due to product quality requirements or specifications.
d.	High-solids enamel coating	Use of enamel coating with a solids content of up to 45 %. In the case of fine wires (with a diameter less than or equal to 0.1 mm), the solids content is up to 30 %.	

Table 18.20: BAT-associated emission level (BAT-AEL) for total emissions of VOCs from the manufacture of winding wire

Parameter	Product type	Unit	BAT-AEL (Yearly average)
Total VOC emissions as calculated by the solvent mass balance	Coating of winding wire with an average diameter greater than 0.1 mm	g VOCs per kg of coated wire	1–3.3

The associated monitoring is given in BAT 10.

Table 18.21: BAT-associated emission level (BAT-AEL) for VOC emissions in waste gases from the manufacture of winding wire

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
TVOC	mg C/Nm^3	5–40

The associated monitoring is given in BAT 11.

18.1.10 BAT conclusions for the coating and printing of metal packaging

The emission levels for the coating and printing of metal packaging given below are associated with the general BAT conclusions given in Section 18.1.1.

Table 18.22: BAT-associated emission level (BAT-AEL) for total emissions of VOCs from the coating and printing of metal packaging

Parameter	Unit	BAT-AEL (Yearly average)
Total VOC emissions as calculated by the solvent mass balance	g VOCs per m^2 of coated/printed surface	< 1–3.5

The associated monitoring is given in BAT 10.

As an alternative to the BAT-AEL in Table 18.22, the BAT-AELs in both Table 18.23 and Table 18.24 may be used.

Table 18.23: BAT-associated emission level (BAT-AEL) for fugitive emissions of VOCs from the coating and printing of metal packaging

Parameter	Unit	BAT-AEL (Yearly average)
Fugitive VOC emissions as calculated by the solvent mass balance	Percentage (%) of the solvent input	< 1–12

The associated monitoring is given in BAT 10.

Table 18.24: BAT-associated emission level (BAT-AEL) for VOC emissions in waste gases from the coating and printing of metal packaging

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
TVOC	mg C/Nm^3	1–20 (1)
(1) For plants using BAT 16 (c) in combination with an off-gas treatment technique, an additional BAT-AEL of less than 50 mg C/Nm^3 applies to the waste gas of the concentrator.		

The associated monitoring is given in BAT 11.

18.1.11 BAT conclusions for heatset web offset printing

The BAT conclusion in this section applies to heatset web offset printing, and applies in addition to the general BAT conclusions given in Section 18.1.1.

BAT 28. In order to reduce total VOC emissions, BAT is to use a combination of the techniques given below.

Technique		Description	Applicability
Material-based and printing techniques			
a.	Use of low-IPA or IPA-free additives in dampening solutions	Reduction or avoidance of isopropanol (IPA) as a wetting agent in dampening solutions, through substitution by mixtures of other organic compounds which are not volatile or have a low volatility.	Applicability may be limited by technical and product quality requirements or specifications.
b.	Waterless offset	Modification of the press and the pre-press processes to enable the use of specially coated offset plates, eliminating the need for dampening.	May not be applicable for long print runs due to the need for more frequent change of plates.
Cleaning techniques			
c.	Use of VOC-free solvents or solvents with low volatility for automatic blanket cleaning	Use of organic compounds which are not volatile or have a low volatility as cleaning agents for automatic blanket cleaning.	Generally applicable.
Off-gas treatment techniques			
d.	Web offset dryer integrated with off-gas treatment	A web offset dryer with an integrated off-gas treatment unit, enabling incoming dryer air to be mixed with a part of the waste gases returned from the off-gas thermal treatment system.	Applicable to new plants or major plant upgrades.
e.	Extraction and treatment of air from the press room or the press encapsulation	Routing of extracted air from the press room or the press encapsulation to the dryer. As a result, a part of the solvents evaporated in the press room or press encapsulation is abated by the thermal treatment (see BAT 15) downstream of the dryer.	Generally applicable.

Table 18.25: BAT-associated emission level (BAT-AEL) for total emissions of VOCs from heatset web offset printing

Parameter	Unit	BAT-AEL (Yearly average)
Total VOC emissions as calculated by the solvent mass balance	kg VOCs per kg of ink input	< 0.01–0.04 (1)
(1) The upper end of the BAT-AEL range is related to the production of high-quality products.		

The associated monitoring is given in BAT 10.

As an alternative to the BAT-AELs in Table 18.25, the BAT-AELs in both Table 18.26 and Table 18.27 may be used.

Table 18.26: BAT-associated emission level (BAT-AEL) for fugitive emissions of VOCs from heatset web offset printing

Parameter	Unit	BAT-AEL (Yearly average)
Fugitive VOC emissions as calculated by the solvent mass balance	Percentage (%) of the solvent input	< 1–10 (1)
(1) The upper end of the BAT-AEL range is related to the production of high-quality products.		

The associated monitoring is given in BAT 10.

Table 18.27: BAT-associated emission level (BAT-AEL) for VOC emissions in waste gases from heatset web offset printing

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
TVOC	mg C/Nm^3	1–15

The associated monitoring is given in BAT 11.

18.1.12 BAT conclusions for flexography and non-publication rotogravure printing

The emission levels for flexography and non-publication rotogravure printing given below are associated with the general BAT conclusions given in Section 18.1.1.

Table 18.28: BAT-associated emission level (BAT-AEL) for total emissions of VOCs from flexography and non-publication rotogravure printing

Parameter	Unit	BAT-AEL (Yearly average)
Total VOC emissions as calculated by the solvent mass balance	kg VOCs per kg of solid mass input	< 0.1–0.3

The associated monitoring is given in BAT 10.

As an alternative to the BAT-AEL in Table 18.28, the BAT-AELs in both Table 18.29 and Table 18.30 may be used.

Table 18.29: BAT-associated emission level (BAT-AEL) for fugitive emissions of VOCs from flexography and non-publication rotogravure printing

Parameter	Unit	BAT-AEL (Yearly average)
Fugitive VOC emissions as calculated by the solvent mass balance	Percentage (%) of the solvent input	< 1–12

The associated monitoring is given in BAT 10.

Table 18.30: BAT-associated emission level (BAT-AEL) for VOC emissions in waste gases from flexography and non-publication rotogravure printing

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
TVOC	mg C/Nm^3	1–20 (1)(2)

(1) The upper end of the BAT-AEL range is 50 mg C/Nm^3 if techniques are used which allow the reuse/recycling of the recovered solvent.
(2) For plants using BAT 16 (c) in combination with an off-gas treatment technique, an additional BAT-AEL of less than 50 mg C/Nm^3 applies to the waste gas of the concentrator.

The associated monitoring is given in BAT 11.

18.1.13 BAT conclusions for publication rotogravure printing

The BAT conclusion in this section applies to publication rotogravure printing, and applies in addition to the general BAT conclusions given in Section 18.1.1.

BAT 29. In order to reduce VOC emissions from publication rotogravure printing, BAT is to use a toluene recovery system based on adsorption and one or both of the techniques given below.

Technique		Description
a.	Use of retention inks	Retention inks slow the formation of the dried film surface, which allows toluene to evaporate over a longer time and therefore more toluene to be released in the dryer and recovered by the toluene recovery system.
b.	Automatic cleaning systems connected to the toluene recovery system	Automated cylinder cleaning with air extraction to the toluene recovery system.

Table 18.31: BAT-associated emission level (BAT-AEL) for fugitive emissions of VOCs from publication rotogravure printing

Parameter	Unit	BAT-AEL (Yearly average)
Fugitive VOC emissions as calculated by the solvent mass balance	Percentage (%) of the solvent input	< 2.5

The associated monitoring is given in BAT 10.

Table 18.32: BAT-associated emission level (BAT-AEL) for VOC emissions in waste gases from publication rotogravure printing

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
TVOC	mg C/Nm^3	10–20

The associated monitoring is given in BAT 11.

18.1.14 BAT conclusions for the coating of wooden surfaces

The emission levels for the coating of wooden surfaces given below are associated with the general BAT conclusions given in Section 18.1.1.

Table 18.33: BAT-associated emission level (BAT-AEL) for total emissions of VOCs from the coating of wooden surfaces

Parameter	Coated substrates	Unit	BAT-AEL (Yearly average)
Total VOC emissions as calculated by the solvent mass balance	Flat substrates	kg VOCs per kg of solid mass input	< 0.1
	Other than flat substrates		< 0.25

The associated monitoring is given in BAT 10.

As an alternative to the BAT-AELs in Table 18.33, the BAT-AELs in both Table 18.34 and Table 18.35 may be used.

Table 18.34: BAT-associated emission level (BAT-AEL) for fugitive emissions of VOCs from the coating of wooden surfaces

Parameter	Unit	BAT-AEL (Yearly average)
Fugitive VOC emissions as calculated by the solvent mass balance	Percentage (%) of the solvent input	< 10

The associated monitoring is given in BAT 10.

Table 18.35: BAT-associated emission level (BAT-AEL) for VOC emissions in waste gases from the coating of wooden surfaces

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
TVOC	mg C/Nm^3	5-20 (1)
(1) For plants using BAT 16 (c) in combination with an off-gas treatment technique, an additional BAT-AEL of less than 50 mg C/Nm^3 applies to the waste gas of the concentrator.		

The associated monitoring is given in BAT 11.

18.2 BAT conclusions for preservation of wood and wood products with chemicals

18.2.1 Environmental management systems

BAT 30. In order to improve the overall environmental performance, BAT is to elaborate and implement an Environmental Management System (EMS) that incorporates all of the features (i) to (xx) of BAT 1 as well as the following specific features:

i. Keeping up to date with the developments in biocidal products and in associated legislation (e.g. authorisation of products under the BPR) with a view to using the most environmentally friendly processes.
ii. Inclusion of a solvent mass balance for solvent-based and creosote treatment (see BAT 33(c)).
iii. Identification and listing of all environmentally critical process and abatement equipment (whose failure could have an impact on the environment) (see BAT 46(c)). The list of critical equipment is kept up to date.
iv. Inclusion of plans for the prevention and control of leaks and spillages, including waste management guidelines for dealing with waste arising from spillage control (see BAT 46).
v. Recording of accidental leakages and spillages, and improvement plans (counter measures).

Note
Regulation (EC) No 1221/2009 establishes the European Union eco-management and audit scheme (EMAS), which is an example of an EMS consistent with this BAT.

Applicability
The level of detail and the degree of formalisation of the EMS will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

18.2.2 Substitution of harmful/hazardous substances

BAT 31. In order to prevent or reduce emissions of PAHs and/or solvents, BAT is to use water-based preservatives.

Description
Solvent-based preservatives or creosote are replaced by water-based preservatives. Water acts as the carrier for the biocides.

Applicability
The applicability may be restricted due to product quality requirements or specifications.

BAT 32. In order to reduce the environmental risk posed by the use of treatment chemicals, BAT is to substitute treatment chemicals currently in use with less hazardous ones based on a regular (e.g. once every year) check aiming at identifying potentially new available and safer alternatives.

Applicability
Substitution may be restricted due to product quality requirements or specifications.

18.2.3 Resource efficiency

BAT 33. In order to increase resource efficiency and to reduce the environmental impact and risk associated with the use of treatment chemicals, BAT is to reduce their consumption by using all of the techniques given below.

Technique		Description	Applicability
a.	Use of an efficient preservative application system	Application systems where the wood is immersed in the preservative solution are more efficient than, for example, spraying. The application efficiency of vacuum processes (closed system) is close to 100 %. The selection of the application system takes into account the use class and the penetration level needed.	Only applicable to new plants or major plant upgrades.
b.	Control and optimisation of the consumption of the treatment chemicals for the specific end use	Control and optimisation of the consumption of the treatment chemicals by: a) weighing the wood/wood products before and after impregnation; or b) determining the amount of preservative solution during and after impregnation. The consumption of the treatment chemicals follows suppliers' recommendations and does not lead to exceedances of the retention requirements (e.g. set in product quality standards).	Generally applicable.
c.	Solvent mass balance	The compilation, at least once every year, of organic solvent inputs and outputs of a plant as defined in Part 7(2) of Annex VII to Directive 2010/75/EU.	Only applicable to plants using solvent-based treatment chemicals or creosote.
d.	Measurement and adjustment of wood moisture before treatment	Wood moisture is measured prior to treatment (e.g. by measuring the electric resistance or by weighing) and adjusted if needed (e.g. by further seasoning of the wood) in order to optimise the impregnation process and ensure the required product quality.	Only applicable if wood with a specific moisture content is needed.

18.2.4 Delivery, storage and handling of treatment chemicals

BAT 34. In order to reduce emissions from delivery, storage and handling of treatment chemicals, BAT is to use technique (a) or (b) and all of the techniques (c) to (f) given below.

Technique		Description
a.	Back-venting	Also referred to as vapour balancing. Vapours of solvents or creosote which are displaced from the receiving tank during filling are collected and returned to the tank or truck from which the liquid is delivered.
b.	Capture of displaced air	Vapours of solvents or creosote which are displaced from the receiving tank during filling are collected and led to a treatment unit, e.g. an activated carbon filter or a thermal oxidation unit.
c.	Techniques to reduce evaporation losses due to heating up of stored chemicals	When exposure to sunlight may lead to evaporation of solvents and creosote stored in above-ground storage tanks, tanks are covered by a roof or coated with light-coloured paint to reduce the heating up of stored solvents and creosote.
d.	Securing delivery connections	Delivery connections to storage tanks located within the bunded/contained area are secured and shut off when not in use.
e.	Techniques to prevent overflows during pumping	This includes ensuring that: • the pumping operation is supervised; • for larger quantities, bulk storage tanks are fitted with acoustic and/or optical high-level alarms, with shut-off systems if necessary.
f.	Closed storage containers	Use of closed storage containers for treatment chemicals.

18.2.5 Preparation/conditioning of wood

BAT 35. In order to reduce the consumption of treatment chemicals and the consumption of energy and to reduce emissions of treatment chemicals, BAT is to optimise the wood charge of the vessel and to avoid trapping of treatment chemicals by using a combination of the techniques given below.

Technique		Description	Applicability
a.	Separation of wood in packs by spacers	Spacers are placed at regular intervals in the packs to facilitate the flow of treatment chemicals through the pack and the draining after treatment.	Generally applicable.
b.	Sloping of wood packs in traditional horizontal treatment vessels	Wood packs are inclined in the treatment vessel to facilitate the flow of treatment chemicals and the draining after treatment.	Generally applicable.
c.	Use of tilting pressure treatment vessels	The whole treatment vessel is inclined after treatment so that excess treatment chemicals drain easily and can be recovered from the bottom of the vessel.	Only applicable to new plants or major plant upgrades.
d.	Optimised positioning of shaped wood pieces	Shaped wood pieces are positioned so as to prevent trapping of treatment chemicals.	Generally applicable.
e.	Securing wood packs	The wood packs are secured inside the treatment vessel in order to limit the movement of wood pieces which could change the structure of the pack and reduce the impregnation efficiency.	Generally applicable.
f.	Maximisation of the wood load	The wood load in the treatment vessel is maximised to ensure the best ratio between the wood to be treated and the treatment chemicals.	Generally applicable.

18.2.6 Preservative application process

BAT 36. In order to prevent accidental leakage and emissions of treatment chemicals from non-pressure processes, BAT is to use one of the techniques given below.

Technique	
a.	Double-walled treatment vessels with automatic leak detection devices
b.	Single-walled treatment vessels with sufficiently large and wood-preservative-resistant containment, fender and automatic leak detection device

BAT 37. In order to reduce emissions of aerosols from wood and wood products preservation using water-based treatment chemicals, BAT is to enclose spraying processes, collect overspray and reuse it in the preparation of wood preservation solution.

BAT 38. In order to prevent or reduce emissions of treatment chemicals from pressure processes (autoclaves), BAT is to use all of the techniques given below.

Technique		Description
a.	Process controls to prevent operation unless the treatment vessel door is locked and sealed	The treatment vessel door is locked and sealed once the treatment vessel is loaded and before treatment takes place. Process controls are in place that prevent the operation of the treatment vessel unless the door is locked and sealed.
b.	Process controls to prevent the treatment vessel from opening while it is pressurised and/or filled with preservative solution	Process controls display the pressure and whether liquid is present in the treatment vessel. They prevent the opening of the treatment vessel while it is still pressurised and/or filled.
c.	Catch-lock for the treatment vessel door	The door of the treatment vessel is equipped with a catch-lock to prevent the release of liquids in the event that the treatment vessel door needs to be opened in an emergency situation (e.g. door seal is broken). The catch-lock permits the door to be partially opened to release the pressure while retaining liquids.
d.	Use and maintenance of safety relief valves	Treatment vessels are fitted with safety relief valves to protect the vessels from excessive pressure. The valves' discharge is directed to a tank of sufficient capacity. Safety relief valves are regularly inspected (e.g. once every 6 months) for signs of corrosion, contamination or incorrect fitting and are cleaned and/or repaired as required.
e.	Control of emissions to air from the vacuum pump exhaust	Air extracted from pressure treatment vessels (i.e. the vacuum pump outlet) is treated (e.g. in a vapour-liquid separator).
f.	Reduction of emissions to air when opening the treatment vessel	Sufficient time for dripping and condensation is allowed between the depressurisation period and the opening of the treatment vessel.
g.	Application of a final vacuum to remove excess treatment chemicals from the surface of treated wood	To avoid dripping, a final vacuum is applied in the treatment vessel before opening it to remove excess treatment chemicals from the surface of treated wood. Application of a final vacuum may not be necessary if the removal of excess treatment chemicals from the surface of treated wood is ensured by the application of an appropriate initial vacuum (e.g. less than 50 mbar).

BAT 39. In order to reduce energy consumption in pressure processes (autoclaves), BAT is to use variable pump control.

Description

After reaching the required working pressure, the treatment system is switched to a pump with reduced power and energy consumption.

Applicability

Applicability may be limited in the case of oscillating pressure processes.

18.2.7 Post-treatment conditioning and interim storage

BAT 40. In order to prevent or reduce the contamination of soil or groundwater from the interim storage of freshly treated wood, BAT is to allow sufficient dripping time after treatment and to remove the treated wood from the contained/bunded area only once it is deemed dry.

Description
To allow the surplus treatment chemicals to drip back into the treatment vessel, treated wood/wood packs are held in the contained/bunded area (e.g. above the treatment vessel or over a dripping pad) for a sufficient time after the treatment and before transfer to the post-treatment drying area. Then, before leaving the post-treatment drying area, treated wood/wood packs are, for example, lifted by mechanical means and suspended for a minimum of 5 minutes. If no dripping of treatment solution occurs, the wood is deemed to be dry.

18.2.8 Waste management

BAT 41. In order to reduce the quantity of waste sent for disposal, especially of hazardous waste, BAT is to use the techniques (a) and (b) and one or both of the techniques (c) and (d) given below.

Technique		Description
a.	Removal of debris prior to treatment	Debris (e.g. sawdust, woodchips) is removed from the surface of the wood/wood products before treatment.
b.	Recovery and reuse of waxes and oils	When waxes or oils are used for impregnation, surplus waxes or oils from the impregnation process are recovered and reused.
c.	Bulk delivery of treatment chemicals	Delivery of treatment chemicals in tanks to reduce the amount of packaging.
d.	Use of reusable containers	Reusable containers used for treatment chemicals (e.g. intermediate bulk containers) are returned to the supplier for reuse.

BAT 42. In order to reduce the environmental risk related to waste management, BAT is to store waste in suitable containers or on sealed surfaces and to keep hazardous waste separately in a designated weather-protected and contained/bunded area.

18.2.9 Monitoring

18.2.9.1 Emissions to water

BAT 43. BAT is to monitor pollutants in waste water and potentially contaminated surface run-off water prior to each batch discharge in accordance with 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.

Substance/Parameter	Standard(s)
Biocides (1)	EN standards might be available depending on the composition of the biocidal products
Cu (2)	Various EN standards available (e.g. EN ISO 11885, EN ISO 17294-2, EN ISO 15586)
Solvents (3)	EN standards available for some solvents (e.g. EN ISO 15680)
PAHs (4)	EN ISO 17993
Benzo[*a*]pyrene (4)	EN ISO 17993
HOI	EN ISO 9377-2

(1) Specific substances are monitored, depending on the composition of the biocidal products in use in the process.
(2) The monitoring only applies if copper compounds are used in the process.
(3) The monitoring only applies to plants using solvent-based treatment chemicals. Specific substances are monitored, depending on the solvents in use in the process.
(4) The monitoring only applies to plants using creosote treatment.

18.2.9.2 Groundwater quality

BAT 44. BAT is to monitor pollutants in groundwater with a frequency of at least once every 6 months and in accordance with 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.

The monitoring frequency may be reduced to once every 2 years based on a risk assessment or if pollutant levels are proven to be sufficiently stable (e.g. after a period of 4 years).

Substance/Parameter (1)	Standard(s)
Biocides (2)	EN standards might be available depending on the composition of the biocidal products
As	Various EN standards available (e.g. EN ISO 11885, EN ISO 17294-2, EN ISO 15586)
Cu	
Cr	
Solvents (3)	EN standards available for some solvents (e.g. EN ISO 15680)
PAHs	EN ISO 17993
Benzo[*a*]pyrene	EN ISO 17993
HOI	EN ISO 9377-2

(1) The monitoring may not apply if the substance concerned is not used in the process and if the groundwater is proven not to be contaminated with this substance.
(2) Specific substances are monitored, depending on the composition of biocidal products which are used or were previously used in the process.
(3) The monitoring only applies to plants using solvent-based treatment chemicals. Specific substances are monitored, depending on the solvents in use in the process.

18.2.9.3 Emissions in waste gases

BAT 45. BAT is to monitor emissions in waste gases with a frequency of at least once every year and in accordance with 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	**Process**	**Standard(s)**	**Monitoring associated with**
TVOC (1)	Wood and wood products preservation using creosote and solvent-based treatment chemicals	EN 12619	BAT 49, BAT 51
PAHs (1)(2)	Wood and wood products preservation using creosote	No EN standard available	BAT 51
NO_X (3)	Wood and wood products preservation using creosote and solvent-based treatment chemicals	EN 14792	BAT 52
CO (3)		EN 15058	

(1) To the extent possible, the measurements are carried out at the highest expected emission state under normal operating conditions.

(2) This includes: acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene and pyrene.

(3) The monitoring only applies to emissions from the thermal treatment of off-gases.

18.2.10 Emissions to soil and groundwater

BAT 46. In order to prevent or reduce emissions to soil and groundwater, BAT is to use all of the techniques given below.

Technique		Description
a.	Plant and equipment containment or bund	The parts of the plant in which treatment chemicals are stored or handled, i.e. treatment chemicals storage area, treatment, post-treatment conditioning and interim storage areas (comprising treatment vessel, working vessel, unloading/pull-out facilities, dripping/drying area, cooling zone), pipes and ductwork for treatment chemicals, and creosote (re)conditioning facilities, are contained or bunded. Containments and bunds have impermeable surfaces, are resistant to treatment chemicals and have sufficient capacity to capture and hold the volumes handled or stored in the plant/equipment. Drip trays (made of treatment-chemical-resistant material) may also be used as local containments for the collection and recovery of drips and spills of treatment chemicals from critical equipment or processes (i.e. valves, inlets/outlets of storage tanks, treatment vessels, working tanks, unloading/pull-out zones, handling of freshly treated wood, cooling/drying zone). The liquids in the containments/bunds and drip trays are collected to recover the treatment chemicals for their reuse in the treatment chemicals' system. Sludge generated in the collection system is disposed of as hazardous waste.
b.	Impermeable floors	Floors of areas which are not contained or bunded, and where drips, spills, accidental releases or leaching of treatment chemicals may occur are impermeable to the substances concerned (e.g. storage of treated wood on impermeable floors in the event that it is required in the BPR authorisation for the wood preservative used for the treatment). The liquids on the floors are collected to recover the treatment chemicals for their reuse in the treatment chemicals system. Sludge generated in the collection system is disposed of as hazardous waste.
c.	Warning systems for equipment identified as 'critical'	'Critical' equipment (see BAT 30) is equipped with warning systems to indicate malfunctions.
d.	Prevention and detection of leaks from underground storage and ductwork for harmful/hazardous substances and record-keeping	The use of underground components is minimised. When underground components are used for the storage of harmful/hazardous substances, secondary containment (e.g. double-walled containment) is put in place. Underground components are equipped with leak detection devices. Risk-based and regular monitoring of underground storage and ductwork is carried out to identify potential leakages; when necessary, leaking equipment is repaired. A record is kept of incidents that may cause soil and/or groundwater pollution.
e.	Regular inspection and maintenance of plant and equipment	The plant and the equipment are regularly inspected and serviced to ensure proper functioning; this includes in particular checking the integrity and/or leak-free status of valves, pumps, pipes, tanks, pressure vessels, drip trays, and containments/bunds and the proper functioning of warning systems.
f.	Techniques to prevent cross-contamination	Cross-contamination (i.e. the contamination of plant areas that usually do not come into contact with treatment chemicals) is prevented by using appropriate techniques such as: • design of drip trays in such a way that forklifts are not in contact with potentially contaminated surfaces of the drip trays; • design of charging equipment (used to remove treated wood from the treatment vessel) in such a way that the carry-over of treatment chemicals is prevented; • use of a crane system for handling treated wood; • use of dedicated transport vehicles for potentially contaminated areas; • restricted access to potentially contaminated areas; • use of grit walkways.

18.2.11 Emissions to water and waste water management

BAT 47. In order to prevent or, where that is not practicable, to reduce emissions to water and to reduce water consumption, BAT is to use all of the techniques given below.

Technique		Description	Applicability
a.	Techniques to prevent contamination of rain and surface run-off water	Rain and surface run-off water are kept separated from areas where treatment chemicals are stored or handled, from areas where freshly treated wood is stored and from contaminated water. This is achieved by using at least the following techniques: - drainage channels and/or an outer kerb bund around the plant; - roofing with roof guttering of areas where treatment chemicals are stored or handled (i.e. treatment chemicals' storage area; treatment, post-treatment conditioning and interim storage areas; pipes and ductwork for treatment chemicals; creosote (re)conditioning facilities); - weather protection (e.g. roofing, tarpaulins) for the storage of treated wood in the event that it is required in the BPR authorisation for the wood preservative used for the treatment.	For existing plants, the applicability of drainage channels and an outer kerb bund may be restricted by the size of the plant area.
b.	Collection of potentially contaminated surface run-off water	Surface run-off water from areas that are potentially contaminated with treatment chemicals is collected separately. Collected waste water is discharged only after appropriate measures are taken (e.g. monitor (see BAT 43), treat (see BAT 47 (e)), use (see BAT 47 (c)).	Generally applicable.
c.	Use of potentially contaminated surface run-off water	After its collection, potentially contaminated surface run-off water is used for the preparation of water-based wood preservative solutions.	Only applicable to plants using water-based treatment chemicals. Applicability may be restricted by the quality requirements for its intended use.
d.	Reuse of cleaning water	Water used to wash equipment and containers is recovered and reused in the preparation of water-based wood preservative solutions.	Only applicable to plants using water-based treatment chemicals.
e.	Treatment of waste water	Where contamination in the collected surface run-off water and/or cleaning water is detected or can be expected, and where the use of the water is not feasible, the waste water is treated in an adequate WWTP (on or off site).	Generally applicable.
f.	Disposal as hazardous waste	Where contamination in the collected surface run-off water and/or cleaning water is detected or can be expected, and where the treatment or use of the water is not feasible, the collected surface run-off water and/or cleaning water is disposed of as hazardous waste.	Generally applicable.

BAT 48. In order to reduce emissions to water from wood and wood products preservation using creosote, BAT is to collect the condensates from the depressurisation and vacuum operation of the treatment vessel and from creosote (re)conditioning and either treat them on site using an activated carbon or sand filter or dispose of them as hazardous waste.

Description

Condensate volumes are collected, allowed to settle and treated in an activated carbon or sand filter. The treated water is either reused (closed circuit) or discharged to the public sewer system. Alternatively, the collected condensates may be disposed of as hazardous waste.

18.2.12 Emissions to air

BAT 49. In order to reduce emissions of VOCs to air from wood and wood products preservation using solvent-based treatment chemicals, BAT is to enclose the emitting equipment or processes, extract the off-gases and send them to a treatment system (see techniques in BAT 51).

BAT 50. In order to reduce emissions of organic compounds and odour to air from wood and wood products preservation using creosote, BAT is to use low-volatility impregnating oils, i.e. Grade C creosote instead of Grade B.

Applicability

Grade C creosote may not be applicable in the case of cold climatic conditions.

BAT 51. In order to reduce emissions of organic compounds to air from wood and wood products preservation using creosote, BAT is to enclose emitting equipment or processes (e.g. storage and impregnation tanks, depressurisation, creosote reconditioning), extract the off-gases and use one or a combination of the treatment techniques given below.

Technique		Description	Applicability
a.	Thermal oxidation	See BAT 15 (i). Exhaust heat can be recovered by means of heat exchangers.	Generally applicable.
b.	Sending off-gases to a combustion plant	Part or all of the off-gases are sent as combustion air and supplementary fuel to a combustion plant (including CHP (combined heat and power) plants) used for steam and/or electricity production.	Not applicable for off-gases containing substances referred to in IED Article 59(5). Applicability may be restricted due to safety considerations.
c.	Adsorption using activated carbon	Organic compounds are adsorbed on the surface of activated carbon. Adsorbed compounds may be subsequently desorbed, e.g. with steam (often on site) for reuse or disposal and the adsorbent is reused.	Generally applicable.
d.	Absorption using a suitable liquid	Use of a suitable liquid to remove pollutants from the off-gases by absorption, in particular soluble compounds.	Generally applicable.
e.	Condensation	A technique for removing organic compounds by reducing the temperature below their dew points so that the vapours liquefy. Depending on the operating temperature range required, different refrigerants are used, e.g. cooling water, chilled water (temperature typically around 5 °C), ammonia or propane. Condensation is used in combination with another abatement technique.	Applicability may be restricted where the energy demand for recovery is excessive due to the low VOC content.

Table 18.36: BAT-associated emission levels (BAT-AELs) for TVOC and PAH emissions in waste gases from wood and wood products preservation using creosote and/or solvent-based treatment chemicals

Parameter	Unit	Process	BAT-AEL (Average over the sampling period)
TVOC	mg C/Nm^3	Creosote and solvent-based treatment	< 4–20
PAHs	mg/Nm^3	Creosote treatment	< 1 (^{1})

(^{1}) The BAT-AEL refers to the sum of the following PAH compounds: acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene and pyrene.

The associated monitoring is given in BAT 45.

BAT 52. In order to reduce NO_X emissions in waste gases while limiting CO emissions from the thermal treatment of off-gases in wood and wood products preservation using creosote and/or solvent-based treatment chemicals, BAT is to use technique (a) or both of the techniques given below.

Technique		Description	Applicability
a.	Optimisation of thermal treatment conditions (design and operation)	See BAT 17(a).	Design applicability may be restricted for existing plants.
b.	Use of low-NO_X burners	See BAT 17(b).	Applicability may be restricted at existing plants by design and/or operational constraints.

Table 18.37: BAT-associated emission level (BAT-AEL) for NO_X emissions in waste gases and indicative emission level for CO emissions in waste gases to air from the thermal treatment of off-gases in wood and wood products preservation using creosote and/or solvent-based treatment chemicals

Parameter	Unit	BAT-AEL (1) (Average over the sampling period)	Indicative emission level (1) (Average over the sampling period)
NO_X	mg/Nm^3	20–130	No indicative level
CO		No BAT-AEL	20–150
(1) The BAT-AEL and indicative level do not apply where off-gases are sent to a combustion plant.			

The associated monitoring is given in BAT 45.

18.2.13 Noise

BAT 53. In order to prevent or, where that is not practicable, to reduce noise emissions, BAT is to use one or a combination of the techniques given below.

Technique	
Storage and handling of raw materials	
a.	Installation of noise walls and utilisation/optimisation of the noise-absorbing effect of buildings
b.	Enclosure or partial enclosure of noisy operations
c.	Use of low-noise vehicles/transport systems
d.	Noise management measures (e.g. improved inspection and maintenance of equipment, closing of doors and windows)
Kiln drying	
e.	Noise reduction measures for fans

Applicability

The applicability is restricted to cases where a noise nuisance at sensitive receptors is expected and/or has been substantiated.

19 EMERGING TECHNIQUES FOR SURFACE TREATMENT USING SOLVENTS AND PRESERVATION OF WOOD AND WOOD PRODUCTS WITH CHEMICALS

Article 3(14) of Directive 2010/75/EU defines an ‘emerging technique’ as a ‘novel technique for an industrial activity that, if commercially developed, could provide either a higher general level of protection of the environment or at least the same level of protection of the environment and higher cost savings than existing best available techniques’. This chapter contains those techniques that may appear in the near future and that may be applicable to the surface treatment using organic solvents sector as well as to the sector of preservation of wood and wood products with chemicals.

19.1 Winding wire manufacture

19.1.1 Water-based enamel coatings

Description
Tests were performed with acrylic enamels some years ago. They did not meet the required International Electrotechnical Commission (IEC) standard and the increasing requirements for electrical and mechanical performance needed by the customer. A small amount of solvent (up to 15 % alcohol and aminos) is necessary to maintain surface performance.

Achieved environmental benefits
A significant reduction of solvent emissions.

Environmental performance and operational data
The use of water-based systems requires higher energy consumption to ensure a longer, and hotter, drying zone. Furthermore, the installations have to be equipped with stainless steel pipes. Due to the high costs and technological aspects, this alternative is not yet proven as suitable.

Cross-media effects
Emissions to water, and a huge increase in the energy input needed due to drying and energy recovery from the incinerator is no longer being possible.

Technical considerations relevant to applicability
Not currently applicable.

Economics
Low cost benefit. Retrofitting is an expensive operation because all pipes have to be replaced by stainless steel material. Also, the drying zone has to be changed (longer/warmer).

Reference literature
[28, EWWG 2004] [78, TWG 2005]

19.1.2 UV-cured enamel coatings

Description
UV-cured enamel coatings might be a possible alternative for conventional solvent-based enamel coatings.

Achieved environmental benefits
Solvent emissions from the coating system are reduced to zero.

Environmental performance and operational data
The existing materials will not meet the required specifications. Great problems are anticipated if the correct thickness is to be reached, and the creation of blisters will cause a bad electrical performance. The UV-cured enamels have an unpleasant odour and workers might be allergic to them. Furthermore, the acrylates used cannot fulfil the required temperature resistance.

Due to the lack of performance, high costs, and technological and safety aspects, this alternative is not yet proven as suitable.

Cross-media effects
UV lamps are needed for the drying. High energy consumption.

Technical considerations relevant to applicability
The method/process has not been used in practice yet. Developments are ongoing.

Economics
Low cost benefit. Retrofitting is an expensive operation. High material costs are also expected.

Reference literature
[4, Germany 2002] [28, EWWG 2004] [78, TWG 2005] [EWWG/ORGALIM comment #46 in [212, TWG 2018]]

19.1.3 Hot-melt enamel coatings

Description
A thermosetting material is applied to the copper conductor. This substitute is thermoplastic until 100 °C, and then the resin is maintained as liquid at approximately 80 °C and can be applied with dies onto the copper conductor.

Tests have been performed, especially with wire diameters > 0.355 mm, but not all wires could satisfy the typical and increasing demands of modern wire processing regarding adherence and flexibility, heat-shock, cut-through, thermal resistance, resistance to abrasion and centricity of insulation film. Due to the nearly 100 % solids content and the resulting lower number of insulation layers, it is not possible to realise small tolerances of film thicknesses in a precise way. Fewer layers and bad centricity cause a worsening of the dielectric strength of the insulation film.

Achieved environmental benefits
Since this is an almost solvent-free process, a significant reduction in solvent emissions can be achieved.

Environmental performance and operational data
The application of the hot melts requires temperatures of about 80 °C to 100 °C in the resin-circulating pumps, which could result in some problems in the working area for the workers.

No recovery of energy is possible from the oven, due to the lack of solvent.

Cross-media effects
The hot melts still contain small quantities of alcoholic substances which cause a flue smell by oxidation and cracking during the enamelling process. A high input of electrical energy is required for curing.

Technical considerations relevant to applicability
Not the whole range of current products can be produced using hot melts. There is no solution for a direct (1:1) replacement of existing insulating systems. Tests have been performed since the mid-1990s without success. This technique is not applicable for wire sizes (diameters) below 0.15 mm, as the wire will break because of the viscosity of the molten polymer. Due to the lack of performance, high costs, and technological and safety aspects, this alternative is not yet proven as suitable.

Economics
Low cost benefit. The machinery has to be completely changed from the existing one. New insulation materials have to be developed, tested by the winding wire manufacturer and approved by the customers.

Reference literature
[28, EWWG 2004] [38, TWG 2004] [78, TWG 2005]

19.1.4 Waxing of fine wires

Description
Techniques are being considered to reduce the solvent emissions from the final drying of wax on fine wires (0.01-0.1 mm).

Achieved environmental benefits
Reduction of VOC consumption and emissions.

Reference literature
[38, TWG 2004]

19.2 Coating of vehicles (passenger cars and light vans)

[5, DFIU et al. 2002] [38, TWG 2004]

19.2.1 Water-based or ultra-high-solids one- and two-component clear coating

Description

New products in the form of improved water-dilutable one- and two-component clear coating systems as well as 'ultra-high-solids' two-component clear coating systems (with a solids content of up to 90 wt-%) are expected in the future. Water-soluble clear coats have been tested but have not met performance requirements. Currently, solvent-based high-solids 2K clear coat materials have an average solid content in the range of 55-65 % (see Section 2.2.3.3 and Table 2.5).

Achieved environmental benefits

The main advantage of water-based paints is the reduction of VOC emissions.

Cross-media effects

The energy demand for the drying may be expected to be higher in the case of water-based coatings.

Technical considerations relevant to applicability

Water-based clear coats are not currently used for the coating of passenger cars due to their poor appearance and quality (see Section 2.2.3.3).

Driving force for implementation

Possible reduction in off-gas treatment needs.

Example plants

See Section 2.2.3.3.

Reference literature

[265, TWG 2019]

19.2.2 Developments in powder coating

Description

The application of powder topcoating on a larger scale may be expected in the future. According to statements from paint producers, a variety of pigmented finish coating systems based on powder are already available; however, these are not yet in serial application. According to industry, this may be due to the difficulty in colour mixing, making recycling impossible. Powder coating has been tested in the automotive industry but has not been successful. The current powder coats do not meet most European manufacturers' requirements for durability and physical and chemical resistance.

Cross-media effects

Some health and safety considerations with the powder coatings.

Economics

The price of powder coating systems is higher than that of conventional coating systems [183, ACEA 2017].

Example plants

So far, all relevant projects have been unsuccessful [ACEA comment 575 in [212, TWG 2018]]. The technique was implemented in PSA plant Mulhouse [183, ACEA 2017] but the use of powder coatings has been stopped [265, TWG 2019].

Reference literature

[78, TWG 2005] [110, Eurocar 2005] [212, TWG 2018] [265, TWG 2019]

19.2.3 Increased use of pre-coated materials

Description

A further development may be an increasing share of completely finished coil coating parts so that certain painting processes will no longer be performed by the car manufacturer (see Chapter 6).

Achieved environmental benefits

Because pre-coated materials are coated before forming (shaping) and completion of sub-assemblies (e.g. doors), the application and extraction techniques enable a lower VOC emission per m^2 coated than post-forming painting.

Cross-media effects

VOC emissions (although reduced) remain but are transferred to the production of the pre-coated materials.

19.2.4 Polyurethane (PU) paint systems

Description

Paint systems based on polyurethane can be already burned-in at temperatures below 100 °C. This allows the lacquer finish of both metal bodies and plastic mounted parts within a single painting process. A so-called ‘in-line lacquer finish’ would solve the problem of the colour adjustment between the metal body and the coloured plastic parts.

Technical considerations relevant to applicability

The wide range of PU-based paint systems is available for all layers of the paint structure, ranging from the primer to the finish coating as well as for sound absorption and underbody protection. The low burn-in temperatures allow for the use of a wide range of plastics.

19.2.5 Overspray-free paint applications

[ACEA comment #481 in [212, TWG 2018]]

Description

New paint atomisation technique which generates precise droplet sizes without air, avoiding the creation of overspray. A robot-guided, high-precision measuring device measures the laser-soldered seam between the roof and side wall frame of every car before painting. A special applicator then applies the black paint directly to the body with millimetric precision in individual strips. The applicator places the colour strips with sharp edges and without spray mist.

Achieved environmental benefits

Elimination of overspray. This technology makes it possible to paint certain surfaces of a body in a different colour – in one and the same painting process.

Environmental performance and operational data

Time- and material-intensive masking is no longer required for overspray-free painting.

Economics
Time savings and cost reduction.

Example plants
Currently being tested in an Audi pilot plant in Ingolstadt with car roofs in black contrast.

Reference literature
[212, TWG 2018] [217, AUDI 2018]

19.2.6 Inside-out curing

[ACEA comment #481 in [212, TWG 2018]]

Description
The inflow of hot air through the opening of the windshield, thus heating the car body panels from the inside out. This reduces the risk of pinholing, since the paint layers are heated from the bottom. The film on the paint surface only forms once the residual moisture and solvent have completely evaporated.

Environmental performance and operational data
Temperature differences within the car body can thus be reduced by 50 % and heating times by 30 %.

Example plants
Skoda plant in Mlada Boleslav (Czech Republic).

Reference literature
[212, TWG 2018] [218, Durr 2018]

19.3 Coating of ships and yachts

19.3.1 Replacement of antifouling paints based on biocides (substitution)

Techniques presented in the following subsections which are alternatives to the use of antifouling coatings based on biocides are mainly related to the environmental performance of the ship and not of the plant (shipyard).

19.3.1.1 Paints with natural biocides

Description
Natural biocides are produced, for example, by some coral species as a protection against fouling.

Achieved environmental benefits
This antifouling system does not contain heavy metals or biocides.

Environmental performance and operational data
These substances show a lower persistence due to a better biodegradability rating compared to inorganic materials such as copper compounds or TBT.

Technical considerations relevant to applicability
Paints containing natural biocides are still being tested.

Reference literature
[5, DFIU et al. 2002].

19.3.1.2 Coatings with special surface properties for a reduction of fouling

Description
Coatings with a special surface structure such as micro-roughness can be used for a reduction of fouling.

Achieved environmental benefits
This antifouling system does not contain heavy metals or biocides.

Environmental performance and operational data
A pilot project for the testing of environmentally sound antifouling coatings was carried out by an environmental regulator, an environmental NGO and coating manufacturers. During the study, this type of coating performed the best out of all biocide-free materials.

Technical considerations relevant to applicability
Applicable to all ships.

Economics
Costs are claimed to comparable to other tin- and copper-free antifoulings.

Reference literature
[5, DFIU et al. 2002] [33, Watermann et al. 2003] [78, TWG 2005]

19.3.2 Coating removal from ship hull by induction heating by laser

Description

This is a recognised method for removal of paint and coatings on steel surfaces by induction heating by laser. Controlled induction heating by laser is used to heat the steel surface so that the coating debonds and can be easily removed. This technology is especially efficient on thick paints and coatings. See also Section 4.4.3.4.

Achieved environmental benefits

Fast removal rate on thick, difficult coatings, reduction in energy consumption, and less emissions and noise.

Example plants

The technology is used, for example, on bridges, offshore installations, steel construction, storage tanks, pipes and marine ships.

Reference literature

[154, Nordic Council of Ministers 2016]

19.4 Coil coating industries

19.4.1 UV/EB radiation curing processes

Description
No commercial application is known for coil coating applications. See also Section 6.4.4.3 on infrared radiation curing for coil coating.

For a general description of radiation curing processes, see Section 17.8.5. Detailed information on UV curing and EB curing can be found in Sections 17.8.5.4 and 17.8.5.5.

Achieved environmental benefits
Reduced solvent emissions.

Environmental performance and operational data
UV and/or EB radiation curing may become an important technology for new lines but it is difficult to see how it could be a viable replacement for a conventional solvent-based coating as a retrofit on an existing line. In its current state of development, radiation curing cannot meet the specifications for the whole range of coil coating products. Small-scale trials continue with development products. UV lamps or EB units will need to be installed on lines wishing to run radiation-cured coatings. These factors mean that a changeover to UV- and/or EB-radiation-cured coatings is not feasible for coil coating installations at present.

Reference literature

[22, ECCA 2004] [38, TWG 2004],

19.5 Coating of wooden surfaces

19.5.1 Powder coating

Description
At present, research into the application of powder coatings for the woodworking industry is strongly associated with the development of new generations of powder coating materials, which have more suitable melting and curing processes. Powder coating systems cross-linking by UV radiation are still at an early stage of their development, but UV-cured powders are already used in production for, e.g. MDF and flat wood panels. At present, the electrostatically assisted application of powder coatings onto non-conductive wood and wood materials is under development.

Achieved environmental benefits
In this context, the earthing of electric charges via freshly produced wet lacquer film has been examined. This painting principle has been used for furniture fronts and has produced the following results:

- in comparison to the low-pressure procedure (HVLP), electrostatic high-rotation atomisation increases the application efficiency by approximately 35 %, and accordingly the material efficiency by approximately 30 %;
- it reduces the generation of waste (paint) by approximately 80 %.

Technical considerations relevant to applicability
So far, electrostatically assisted painting processes can only be applied in rare individual cases in wood processing. Therefore, further research is necessary.

Reference literature
[5, DFIU et al. 2002]

19.5.2 Peroxide and IR bleaching

Description
A new method for bleaching has been developed which combines peroxide application and infrared radiation. No further information has been provided.

Reference literature
https://www.mdpi.com/2073-4360/11/5/776.

19.5.3 Non-thermal plasma treatment of off-gases

Description
In the off-gas, a plasma is created at low temperatures (30-120 ºC) by routing the off-gas through two electrodes with an alternating current of 20-30 kV. In the plasma, the VOC vapours react very quickly with oxygen to form CO_2 and water vapour.

In a plasma, the molecules of the gas flow are in a partly ionised condition. This condition is normally achieved by extremely high temperatures, such as that caused by lightning. However, it can also be created at ambient temperatures if enough energy is added.

Achieved environmental benefits
Efficiencies of 97-99.9 % are achieved without heating the off-gas. The installation for this technique is very compact compared to thermal oxidation and also consumes far less energy.

Environmental performance and operational data

Different layouts are available. Sometimes the space between the electrodes is filled with small glass balls to amplify the electric field.

Cross-media effects

Energy consumption of 0.5-3.0 kWh electric energy per 1 000 m^3 of off-gas treated.

Technical considerations relevant to applicability

This technique has only been commercially applied for a few years to reduce odour emissions and sometimes to treat off-gases containing VOCs. At the moment, the technique is used as a pilot in a demonstration project applied to treat VOC emissions from the drying of wood.

In theory, there is no restriction in applications concerning the VOC concentrations in the off-gas; however, it is currently applied for treating low concentrations. Also, small or large flows can be treated.

Economics

No data on cost are available yet. However, this technique is expected to be cheaper than thermal oxidation or adsorption.

Reference literature

[27, VITO 2003] [38, TWG 2004]

19.6 Preservation of wood and wood products with chemicals

19.6.1 Chemical wood modification (CWM)

Description

Chemical wood modification is a biocide- and solvent-free process which induces a reaction between an introduced molecule and the wood polysaccharides, creating a permanent change throughout an entire section of wood [238, WPA 2009].

Technical description

Chemical wood modification changes the chemical composition of the cell wall by reaction with chemical reagents. These are introduced into the wood - usually in aqueous form (in pure form, dissolved in water or dissolved in organic solvents) - by pressure impregnation. The chemical reaction is triggered by increasing the temperature (up to 140 °C). After removal of the excess impregnating agent (vacuum), the timber is dried to delivery or service moisture content. Chemical wood modification is always carried out in closed plants [230, VDI 2014] [DE comment #391 in [212, TWG 2018]].

Chemical wood modification processes used on a commercial scale include acetylation, furfurylation and polymerisation [230, VDI 2014].

Acetylation

The acetylation process uses acetic acid anhydride as a reagent to react with functional groups in the wood. During the modification process, acetic acid is generated as a by-product which is treated and reused. The acetylated wood may contain residual reagent concentrations; occupational health and safety regulations have to be taken into account during further processing [230, VDI 2014].

For the acetylation process, acetyl chloride can also be used, which results in the formation of hydrochloric acid during treatment, which can cause destruction of wood at high temperatures. In comparison to hydrochloric acid, acetic acid is less destructive but difficult to remove from treated wood, which causes emissions of VOCs and odour over the period of usage of the end product. In addition, high corrosivity of the chemicals for the acetic anhydride process needs to be considered for the installation/equipment properties [DE comment #392 in [212, TWG 2018]].

Furfurylation

The furfurylation process is similar to acetylation treatment except that it uses furfuryl alcohol as a reagent [230, VDI 2014].

Achieved environmental benefits

No use of biocides (including creosote) or solvents as the carrier liquid for the wood preservatives.

Environmental performance and operational data

Emissions including odorant emissions may be generated when opening the impregnation and reaction vessels, during transfer of the treated wood to the drying kilns and during drying [230, VDI 2014].

A comment received indicates that there is a need for the use of an off-gas treatment system, but no further information was provided [DE comment #395 in [212, TWG 2018]].

Cross-media effects

A comment received underlines that energy consumption may be higher, but no further information was provided [DE comment #393 and IT comment #79 in [212, TWG 2018]].

Used chemicals may have hazardous properties. Acetic anhydride (CAS number 108-24-7) is suspected of causing respiratory irritation according to the CLP Regulation. Furfuryl alcohol (CAS number 98-00-0) is included in the Community Rolling Action Plan (CoRAP, 2018 data[51]) under REACH and is also suspected of causing cancer according to the CLP Regulation.

Technical considerations relevant to applicability
Applicable to new plants or major upgrades of existing plants. The applicability may be restricted due to product quality requirements or specifications.

Reference literature
[230, VDI 2014] [238, WPA 2009] [DE comment #393 in [212, TWG 2018]]

19.6.2 Thermal wood modification (TWM)

Description
Thermal wood modification is a biocide- and solvent-free process which induces a permanent change in the polysaccharides (e.g. starch and cellulose) of the wood to enhance its performance. Wood is heated to a temperature in excess of 160 °C in an environment in which oxygen is restricted or eliminated to achieve the desired performance characteristics without charring of the surface [238, WPA 2009].

Technical description
Thermal wood modification is a process by which the composition of the cell wall material and its physical properties are modified by exposure to temperatures higher than 160 ºC and conditions of reduced oxygen availability. The wood is altered in such way that at least some of the wood properties are permanently affected through the cross-section of the timber [246, CEN 2007].

Thermal wood modification is typically achieved by exposure of the wood to temperatures of 160 °C to 250 °C under reduced oxygen availability with the result of a permanent change in the wood's essential properties. Typical starting materials are dried roundwood and sawn timber, either softwood or hardwood. Wood modification is carried out in closed plants. There are several process variants that essentially produce similar effects, but differ in the way the oxygen reduction is accomplished and in the temperature, humidity and pressure conditions during the process [230, VDI 2014]. Treatment methods differ based on the applied conditions. The most common practice is thermal modification in an atmosphere of water vapour and wood gases at normal pressure. However, different process conditions are also applied such as:
in an atmosphere of water vapour and wood gases at high pressure;

- in an atmosphere of wood gases at normal pressure;
- in an atmosphere of wood gases under vacuum;
- as an additional step to a high-temperature curing stage (see hydrothermal wood modification below);
- in an atmosphere of wood gases and nitrogen;
- in a hot oil bath [249, IHD 2018].

Two example processes are described below:

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[51] See https://echa.europa.eu/

Thermal treatment based on the pressure impregnation technology

This process requires no chemicals or inert gases. As such, it is a completely solvent-free process. This treatment is applicable to all types of wood (dry or fresh), and it is especially suitable for European wood. The thermally treated wood can be used for both outdoor (not for ground contact) and indoor applications [148, COM 2009].

The process consists of steam-treating the wood in an autoclave at a temperature of 140-210 °C and a pressure of 14-20 bar. The process modifies the cell structure of the wood, thus reducing its water-absorption capacity. Additionally, the dimension stability is improved and the wood becomes more durable. The wood is preserved throughout its cross-section whereas in the case of impregnation, this can only be achieved for wood of small dimensions [148, COM 2009].

Hydrothermal wood modification

The process consists of five steps:

- Pre-drying stage.
- Hydro-thermolysis stage. The wood is heated to 150-180 °C in an aqueous environment. The cellulose remains intact and the wood therefore keeps its good mechanical properties.
- Drying stage. The wood is reconditioned to a dry environment in a conventional industrial wood kiln.
- Curing stage. The wood is heated to 150-190 °C under dry conditions.
- Conditioning stage. The moisture content of the wood is elevated to a level which is necessary for manufacturing [148, COM 2009].

Also, liquid organic heat transfer fluids (e.g. rapeseed oil) have been reported to be used to provide the heat input for the thermal modification process [230, VDI 2014].

Achieved environmental benefits

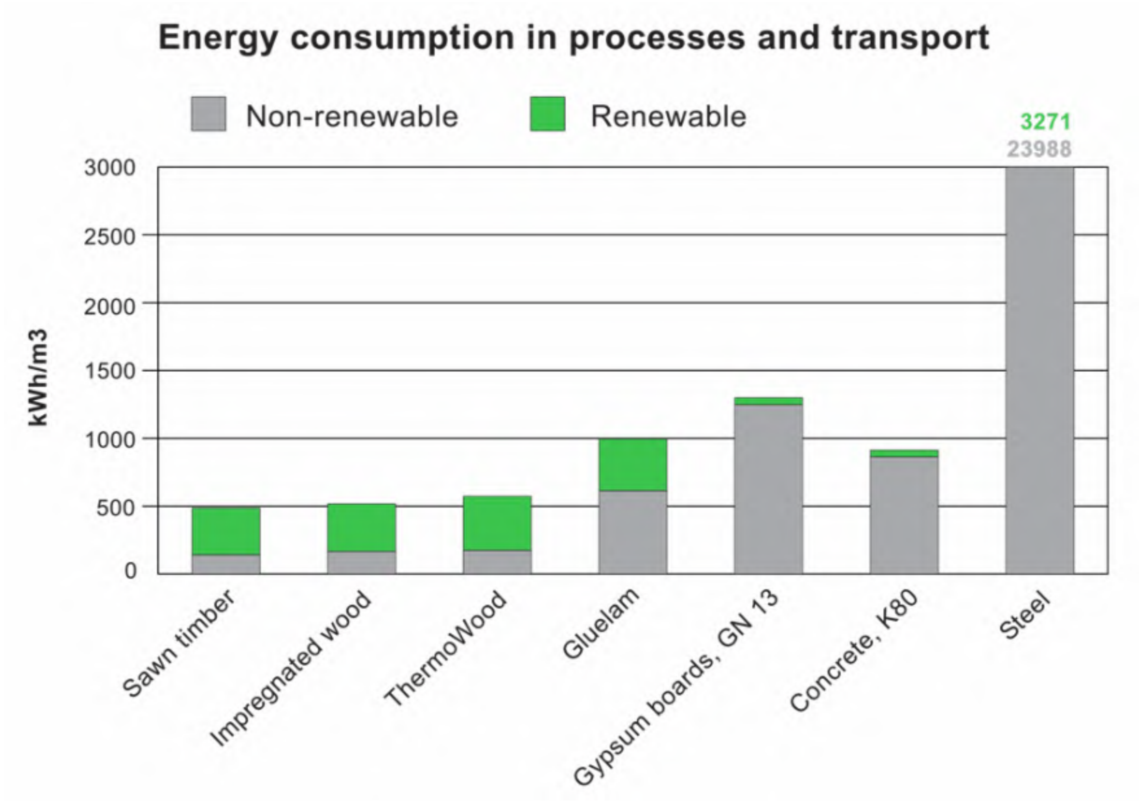
- No use of treatment chemicals (biocides (including creosote), solvents).
- No emission of VOCs from the use of treatment chemicals.

Environmental performance and operational data

The average electric and thermal energy consumption for the thermal modification of 1 m^3 of wood ranges between 400 kWh and 550 kWh [230, VDI 2014].

Thermal wood modification can be seen as partial pyrolysis of the wood. Exposure to elevated temperatures causes volatile organic compounds - part of which are odorous - to be driven off and results in the thermal modification of the wood components, mainly the hemicelluloses (wood sugar) but partly also the celluloses and lignin. The resulting decomposition products either remain in the wood or are emitted during or after treatment. Depending on the wood species, process and treatment intensity, the resulting mass loss is about 3 % to 5 % [230, VDI 2014].

The thermal modification process generates gaseous and aerosol emissions. These consist in particular of terpenes, organic acids (e.g. acetic acid, formic acid) or aldehydes (e.g. furfural). The composition, concentration and physical state of the emissions are governed by the wood species, the process and the treatment intensity. Moreover, the process generates condensates [230, VDI 2014].



Source: [245, ThermoWood 2018]

Figure 19.1: Comparison of specific energy consumption for impregnated wood and thermally modified wood

Cross-media effects

Emissions to air and consumption of energy. The latter is increased due to the higher temperatures and longer treatment times compared with other treatments [148, COM 2009].

Technical considerations relevant to applicability

Applicable to new plants or major upgrades of existing plants. The applicability may be restricted due to product quality requirements or specifications.

The process is already used on an industrial scale but to improve product quality is ongoing. It seems that the durability and preservation resulting from this process, if applied properly, are similar to those of creosote-impregnated wood. The heat treatment may affect the product quality. It results in a loss of the wood's elasticity and solidity and, as a consequence, its mechanical strength. In addition, a darkening of the wood occurs. In some cases, a change of shape may result from it. Finally, choice of the correct temperature curve for each wood requires skill and experience [148, COM 2009]

The use of thermally modified wood for load-bearing applications is only permissible if its usability for such purposes has been proven appropriately. The reasons for that are particularly:

- its usually reduced strength, and therefore its load-bearing capacity, as well as the altered behaviour of rupture of thermally modified wood as compared to untreated wood;
- the absence of statically secured values for calculations and measurements;
- the requirements of construction law: thermally modified wood is not to be regarded as a regulated construction product since its properties substantially deviate from regulated construction products [249, IHD 2018].

Economics
The investment cost for thermal treatment installations is nearly double that of water-based systems. The process is generally more expensive than other preservation techniques; there is no preservative cost but the process take two to five times longer [148, COM 2009].

Investment costs for thermal treatment equipment are typically between EUR 500 000 and EUR 1 000 000 for a batch size of 50 m^3 or more, and the operational costs are about EUR 50-100/m^3 [148, COM 2009].

Reference literature
[148, COM 2009] [230, VDI 2014] [238, WPA 2009] [246, CEN 2007] [249, IHD 2018]

19.6.3 Supercritical carbon dioxide process

Description
The supercritical carbon dioxide process is a pressure impregnation process in which supercritical CO_2 is used as a carrier for the active substances (instead of liquid organic solvents).

Technical description
The impregnation takes place in a closed processing facility with high recirculation of the excipients. The wood is placed in a treatment vessel - similar to those used in normal pressure treatment processes - and the wood preservative (treatment chemicals) is added. The pressure in the container is slowly increased by the addition of carbon dioxide. When the pressure exceeds 74 bar and a temperature of 31 °C, the carbon dioxide enters the supercritical state. In this state the CO_2 behaves as a fluid and serves as a carrier for the preservatives. It carries the impregnating agent into the wood and the entire cross-section of the wood is impregnated. After a short time, the pressure in the impregnating vessel is lowered to atmospheric pressure by extracting the carbon dioxide from the container and thus from the wood. The preservatives remain in the wood. The carbon dioxide is recirculated [239, Superwood 2017].

The preservative used consists of three organic fungicides: propiconazole, tebuconazole and 3-iodo-2-propynyl butyl carbamate (IPBC) and a binding agent, which binds the active substances and provides the wood with a water-repellent effect [239, Superwood 2017].

Afterwards, the impregnated wood has the same moisture percentage and the same mechanical properties as before the treatment. The wood can be delivered and no additional fixation or drying is required before use. The wood produced by this process is suitable for niche products in above-ground uses such as facade cladding. It should not be used in permanent contact with soil or water, and it may not be used in direct contact with food [239, Superwood 2017].

Like liquids, supercritical CO_2 has a high density, allowing for dissolution of biocides. However, supercritical CO_2 has no surface tension and the viscosity is closer to that of gases. Consequently, supercritical CO_2 penetrates wood more easily than liquid solvents, allowing for the impregnation of refractory wood species like spruce, which are difficult to impregnate using liquid solvents. Another feature that separates the supercritical impregnation process from conventional liquid impregnation techniques is that the process is a dry impregnation process. Being a gas, supercritical CO_2 does not wet the wood and the wood is dry before, during and after impregnation. Because the wood is dry after impregnation, quality control of chemical uptake cannot be checked by simply weighing the wood, but has to be carried out by chemical analysis. Supercritical CO_2 acts as a non-polar solvent and does not allow for impregnation of wood with metal ions such as copper or boron. The choice of available actives for supercritical wood impregnation is therefore limited to molecules that can be solubilised in supercritical CO_2, typically organic molecules [240, Denmark 2017].

Achieved environmental benefits

- No use of solvents or heavy metals.
- No waste water is generated.
- After the treatment process, the wood is dry and no dripping will occur (reduced risk of soil and groundwater pollution) [240, Denmark 2017].

Environmental performance and operational data

In an acknowledgement of the potential environmental benefits, Superwood (Plant DK-2) was awarded the European Award for the Environment in 2002 [240, Denmark 2017].

Cross-media effects

Pressure levels applied for the supercritical carbon dioxide process are approximately seven times higher than conventional pressurised treatment processes [240, Denmark 2017].

Technical considerations relevant to applicability

A special design of plant is needed [240, Denmark 2017].

Applicable to new plants or major upgrades of existing plants. The applicability may be restricted due to product quality requirements or specifications.

Driving force for implementation

No use of solvents. No use of heavy metals. No dripping/fixation area needed [240, Denmark 2017].

Example plants

Plant DK-2 in [236, TWG 2017].

Reference literature

[236, TWG 2017] [239, Superwood 2017] [240, Denmark 2017]

19.7 Off-gas treatment

19.7.1 Electrically heated carbon adsorption tubes

Description
Carbon adsorption tubes can be mounted on individual printing/coating application lines and used to adsorb VOCs. The VOCs can then be recovered by passing a current through the electrically conducting carbon tubes.

Example plants
Small-scale trials have been shown to be successful in the UK.

Reference literature
[38, TWG 2004]

19.8 Waste water treatment

19.8.1 Wet separation spray booth with SiO_2 particles

Description
Overspray in a spray booth where surfaces are sprayed with paint materials can be intercepted by applying a water curtain. The water-paint mixture is captured and treated in a reservoir below the spray booth. SiO_2 particles are added to the water reservoir and, while floating on the surface, are adsorbing the paint particles. When the SiO_2 particles are saturated with paint, they are removed from the reservoir and are recovered as a new paint.

Achieved environmental benefits
VOC emissions are reduced and the recovered paint and SiO_2 particles can be reused in a new paint.

Environmental performance and operational data
The process is fully developed and ready for commercialisation; however, it is not yet available on a large scale.

Cross-media effects
Arising of waste water which can often be reused.

Technical considerations relevant to applicability
Wet separation spray booths are common practice in wood and furniture painting and in the automotive industry. They are applicable to water- and solvent-based paints.

The technique is currently not applied on a commercial level.

Economics
Not known yet.

Reference literature
[27, VITO 2003]

20 CONCLUDING REMARKS AND RECOMMENDATIONS FOR FUTURE WORK

Timing of the review process

The key milestones of the review process are summarised in Table 20.1 below.

Table 20.1: Key milestones of the STS BREF review process

Key milestone	Date
Reactivation of the TWG	10 December 2014
Call for initial positions	26 June 2015
Kick-off meeting	16 to 19 November 2015
Drawing up of questionnaire	December 2015 to July 2016
Information and data collection	July to October 2016
Draft 1 of the revised STS BREF	October 2017
End of commenting period on Draft 1 (2 512 comments received)	15 December 2017
Final TWG meeting	10 to 14 December 2018

During the BREF review process, a total of 13 plants were visited in Belgium, France, Germany, Italy, the Netherlands and the United Kingdom.

In addition, three events were organised to improve the exchange of information:

- a webinar in June 2016 to finalise the questionnaire template;
- a webinar in February 2017 on the data collected via the questionnaires;
- an informal TWG meeting in June 2018 for an exchange of views on the data situation of the STS BREF review in advance of the final TWG meeting.

Sources of information and information gaps

The main sources of information for the review process were:

- scientific and technical literature;
- 196 filled-in questionnaires from operators of plants for surface treatment using organic solvents and for wood and wood products preservation with chemicals;
- additional information from the TWG members;
- 2 512 comments on Draft 1 of the revised BREF;
- information gathered from site visits;
- outcomes of the workshop and the webinars mentioned above.

In total, approximately 400 documents have been posted in BATIS, and most of them have been referenced in the revised STS BREF.

Degree of consensus reached during the information exchange

At the final TWG meeting in December 2018, a high degree of consensus was reached on most of the BAT conclusions. However, 17 split views were expressed, which fulfil the conditions set out in Section 4.6.2.3.2 of Commission Implementing Decision 2012/119/EU. They are summarised in Table 20.2 below.

Table 20.2: Split views expressed

BAT conclusion / table number	Split view	View expressed by	Alternative proposed level (if any)
-	Reinstate BAT 4 of the revised D1 version in the BAT conclusions stating that 'The use of Cr(VI) in (pre)treatment and coating activities is not BAT' and amend its applicability.	EEB	NA
BAT 11	Restrict the continuous monitoring to stacks that are connected to an off-gas treatment system. Extend the application of Footnote (2) to any stack with a TVOC load up to 10 kg C/h and to unabated stacks.	ESVOC, ACEA, AFERA, CEFIC, ECCA, EWWG, FPE, INTERGRAF, MPE, ORGALIM, ASD, SK	NA
	Increase the monitoring frequency for any stack with a TVOC load < 10 kg C/h to once every 3 months. Amend Footnote (2) to 'In the case of a TVOC load of less than 4 tonnes/year over a 2-year period, or less than 0.1 kg C/h, or in the case of an unabated and stable TVOC load of less than 0.3 kg C/h, the monitoring frequency may be reduced to once every year provided the gas stream does not contain any CMR substances or SVHC.'	EEB	NA
	Increase the monitoring frequency for DMF emissions in waste gases to at least once every month.	EEB	NA
BAT 17, Table 18.1	Decrease the upper end of the BAT-AEL range for NO_X emissions in waste gases from the thermal treatment of off-gases.	DE	100 mg/Nm^3
BAT 18, Table 18.2	Increase the upper end of the BAT-AEL range for dust emissions for existing plants using wet scrubbers.	ACEA	5 mg/Nm^3
BAT 19, Table 18.3	Set separate BAT-AEPLs for the consumption of gas and of electricity.	INTERGRAF	For gas consumption: < 9 Wh/m^2 For electricity consumption: 4-8 Wh/m^2
BAT 21, Table 18.5	Decrease the upper end of the BAT-AEL range for TSS.	EEB	20 mg/l
BAT 21, Table 18.5 & 18.6	Decrease the upper end of the BAT-AEL range for nickel, for direct and indirect discharges.	EEB	0.2 mg/l
BAT 24, Table 18.7	Increase the upper end of the BAT-AEL range for total VOC emissions for the coating of passenger cars for existing plants.	UK, ACEA, SK	35 g/m^2
	Increase the upper end of the BAT-AEL range for total VOC emissions for the coating of passenger cars for new plants.	UK, ACEA	25 g/m^2
	Decrease the upper end of the BAT-AEL ranges for total VOC emissions for the coating of vehicles for existing plants.	EEB	Passenger cars: 20 g/m^2 Vans: 35 g/m^2 Trucks (truck chassis) & truck cabins: 20 g/m^2

			Buses: 100 g/m^2
BAT 25, Table 18.12	Increase the BAT-AEL for total VOC emissions for the coating of ships and yachts.	ORGALIM, PT	< 0.45 kg VOCs per kg of solid mass input
Table 18.14	Increase the upper end of the BAT-AEL range for fugitive VOC emissions for coil coating to 8 % of solvent input.	ECCA	6.4 % of solvent input
Table 18.15	Increase the upper end of the BAT-AEL range for VOC emissions in waste gases for coil coating.	ECCA	30 mg C/Nm^3
Table 18.19	Increase the upper end of the BAT-AEL range for VOC emissions in waste gases for the coating of textiles, foils and paper.	EURATEX	25 mg C/Nm^3
Table 18.36	Change the BAT-AEL range for VOC emissions in waste gases from creosote and solvent-based treatment.	EEB	< 1-4 mg C/Nm^3

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 Surface treatment using organic solvents including preservation of wood and wood products with chemicals in its meeting of 14 October 2019.

1. The Forum welcomed the draft Best Available Techniques (BAT) reference document for Surface treatment using organic solvents including preservation of wood and wood products with chemicals as presented by the Commission.
2. The Forum acknowledged the discussions held at its meeting of 14 October 2019 and agreed that the changes to the draft Best Available Techniques (BAT) reference document for Surface treatment using organic solvents including preservation of wood and wood products with chemicals, 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 surface treatment using organic solvents (including preservation of wood and wood products with chemicals) industries. The IED Article 75 Committee, through a written procedure lasting until 17 April 2020, gave a positive opinion on this draft Commission Implementing Decision.

Subsequently, the Commission Implementing Decision (EU) establishing best available techniques (BAT) conclusions for the surface treatment using organic solvents (including preservation of wood and wood products with chemicals) industries was adopted on 22 June 2020 and published in the Official Journal of the European Union (OJ L 414, 9.12.2020, p. 19).

Recommendations for future work

The information exchange revealed a number of issues that should be addressed during the next review of the STS BREF. The recommendations for the next review include the following:

- Related to the specific energy consumption:
  - to collect information on coating of vans, tracks, truck cabins and buses;
  - to collect information on coil coating when a third oven is used;
  - to collect information on heatset web offset printing;

  - to further specify the unit ‘m^2 printed area’ which is used for the BAT-AEPL of the printing sectors (heatset web offset printing, flexography and non-publication rotogravure, publication rotogravure printing).
- Related to the specific water consumption:
  - to collect information on coating of vans, trucks, truck cabins and buses;
  - to collect information for the sector of coating of vehicles in the unit ‘m^3 of water consumed per m^2 of surface coated’;
  - to collect information on coating of other cans including food cans for the printing and coating of metal packaging sector.
- Related to the extraction and treatment of off-gases:
  - to collect information on the conditions under which it is BAT to enclose STS activities or to extract and treat off-gases.
- Related to total VOC emissions from the coating of vehicles:
  - to collect information on coating of trucks and buses.
- Related to the specific waste quantity sent off site from the coating of vehicles:
  - to examine the waste quantity levels, especially in terms of waste generated and waste sent for disposal.
- Related to the coating of ships and yachts:
  - to collect information on total VOC emissions.
- Related to the coating of aircraft:
  - to collect information on the real VOC content of the coatings.
- Related to coil coating:
  - to collect information on the influence of the product type (e.g. of the coating thickness) on VOC emission levels in waste gases.
- Related to the manufacturing of adhesive tapes:
  - to collect information on total VOC emissions expressed as ‘per kg of solid mass input’ with a view to expressing the BAT-AEL for total VOC emissions in that unit;
  - to collect information on total VOC emissions and VOC emissions in waste gases from the manufacturing of plastic films used in temporary surface protection.
- Related to the manufacturing of winding wire:
  - to collect information on VOC emissions in waste gases from the coating of winding wires with an average diameter smaller than 0.1 mm.
- Related to heatset web offset printing:
  - to collect information on the use of the technique ‘waterless offset’.
- Related to preservation of wood and wood products with chemicals:
  - to collect information on the use of substitution techniques (i.e. chemical wood modification, thermal wood modification, supercritical CO_2 process);
  - to collect information on TVOC emissions in waste gases and the composition of waste gases from both creosote and solvent-based treatment.

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).

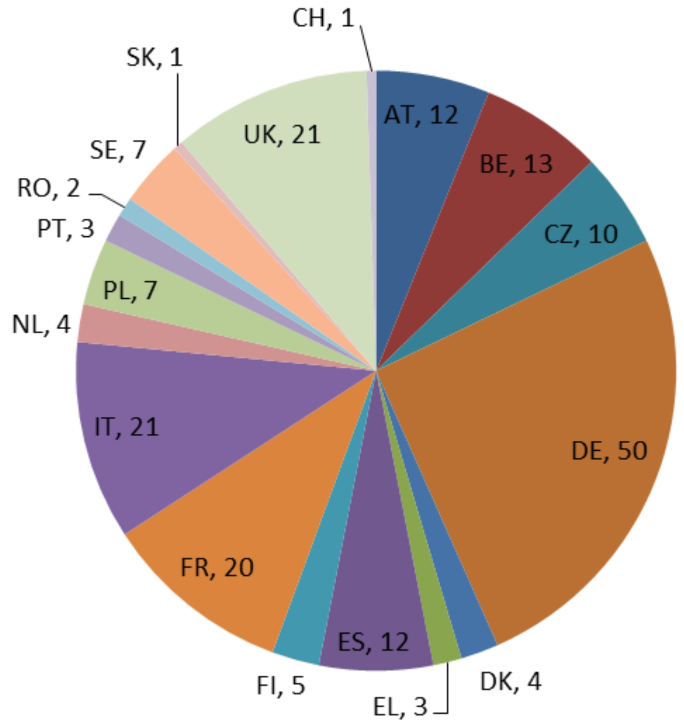
21 ANNEXES

21.1 Data collection and data presentation

21.1.1 Distribution of plants participating in the STS/WPC data collection per sector and per country

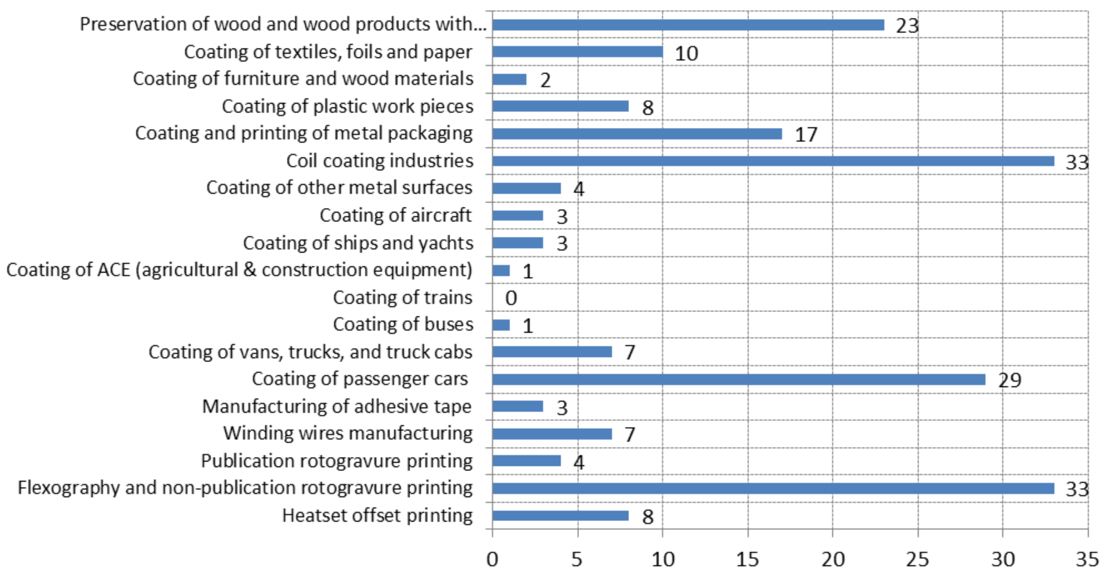
A total of 196 plants (including plants for the WPC activity) across Europe participated in the STS/WPC data collection and submitted filled-in questionnaires.

In the following figures, the distribution of plants that participated in the STS/WPC data collection (per country and per sector) is presented.



Source: [155, TWG, 2016] [236, TWG 2017]

Figure 21.1: Number of plants participating in the STS/WPC data collection per country



Source: [155, TWG, 2016] [236, TWG 2017]

Figure 21.2: Number of plants participating in the STS/WPC data collection per sector

21.1.2 List of plants participating in the STS data collection

Code number	Main STS sector	Country	Installation / Site / Line name	Company name	Town
001	Heatset web offset printing	ES	Altair	Altair	Seseña (Toledo)
002	Heatset web offset printing	ES	ROTOCOBRHI SAU	ROTOCOBRHI SAU	Tres Santos - Madrid
003	Heatset web offset printing	IT	Coptip Industrie Grafiche Soc. Coop. A R.L.	Coptip Industrie Grafiche Soc. Coop. A R.L.	Modena (MO)
004	Heatset web offset printing	PT	Lidergraf	Lidergraf	Vila do Conde
005	Flexography and non-publication rotogravure printing	AT	Jodl Verpackungen GmbH	Jodl Verpackungen GmbH	Lenzing
006	Flexography and non-publication rotogravure printing	AT	TANN Papier GmbH	TANN Papier GmbH	Traun
007	Flexography and non-publication rotogravure printing	AT	PAWAG Verpackungen GmbH	PAWAG Verpackungen GmbH	Wolfurt
008	Flexography and non-publication rotogravure printing	AT	Lenzing Plastics GmbH	Lenzing Plastics GmbH	Lenzing
009	Flexography and non-publication rotogravure printing	AT	Constantia Teich Austria	Constantia Teich Austria	Mühlhofen
010	Flexography and non-publication rotogravure printing	AT	Mondi	Mondi	Korneuburg
011	Flexography and non-publication rotogravure printing	BE	Chiyoda Europe Genk	Chiyoda Europe	Genk
012	Flexography and non-publication rotogravure printing	DE	Constantia Hueck Weiden	Hueck	Pirkmühle
013	Flexography and non-publication rotogravure printing	DE	Constantia-HuN-Hann-Muenden	Haendler & Natermann GmbH	Hann Munden
014	Flexography and non-publication rotogravure printing	DE	Rahning GmbH & Co. KG	Rahning GmbH & Co. KG	Bunde
015	Flexography and non-publication rotogravure printing	DE	AF Rinteln	Amcor Flexibles	Rinteln
016	Flexography and non-publication rotogravure printing	DK	Danapak Flexibles A/S	Danapak Flexibles A/S	Slagelse
017	Flexography and non-publication rotogravure printing	EL	Komotini's Factory	Alfa Beta Roto SA	Komotini, Thrace
018	Flexography and non-publication rotogravure printing	ES	ENPLATER	Envases Plásticos del Ter, SA	Torroella de Montgrí
019	Flexography and non-publication rotogravure printing	FR	Amcor Tobacco Packaging France SAS	AMCOR	Ungersheim
020	Flexography and non-publication rotogravure printing	IT	Goglio Daverio	Goglio S.p.A.	Daverio (VA)

021	Flexography and non-publication rotogravure printing	IT	Gruppo Fabbri Vignola S.p.A.	Gruppo Fabbri Vignola S.p.A.	Vignola (MO)
022	Flexography and non-publication rotogravure printing	IT	Safta S.p.A.	Gualapack Group	Piacenza
023	Flexography and non-publication rotogravure printing	IT	Centroplast S.p.A.	Centroplast S.p.A.	Meldola (FC)
024	Flexography and non-publication rotogravure printing	IT	Flexible, printed, laminated and cut packaging production plant	Sidac S.p.A.	Forlì
025	Flexography and non-publication rotogravure printing	IT	AF Lugo	Amcor Flexibles	Lugo di Vicenza
026	Flexography and non-publication rotogravure printing	NL	Flexoplast BV	Flexoplast BV	Harligen
027	Flexography and non-publication rotogravure printing	PL	Emsur Polska SP. Z.O.O.	Emsur Polska SP. Z.O.O.	Józefów
028	Flexography and non-publication rotogravure printing	PL	Constantia Teich Poland	Teich Poland	Rogoviec
030	Publication rotogravure printing	FI	Helprint Oy	Circleprinters	Mikkeli
031	Publication rotogravure printing	UK	Bertelsmann Printing Group	Prinovis UK	Liverpool
032	Winding wires manufacturing	AT	Asta Elektrodraht GmbH & Co KG	Asta Elektrodraht GmbH & Co KG	Oed
033	Winding wires manufacturing	DE	Schwering & Hasse Elektrodraht	Schwering & Hasse	Lügde
034	Winding wires manufacturing	DE	ESSEX Germany GmbH	ESSEX Germany GmbH	Bramsche
035	Winding wires manufacturing	SE	Dahrentrad	Dahrentrad	Jonslund
036	Manufacturing of adhesive tape	AT	Müroll Papier und Kunststoffverarbeitung GmbH_LINE_1	Müroll Papier und Kunststoffverarbeitung GmbH	Frastanz
038	Coating of passenger cars	AT	Magna Steyr Fahrzeugtechnik AG	Magna Steyr Fahrzeugtechnik AG	Graz
039	Coating of passenger cars	BE	Volvo Cars Gent	Volvo Cars Gent	Ghent
040	Coating of passenger cars	BE	Audi Brussels	VWAG - Audi	Brussels
041	Coating of passenger cars	CZ	Hyundai Manufacturing Czech S.R.O.	Hyundai Manufacturing Czech S.R.O.	Nižní lhoty
042	Coating of passenger cars	CZ	Paint shop of the Skoda plant Mladá Bolelav	Škoda Auto A.S.	Mladá Boleslav
043	Coating of passenger cars	CZ	Paint shop of the Skoda plant Kvasiny	Škoda Auto A.S.	Kvasiny
044	Coating of passenger cars	CZ	Toyota Peugeot Citroen Automobile Czech, S.R.O.	Toyota Peugeot Citroen Automobile Czech, S.R.O.	Kolín
045	Coating of passenger cars	DE	VWAG - VW Emden	VWAG - VW	Emden
046	Coating of passenger cars	DE	VWAG - VW Hannover	VWAG - VW	Hannover

047	Coating of passenger cars	DE	VWAG Leipzig	VWAG - Porsche	Leipzig
048	Coating of passenger cars	DE	BMW Regensburg	BMW Group	Regensburg
049	Coating of passenger cars	DE	General Motors Europe Rüsselsheim	General Motors Europe	Rüsselsheim
050	Coating of passenger cars	DE	Daimler AG Sindelfingen	Daimler AG	Sindelfingen
051	Coating of passenger cars	ES	PSA Peugeot Citroen Madrid	PSA Peugeot Citroen	Madrid
052	Coating of passenger cars	ES	PSA Peugeot Citroen Vigo	PSA Peugeot Citroen	Vigo
053	Coating of passenger cars	ES	Renault Valladolid Montaje	Renault	Valladolid
054	Coating of passenger cars	ES	Volkswagen Navarra, S.A.U.	Volkswagen Navarra, S.A.U.	Arazuri
055	Coating of passenger cars	ES	Renault Palencia	Renault	Villamuriel de Cerrato (Palencia)
056	Coating of passenger cars	ES	Zaragoza Opel plant	GM Spain	Zaragoza
057	Coating of passenger cars	ES	Seat Martorell	Seat, S.A	Martorell
058	Coating of passenger cars	FR	Rennes / Chartres de Bretagne	PSA Peugeot Citroen	Rennes / Chartres de Bretagne
059	Coating of passenger cars	IT	FCA Melfi Plant	FCA Melfi S.p.A.	Melfi (PZ)
060	Coating of vans, trucks, and truck cabs	PL	Volkswagen Poznań Sp. Z O.O.	Volkswagen Poznań Sp. Z O.O.	Poznań
061	Coating of passenger cars	PT	Volkswagen Autoeuropa	Volkswagen Autoeuropa	Palmela
062	Coating of passenger cars	RO	Ford of Europe Craiova	Ford of Europe	Craiova
063	Coating of passenger cars	RO	Renault SA Mioveni	Renault SA	Mioveni
064	Coating of passenger cars	UK	General Motors Europe Ellesmere Port	General Motors Europe	Ellesmere Port
065	Coating of passenger cars	UK	Nissan Sunderland	Nissan Motor Company	Sunderland
066	Coating of vans, trucks, and truck cabs	AT	MAN Truck & Bus Österreich AG	MAN Truck & Bus Österreich AG	Steyr
067	Coating of vans, trucks, and truck cabs	DE	Daimler AG Düsseldorf	Daimler AG	Düsseldorf
068	Coating of vans, trucks, and truck cabs	DE	Daimler AG Wörth	Daimler AG	Wörth
069	Coating of vans, trucks, and truck cabs	FR	Renault Sovab	Renault	Batilly
070	Coating of vans, trucks, and truck cabs	IT	Sevel S.p.A. Atessa Plant	Sevel S.p.A.	Atessa (CH)

071	Coating of vans, trucks, and truck cabs	IT	Iveco Suzzara	CNH Industrial	Suzzara (MN)
072	Coating of buses	DE	Daimler AG Neu-Ulm	Daimler AG	Neu-Ulm
073	Coating of agricultural and construction equipment	UK	JCB World Headquarters	JC Bamford Excavators Limited	Rocester
074	Coating of ships and yachts	FI	Arctech Helsinki Shipyard Oy Yard	Arctech Helsinki Shipyard Oy	Helsinki
075	Coating of ships and yachts	PT	Mitrena Shipyard	Lisnave - Estaleiros Navais, SA	Setúbal
076	Coating of ships and yachts	UK	A&P Falmouth Ltd	A&P Falmouth Ltd	Falmouth
077	Coating of aircraft	DE	Airbus Hamburg-Finkenwerder	Airbus Operations GmbH	Hamburg
078	Coating of aircraft	UK	Airbus Operations Ltd Broughton	Airbus Operations Ltd	Broughton
079	Coating of other metal surfaces	DE	thyssenkrupp Rasselstein GmbH TLA2 - a coating line for tinplate sheets	thyssenkrupp Rasselstein GmbH	Andernach
080	Coating of other metal surfaces	DE	thyssenkrupp Steel Europe AG Coating Line for Heavy Plates (Entzunderungs- und Farbspritzanlage - EFA Hüttenheim)	thyssenkrupp Steel Europe AG	Duisburg
081	Coil coating industries	AT	Voestalpine Stahl GmbH line 1 Linz	Voestalpine Stahl GmbH	Linz
082	Coil coating industries	AT	Voestalpine Stahl GmbH line 2 Linz	Voestalpine Stahl GmbH	Linz
083	Coil coating industries	BE	Arcelor Mittal Belgium Geel	Arcelor Mittal Belgium	Geel
084	Coil coating industries	BE	Arcelormittal Belgium Gent	Arcelormittal Belgium	Ghent
085	Coil coating industries	DE	BBA-2 Duisburg-Beeckerwerth	ThyssenKrupp Steel	Duisburg-Beeckerwerth
086	Coil coating industries	DE	EBA2 Beeckerwerth - Duisburg	ThyssenKrupp Steel	Duisburg-Beeckerwerth
087	Coil coating industries	DE	Kreuztal BBA3	ThyssenKrupp Steel	Kreuztal-Eichen
088	Coil coating industries	DE	Ferdirf - Duisburg BBA4	ThyssenKrupp Steel	Duisburg
089	Coil coating industries	DE	Bochum BNO	ThyssenKrupp Steel	Bochum
090	Coil coating industries	DE	Salzgitter	Salzgitter Flachstahl GmbH	Salzgitter
091	Coil coating industries	DE	Thyssenkrupp Rasselstein GmbH BEA - coating and laminating line for tinplate coils	Thyssenkrupp Rasselstein GmbH	Andernach
092	Coil coating industries	EL	Elval Oinofyta plant	Elval SA	Oinofyta
093	Coil coating industries	EL	VEPAL Thiva Plant	VEPAL SA	Thiva

094	Coil coating industries	FI	SSAB Europe Oy Hämeenlinna Coil Coating line	SSAB	Hämeenlinna
095	Coil coating industries	FI	SSAB Europe Oy Kankaanpää Coil Coating line	SSAB	Kankaanpää
096	Coil coating industries	FR	Arconic ALCOA	Arconic ALCOA	Merxheim
097	Coil coating industries	FR	ArcelorMittal Montataire	ArcelorMittal	Montataire
098	Coil coating industries	IT	Marcegaglia Carbon Steel S.p.A. Ravenna	Marcegaglia Carbon Steel S.p.A.	Ravenna
099	Coil coating industries	IT	ArcelorMittal Piombino	ArcelorMittal	Piombino
100	Coil coating industries	NL	Euramax SPL Roermond	Euramax	SPL Roermond
101	Coil coating industries	NL	Hunter Douglas Europe Rotterdam	Hunter Douglas Europe	Rotterdam
102	Coil coating industries	NL	Tata Steel IJmuiden	Tata Steel	IJmuiden
103	Coil coating industries	PL	ArcelorMittal Poland S.A. Organic coating line 1	ArcelorMittal Poland S.A.	Świętochłowice
104	Coil coating industries	PL	ArcelorMittal Poland S.A. Organic coating line 2	ArcelorMittal Poland S.A.	Świętochłowice
105	Coil coating industries	SK	U.S. Steel Košice	U.S. Steel	Košice
106	Coil coating industries	UK	Tata Steel Deeside, Flintshire	Tata Steel	Deeside, Flintshire
108	Coating and printing of metal packaging	CZ	Ardagh Skřivany	Ardagh Metal Packaging Czech Republic s.r.o.	Skřivany
109	Coating and printing of metal packaging	CZ	ALLTUB CEBTRAL EUROPE Kolin	ALLTUB CEBTRAL EUROPE	Kolin
110	Coating and printing of metal packaging	DE	Ardagh Metal Packaging - Erftstadt	Ardagh	Erftstadt
112	Coating and printing of metal packaging	DK	Glud & Marstrand A/S Odense	Glud & Marstrand A/S	Odense C
113	Coating and printing of metal packaging	FR	Ardagh - La flèche	Ardagh - La flèche	La flèche
114	Coating and printing of metal packaging	FR	Crown - Custines	Crown - Custines	Custines
115	Coating and printing of metal packaging	FR	Crown Emballage France Crown - Nantes	Crown Emballage France Crown - Nantes	Nantes
116	Coating and printing of metal packaging	IT	CROWN AEROSOLS ITALIA S.R.L.	CROWN AEROSOLS ITALIA S.R.L.	Spilamberto (MO)
117	Coating and printing of metal packaging	SE	Ball Beverage Packaging Fosie AB	Ball Beverage Packaging Fosie AB	Malmö
118	Coating and printing of metal packaging	UK	Botcherby	CROWN Packaging UK plc	Carlisle
119	Coating and printing of metal packaging	UK	Braunstone	CROWN Packaging UK plc	Leicester

120	Coating and printing of metal packaging	UK	Sutton-in-Ashfield	CROWN Aerosols UK Ltd	Sutton-in-Ashfield
121	Coating and printing of metal packaging	UK	Ardagh Metal Packaging Norwich	Ardagh Metal Packaging	Norwich
122	Coating and printing of metal packaging	UK	L11 & L17 Scunthorpe	Can Pack UK	Scunthorpe
123	Coating and printing of metal packaging	UK	Ardagh group Wrexham	Ardagh Group	Wrexham
124	Coating and printing of metal packaging	UK	Ardagh group Rugby	Ardagh Group	Rugby
125	Coating and printing of metal packaging	UK	Ball Beverage Packaging Europe - Milton Keynes	Ball Beverage Packaging Europe BBP	Milton Keynes
126	Coating of plastic work pieces	BE	Plastal Gent	Plastal	Ghent
127	Flexography and non-publication rotogravure printing	CZ	FATRA, a.s. Napajedla	FATRA, a.s.	Napajedla
128	Coating of plastic work pieces	CZ	Automotive Lighting s.r.o. Jihlava	Automotive Lighting s.r.o.	Jihlava
129	Coating of plastic work pieces	CZ	PLAKOR CZECH s.r.o.	PLAKOR CZECH s.r.o.	Ostrava
130	Coating of plastic work pieces	CZ	Magna Exteriors (Bohemia) s.r.o. Librec	Magna Exteriors (Bohemia) s.r.o.	Librec
131	Coating of plastic work pieces	IT	Stabilimento V2 Vulcaflex SpA	Vulcaflex SpA	Cotignola (RA)
132	Coating of plastic work pieces	SE	Plastal Arendal	Plastal Industri AB	Gothenburg
133	Flexography and non-publication rotogravure printing	BE	AMCOR FLEXIBLES TRANSPAC GENT BVBA	AMCOR FLEXIBLES TRANSPAC GENT BVBA	Ghent
134	Coating of textiles, foils and paper	BE	Sioen Ardooie	Sioen Fabrics SA	Ardooie
135	Coating of textiles, foils and paper	BE	Sioen Mouscron	Sioen Fabrics SA	Mouscron
136	Coating of textiles, foils and paper	BE	Vetex Ingelmunster	Vetex	Ingelmunster
137	Coating of textiles, foils and paper	DE	Eurofoil Berlin	Eurofoil	Berlin
138	Coating of textiles, foils and paper	PL	Sanwil Polska sp z o.o. Przemyśl	Sanwil Polska sp z o.o.	Przemyśl
139	Coating of textiles, foils and paper	UK	Wrexham Facility	Coveris Advanced Coatings	Wrexham
140	Coating of textiles, foils and paper	UK	Dartex Coatings Long Eaton	Dartex Coatings	Long Eaton
141	Coating of furniture and wood materials	SE	IKEA and SE TWG members	IKEA Industry Älmhult AB	Älmhult
142	Winding wires manufacturing	Other (CH)	CH - Electrisola Feindraht	CH - Electrisola Feindraht	
143	Publication rotogravure printing	FR	BurdaDruck France Thann	BurdaDruck France	Thann

144	Coil coating industries	DE	Novelis Deutschland GmbH	Novelis Deutschland GmbH	Göttingen
145	Coating of aircraft	FR	Airbus Toulouse	Airbus Operations France	Toulouse
146	Coating of passenger cars	FR	Renault Douai	Renault Douai	Douai
147	Coating of vans, trucks, and truck cabs	FR	Renault Maubeuge	Renault Maubeuge	Maubeuge
148	Heatset web offset printing	DE	GD Gotha Druck und Verpackung GmbH & Co. KG	GD Gotha Druck und Verpackung GmbH & Co. KG	Günthersleben-Wechmar
149	Publication rotogravure printing	DE	Burda Druck GmbH	Burda Druck GmbH	Offenburg
150	Heatset web offset printing	DE	WKS-Kraft-Schloetels_Essen	WKS-Kraft-Schloetels	Wassenberg
151	Coating of textiles, foils and paper	DE	BSN medical GmbH	BSN medical GmbH	Hamburg
152	Coil coating industries	FR	Tata Steel Maubeuge	Tata Steel	Maubeuge
153	Coil coating industries	FR	NLMK Strasbourg	NLMK Strasbourg	Strasbourg
154	Heatset web offset printing	DE	Niedermayer Regensburg	Franz Anton Niedermayr Graphische Kunstanstalt GmbH & Co.KG	Niedermayer_Regensburg
155	Flexography and non-publication rotogravure printing	DE	Bischof+Klein-Lengerich	Bischof+Klein-Lengerich	Lengerich
156	Manufacturing of adhesive tape	DE	Tesa Hamburg	tWHH - tesa Werk Hamburg GmbH	Hamburg
157	Flexography and non-publication rotogravure printing	DE	Mondi Halle	Mondi Halle GmbH	Halle in Westfalen
158	Coil coating industries	DE	Huehoco	Huehoco	Wuppertal
159	Flexography and non-publication rotogravure printing	DE	Debatin Bruchsal	Anton Debatin GmbH	Bruchsal
160	Winding wires manufacturing	ES	Ederfil Becker, Koop. E. (Legorreta)	Ederfil Becker, Koop.E.	Legorreta
161	Flexography and non-publication rotogravure printing	FR	Amcor Flexibles Montreuil-Bellay	Amcor Flexibles Montreuil-Bellay	Montreuil-Bellay
162	Heatset web offset printing	DE	Neef + Stumme premium printing GmbH & Co. KG	Neef + Stumme premium printing GmbH & Co. KG	Wittingen
163	Manufacturing of adhesive tape	DE	monta Klebebandwerk GmbH Immenstadt	monta Klebebandwerk GmbH Immenstadt	Immenstadt im Allgäu
164	Coil coating industries	DE	Coil Coating plant 3 Hydro Aluminium Rolled Products GmbH	Hydro Aluminium Rolled Products GmbH	Grevenbroich
165	Coating of other metal surfaces	BE	ALRO N.V.	ALRO N.V.	Dilsen-Stokkem
166	Coating of textiles, foils and paper	BE	Seyntex N.V. - Seyntexlaan 1	Seyntex N.V.	Tielt

167	Winding wires manufacturing	IT	IRCE S.p.A., Imola (BO)	IRCE S.p.A.	Imola (BO)
168	Flexography and non-publication rotogravure printing	IT	Masterpack S.p.A.	Masterpack S.p.A.	Veruno (NO) Piemonte
169	Shoes manufacturing	IT	I.P.R S.p.A.	I.P.R. S.p.A.	Civitanova Marche
170	Shoes manufacturing	IT	Mondial Suole S.p.A.	Mondial Suole S.p.A.	Porto Recanati
171	Coating of textiles, foils and paper	IT	Chiorino S.p.A.	Chiorino S.p.A.	Biella Piedmont
172	Coil coating industries	BE	ArcelorMittal Liege	ArcelorMittal	Ivoz-Ramet Liege
173	Coil coating industries	ES	ArcelorMittal Lesaka	ArcelorMittal España S.A.	Lesaka
174	Flexography and non-publication rotogravure printing	DE	Coveris Halle	Coveris Flexibles Deutschland GmbH	Halle in Westfalen
175	Flexography and non-publication rotogravure printing	DE	Coveris Warburg	Coveris Flexibles Deutschland GmbH	Warburg
176	Coating of other metal surfaces	DE	EOT - Eibach Oberflächentechnik GmbH	Eibach Oberflächentechnik GmbH	Lüdenscheid
177	Coating of furniture and wood materials	DE	Egger Brilon	Egger Holzwerkstoffe Brilon GmbH & Co. KG	Brilon
-	Coating of buses	ES	Irizar S.Coop.-Lezeta	Irizar S.Coop	Ormaiztegi

21.1.3 List of plants participating in the WPC data collection

Abbreviation / Code	Installation/Site name	Company name	Country	Town	Treatment type
FR-1	SNCF E.I.V	SNCF	FR	Biars sur Cere	Creosote
DE-5	DB Schwellenwerk Schwandorf	DB Netz AG Werk Oberbaustoffe Witten	DE	Schwandorf	Creosote
PL-1	Track Tec Lipa Sp. z o.o.	Track Tec Lipa Sp. z o.o.	PL	Lipa	Creosote Water-based
UK-1	Calders & Grandidge	Calders & Grandidge	UK	Boston	Creosote Water-based
SE-1	Octowood	Octowood AB	SE	Kälarne	Creosote Water-based
FR-2	FRANCE BOIS IMPREGNES	FRANCE BOIS IMPREGNES	FR	Boisset Les Montrond	Creosote Water-based
DE-9	Imprägnierwerk Wülknitz	Imprägnierwerk Wülknitz GmbH	DE	Wülknitz	Creosote Water-based
DE-8	Zimmer Zäune GmbH	Zimmer Zäune GmbH	DE	Maring-Noviand	Creosote Water-based
DK-1	Frøslev Træ A/S	Frøslev Træ A/S	DK	Padborg	Water-based
UK-2	Arch Timber Protection	Lonza	UK	Wolverhampton	Water-based
UK-3	Sodra Wood Dundee (was Crown Timber)	Sodra Wood Dundee	UK	Dundee	Water-based
UK-4	Windymains Sawmills	Glennon Brothers	UK	Humbie	Water-based
IT-1	Stella S.p.A	Stella S.p.A. ad Unico Socio	IT	Cuneo	Water-based
SE-2	Bergs Timber Bitus	Bergs Timber Production AB	SE	Nybro	Water-based
SE-3	Varberg Timber AB	Varberg Timber AB	SE	Varberg	Water-based
FR-3	Société Forestière ORIEL	ORIEL	FR	Corcieux	Water-based
FR-4	PIVETEAU BOIS	PIVETEAU BOIS	FR	Saint Florence	Water-based
FI-1	Ab Påras Oy	Ab Påras Oy	FI	Kruunupyy	Water-based
DE-6	Fürstenberg-THP GmbH / Hüfingen	Fürstenberg-THP GmbH	DE	Hüfingen	Water-based
IT-2	Margaritelli Ferroviaria SpA /Rodallo	Margaritelli Ferroviaria SpA /Rodallo	IT	Rodallo	Water-based
DE-7	Klenk Holz AG, Werk Baruth	Klenk Holz AG, Werk Baruth	DE	Baruth/Mark	Water-based
FR-5	ISB France	Groupe ISB - PBM Import	FR	Saint-Malo	Water-based
DK-2	Superwood A/S	Superwood A/S	DK	Hampen	CO_2

21.1.4 Data presentation for emissions in waste gases

In the sector-specific sections, graphs showing the reported levels for emissions of VOCs, dust NO_X and CO in waste gases are included.

In general and based on the applied monitoring frequency, the following approach for the presentation of reported emission data for VOCs, NO_X and CO has been followed:

- For periodic monitoring, the monitoring frequency is shown as ‘A/y’, where A is the number of measurements conducted per year (y).
- For plants/emission points reporting a monitoring frequency of once per year (1/y) or less (e.g. 1/2y, 1/3y), only the reported average concentration values are shown in the relevant graphs, as in this case the maximum and minimum are assumed to represent the highest and lowest values measured in the same measurement campaign.
- For plants/emission points reporting a monitoring frequency of twice per year (2/y), only the reported minimum and maximum concentration values, which correspond to the two average values of the measurement campaigns, are shown in the relevant graphs.
- For plants/emission points reporting a monitoring frequency of three times per year (3/y) or more (e.g. 4/y, 12/y, continuous), all reported concentration values (i.e. average, minimum, maximum and 95th percentile where available) are shown in the relevant graphs.

21.2 Information on the reported use of BAT in the various STS sectors

[262, ESVOC et al. 2019]

The following table contains information as submitted by the STS TWG on the current use of BAT that are discussed in this document for the various STS sectors. The information in this table represents the available knowledge of the STS TWG on which BAT are currently used (at the time of writing) in the various STS sectors in the Member States of the European Union. It cannot be considered an indication of the applicability of those BAT as per IED Article 3(10)(b). Applicability information can be found in the applicability clauses of the BAT conclusions chapter of this document (Chapter 18) as well as in the detailed descriptions of the techniques in Chapter 17 and/or in Sections X.4 for the sector-specific techniques to be considered in the determination of the BAT.

Table 21.1: Information on the reported use of BAT in the various STS sectors

BREF section number	Title of technique	Coating of vehicles					Coating of other metal and plastic surfaces	Coil coating	Winding wire manufacturing	Coating and printing of metal packaging	Heatset web offset printing	Flexography and non-publication rotogravure printing	Publication rotogravure printing	Coating of ships and yachts	Coating of aircraft	Adhesive tape manufacturing	Coating of textiles, foils and paper	Coating of wooden surfaces	Relevant BAT number in Chapter 18
		Passenger cars	Vans	Trucks	Truck cabins	Buses													
17.2.1	Preparation and implementation of a plan for the prevention and control of leaks and spillages	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	5a
17.2.2.1	Sealing or covering of containers and bunded storage area	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	5b
17.2.2.2	Minimisation of storage of hazardous materials in production areas	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	5c
17.2.3.1	Techniques to prevent leaks and spillages during pumping	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	5d
17.2.3.2	Techniques to prevent overflows during pumping	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	5e
17.2.3.3	Capture of VOC vapour during solvent-containing material delivery	N	N	N	N	N	U	U	U	U	N	U	U	N	N	U	U	U	5f
17.2.3.4	Containment for spills and/or rapid take-up when handling solvent-containing materials	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	5g
17.2.4.1	Advanced mixing systems	N	N	N	N	N	U	U	N	U	N	U	N	N	U	U	U	U	6b
17.2.4.2	Centralised supply of VOC-containing materials (e.g. inks, coatings, adhesives, cleaning agents)	U	U	U	U	U	U	U	U	U	U	U	U	N	U	U	N	U	6a
17.2.4.3	Supply of VOC-containing materials (e.g. inks, coatings, adhesives, cleaning agents) at the point of application using a closed system	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	6c
17.2.5	Automation of colour change	U	U	NI	U	U	U	N	N	N	N	U	N	N	N	N	N	U	6d
17.2.5	Robot application	U	U	U	U	U	U	N	N	N	N	N	N	U	U	N	N	U	7o
17.2.5	Machine application	U	U	N	U	U	U	N	N	U	N	N	N	U	U	N	N	U	7p
17.2.5.1	Soft purge in spraying	U	N	N	N	N	N	N	N	N	N	N	N	N	U	N	N	U	6f
17.2.6	Identification of critical equipment	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	13a
17.2.6	Inspection, maintenance and monitoring	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	13b
17.3.2	Implementation of a solvent tracking system	U	U	U	U	U	U	U	U	U	U	U	N	U	U	U	U	U	10b
17.3.3	Full identification and quantification of the relevant solvent inputs and outputs, including the associated uncertainty	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	10a

17.3.4	Monitoring of changes that may influence the uncertainty of the solvent mass balance data	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	10c
17.4.1	Water management plan and water audits	U	U	U	U	U	U	U	N	U	U	U	U	U	N	U	N	U	20a
17.4.3	Reverse cascade rinsing	U	U	U	U	U	U	U	N	U	N	N	U	N	N	N	N	U	20b
17.4.4	Reuse and/or recycling of water	U	U	U	U	U	U	U	N	U	N	N	U	U	N	N	N	U	20c
17.5.1	Energy efficiency plan	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	19a
17.5.2	Energy balance record	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	19b
17.5.3	Thermal insulation of tanks and vats containing cooled or heated liquids, and of combustion and steam systems	U	U	U	U	U	U	U	U	U	U	U	N	N	U	U	N	U	19c
17.5.4	Heat recovery by co-generation – CHP (combined heat and power) or CCHP (combined cooling, heat and power)	N	N	N	N	N	U	N	U	U	N	U	U	N	U	U	N	U	19d
17.5.5	Heat recovery from hot gas streams	U	U	U	U	U	U	U	U	U	U	U	U	N	U	U	U	U	19e
17.5.7	Flow adjustment of process air and off-gases	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	19f
17.5.8	Spray booth off-gas recirculation	U	U	N	U	N	U	N	N	N	N	N	N	N	U	N	N	U	19g
17.5.9	Optimised circulation of warm air in a large-volume curing booth using an air turbulator	N	N	N	N	N	U	N	N	U	N	N	N	N	N	N	N	U	19h
17.6.1	Use of raw materials with a low environmental impact	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	3a
17.6.1	Use of substances which are not VOCs or are VOCs of a lower volatility	U	U	U	U	U	U	U	N	U	U	U	N	U	U	U	N	U	4h
17.6.2	Optimisation of the use of solvents in the process	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	3b
17.6.2.1	Colour grouping	U	U	U	U	N	U	U	N	U	N	U	N	N	N	U	N	U	6e
17.7.2.1	Use of high-solids solvent-based paints / coatings / varnishes / inks / adhesives	U	U	U	U	U	U	U	U	U	N	U	U	U	U	U	N	U	4a
17.7.2.2	Use of water-based paints / coatings / inks / varnishes / adhesives	U	U	U	U	U	U	U	N	U	N	U	N	U	U	U	U	U	4b
17.7.2.3	Use of radiation-cured inks / coatings / paints / varnishes / adhesives	N	N	N	N	N	U	N	N	U	N	U	N	N	U	U	N	U	4c
17.7.2.4	Use of solvent-free two-component adhesives	U	U	U	U	U	N	N	N	N	N	U	N	U	U	U	N	U	4d
17.7.2.5	Use of hot-melt adhesives	U	U	U	U	U	N	N	N	N	N	U	U	N	U	U	U	U	4e
17.7.2.6	Use of powder coating	N	N	U	U	N	U	U	N	U	N	N	N	N	N	N	N	U	4f
17.7.2.8	Use of laminate film for web or coil coating	N	N	N	N	N	U	U	N	U	N	U	N	N	U	U	U	U	4g
17.7.3.1	Roller coating	N	N	N	N	N	U	U	N	U	N	N	N	U	U	U	N	U	7a
17.7.3.2	Doctor blade over roller	N	N	N	N	N	U	U	N	U	N	N	N	U	N	U	U	U	7b

17.7.3.3	No-rinse (dry-in-place) application in the coating of coil	N	N	N	N	N	N	U	N	N	N	U	N	N	N	U	N	U	7c
17.7.3.4	Curtain coating (casting)	N	N	N	N	N	U	N	N	U	N	N	N	N	N	U	N	U	7d
17.7.3.6	Electrocoating (e-coat)	U	U	U	U	U	U	N	N	U	N	N	N	U	N	N	N	N	7e
17.7.3.5	Flooding	U	U	N	N	N	U	N	U	N	N	N	N	N	N	N	N	U	7f
17.7.3.7	Co-extrusion	N	N	N	N	N	N	N	N	N	N	U	N	N	N	U	N	U	7g
17.7.3.8	Air-assisted airless spraying	U	U	U	U	U	U	N	N	U	N	N	N	U	N	N	N	U	7h
17.7.3.9	Pneumatic atomisation with inert gases	U	N	NI	N	N	U	N	N	N	N	N	N	N	N	N	N	N	7i
17.7.3.10	High-volume low-pressure (HVLP) atomisation	U	U	U	U	U	U	N	N	N	N	N	N	N	NI	N	N	U	7j
17.7.3.11	Electrostatically atomisation (fully automated)	U	U	N	U	NI	U	N	N	N	N	N	N	U	NI	N	N	N	7k
17.7.3.12	Electrostatically assisted air or airless spraying	U	U	U	U	U	U	N	N	U	N	N	N	N	U	N	N	U	7l
17.7.3.13	Hot spraying	N	N	N	N	N	U	N	N	N	N	N	N	U	N	N	N	U	7m
17.7.3.14	'Spray, squeegee and rinse' application in the coating of coil	N	N	N	N	N	N	U	N	N	N	N	N	N	N	N	N	N	7n
17.8.1	Inert gas convection drying/curing	N	N	N	N	N	U	N	N	N	N	U	N	N	N	U	N	N	8a
17.8.2	Induction drying/curing	N	N	N	N	N	U	U	N	U	N	N	N	N	N	N	N	N	8b
17.8.3	Microwave and HF drying	N	N	N	N	N	U	N	N	N	N	U	N	N	U	N	N	U	8c
17.8.5	Radiation curing	N	N	N	N	U	U	U	U	U	N	U	N	N	U	U	N	U	8d
17.8.4	Combined convection / IR radiation drying	U	U	U	U	U	U	N	N	U	N	N	N	N	U	U	U	U	8e
17.8.6	Convection drying/curing combined with heat recovery	U	U	U	U	U	U	U	U	U	U	U	U	N	U	N	N	U	8f
17.9.2	Protection of spraying areas and equipment	U	U	U	U	U	U	N	N	U	N	U	U	U	U	N	N	U	9a
17.9.3	Solids removal prior to complete cleaning	U	U	U	U	U	U	U	U	U	N	U	U	U	U	N	U	U	9b
17.9.4	Manual cleaning with pre-impregnated wipes	U	U	U	U	U	U	U	U	U	N	U	N	N	U	N	N	U	9c
17.9.5	Use of low-volatility cleaning agents	U	U	U	U	U	U	U	U	U	U	U	U	N	U	N	U	U	9d
17.9.6	Water-based cleaning	U	U	U	U	U	U	U	U	U	N	U	N	U	U	N	N	U	9e
17.9.7	Enclosed washing machines	N	N	N	N	N	U	N	N	U	N	U	U	N	U	N	N	U	9f
17.9.8	Purging with solvent recovery	U	U	U	U	U	U	U	N	N	N	U	N	U	U	N	U	U	9g
17.9.9	Cleaning with high-pressure water spray	U	U	U	U	U	U	U	N	N	N	U	N	U	U	N	N	U	9h
17.9.10	Ultrasonic cleaning	N	N	N	N	N	N	N	N	U	N	U	N	N	N	N	N	N	9i
17.9.11	Dry ice (CO_2) cleaning	U	U		U	N	U	N	N	U	N	U	U	N	U	N	N	N	9j
17.9.12	Plastic shot-blast cleaning	U	U	U	U	U	U	N	N	N	N	N	N	N	N	N	N	N	9k
17.10.1	System selection, design and optimisation	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	14a
17.10.2.1	Air extraction as close as possible to the point of ink/coating application	U	U	U	U	U	U	U	N	U	N	U	U	N	U	U	U	U	14b

17.10.2.2	Air extraction as close as possible to the point of preparing paints/coatings/inks	U	U	U	U	U	U	U	N	U	N	U	N	N	U	U	U	U	14c
17.10.2.4	Extraction of air from the drying/curing process	U	U	U	U	U	U	U	U	U	U	U	U	N	U	U	U	U	14d
17.10.2.3	Minimisation of fugitive emissions and heat losses from the ovens/dryers either by sealing the entrance and the exit of the curing ovens/dryers or by applying subatmospheric pressure in drying	U	U	U	U	U	U	U	U	U	U	U	U	N	U	U	U	U	14e
17.10.2.5	Extraction of air from the cooling zone	U	U	N	N	N	N	U	N	U	U	U	U	N	N	U	N	N	14f
17.10.2.6	Extraction of air from storage of raw materials, solvents and solvent-containing wastes	N	N	N	N	U	N	U	N	U	N	N	U	U	U	U	U	N	14g
17.10.2.7	Extraction of air from cleaning areas	N	N	N	N	U	U	U	N	U	N	U	U	N	U	U	U	U	14h
17.10.3.1	Maintaining the VOC concentration sent to the off-gas treatment system by using variable frequency drives	U	U	U	U	U	U	U	N	U	N	U	U	N	N	N	U	U	16a
17.10.3.2	Internal concentration of solvents in the off-gases	U	U	U	U	U	U	U	N	N	N	U	U	N	N	U	N	U	16b
17.10.3.3	External concentration of solvents in the off-gases through adsorption	U	U	U	U	U	U	U	N	U	N	U	N	N	N	N	U	U	16c
17.10.3.4	Plenum technique to reduce waste gas volume	N	N	N	N	U	U	NI	N	N	U	U	N	N	N	N	N	U	16d
17.10.4.1	Wet separation spray booth (flushed impact panel)	N	N	U	N	N	U	N	N	N	N	N	N	N	U	N	N	U	18a
17.10.4.2	Absorption using a suitable liquid (wet scrubbing)	U	U	U	U	U	U	U	N	U	N	N	N	N	U	N	N	U	18b
17.10.4.3	Dry overspray separation with pre-coated material	U	U	U	U	N	U	N	N	N	N	N	N	N	N	N	N	U	18c
17.10.4.4	Dry overspray separation using filters	U	U	U	U	U	U	N	N	U	N	N	N	N	U	N	N	U	18d
17.10.4.5	Electrostatic precipitator	U	U	N	U	N	U	N	N	U	N	N	N	N	N	N	N	U	18e
17.10.5.1	Sending off-gases to a combustion plant	N	N	N	N	N	U	U	N	N	N	U	N	N	N	N	N	U	15d
17.10.5.2	Thermal oxidation	N	N	N	N	N	U	U	N	U	U	U	N	N	N	U	N	U	15i
17.10.5.3	Recuperative thermal oxidation	U	U	U	U	U	U	U	N	U	U	U	N	N	N	U	U	U	15e
17.10.5.4- 17.10.5.5	Regenerative thermal oxidation with multiple beds or with a valveless rotating air distributor	U	U	U	U	U	U	U	U	U	U	U	N	N	N	U	U	U	15f
17.10.5.6	Catalytic oxidation	U	N	N	N	N	U	U	U	U	N	U	N	N	N	U	U	U	15g
17.10.6.1	Condensation	N	N	N	N	N	U	N	N	N	U	U	N	N	N	U	N	U	15a
17.10.6.2	Adsorption using activated carbon or zeolites	U	U	N	U	U	U	U	N	U	N	U	U	N	N	U	U	U	15b
17.10.6.3	Absorption using a suitable liquid	U	U	U	U	U	U	U	N	U	N	U	N	N	U	N	U	U	15c
17.10.7	Biological off-gas treatment	N	N	N	N	N	U	N	N	U	N	U	N	N	N	N	N	U	15h
17.10.8.1	Optimisation of thermal treatment conditions (design and operation)	U	U	U	U	U	U	U	U	U	U	U	N	N	N	U	U	U	17a

17.10.8.2	Use of low-NO_X burners	U	U	U	U	U	U	U	N	U	NI	U	N	N	N	U	N	N	17b
17.11.1.2	Equalisation	U	U	U	U	U	U	U	N	U	N	N	N	U	U	N	N	U	21a
17.11.1.1	Neutralisation	U	U	U	U	U	U	U	N	U	N	N	N	U	U	U	N	U	21b
17.11.1.3	Physical separation	U	U	U	U	U	U	U	N	U	N	N	N	U	U	N	N	U	21c
17.11.2.3	Adsorption	N	N	N	N	N	U	N	N	U	N	N	N	N	U	N	N	U	21d
17.11.2.2	Vacuum distillation	N	N	N	N	U	U	N	N	U	N	N	N	N	U	N	N	U	21e
17.11.2.4	Precipitation	U	U	U	U	U	U	U	N	U	N	N	N	U	N	N	N	U	21f
17.11.2.1	Chemical reduction	N	N	N	N	N	U	U	N	N	N	N	U	N	U	N	N	U	21g
17.11.2.5	Ion exchange	U	U	U	U	U	U	U	N	N	N	N	U	N	U	N	N	U	21h
17.11.2.6	Stripping	U	U	U	U	U	N	N	N	N	N	N	N	N	N	U	N	N	21i
17.11.3	Biological treatment	N	N	N	N	N	U	U	N	N	N	N	N	U	N	N	N	U	21j
17.11.4.1	Coagulation and flocculation	U	U	U	U	U	U	U	N	U	N	N	N	U	U	N	N	U	21k
17.11.4.2	Sedimentation	U	U	U	U	U	U	U	N	U	N	N	N	U	N	N	N	U	21l
17.11.4.3	Filtration	U	U	U	U	U	U	U	N	U	N	N	N	U	N	N	N	U	21m
17.11.4.4	Flotation	U	U	U	U	U	U	U	N	U	N	N	NI	U	N	N	N	U	21n
17.12.1	Waste management plan	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	22a
17.12.2	Monitoring of waste quantities	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	22b
17.12.3	Recovery/recycling of solvents	U	U	U	U	U	U	U	N	U	U	U	U	N	U	U	U	U	22c
17.12.4	Waste-stream specific techniques	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	22d
2.4.2.1	Mixed (SB-mix) coating	U	U	U	U	U	N	N	N	N	N	N	N	N	N	N	N	N	24a
2.4.2.2	Water-based (WB) coating	U	U	U	U	U	N	N	N	N	N	N	N	N	N	N	N	N	24b
2.4.2.3	Integrated coating process	U	U	N	U	U	N	N	N	N	N	N	N	N	N	N	N	N	24c
2.4.2.4	Three-wet process	U	U	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	24d
4.4.9.1	Segregation of waste and waste water streams	N	N	N	N	N	N	N	N	N	N	N	N	U	N	N	N	N	25a
4.4.2.1	Partial enclosure of treatment areas	N	N	N	N	N	N	N	N	N	N	N	N	U	N	N	N	N	25c
4.4.2.2	Full enclosure of treatment areas	N	N	N	N	N	N	N	N	N	N	N	N	U	N	N	N	N	25d
4.4.2.3	Restrictions for adverse weather conditions	N	N	N	N	N	N	N	N	N	N	N	N	U	N	N	N	N	25b
4.4.3.1	Dry blasting in a closed system	N	N	N	N	N	N	N	N	N	N	N	N	U	N	N	N	N	25e
4.4.3.2	Wet blasting	N	N	N	N	N	N	N	N	N	N	N	N	U	N	N	N	N	25f
4.4.3.3	(Ultra-)High-Pressure ((U)HP) water jetting or blasting	N	N	N	N	N	N	N	N	N	N	N	N	U	N	N	N	N	25g
4.4.3.4	Stripping of coatings by induction heating	N	N	N	N	N	N	N	N	N	N	N	N	U	N	N	N	N	25h
4.4.3.5	Underwater hull and propeller cleaning system	N	N	N	N	N	N	N	N	N	N	N	N	U	N	N	N	N	25i
5.4.2.2	Enclosure	N	N	N	N	N	N	N	N	N	N	N	N	N	U	N	N	N	26a

5.4.2.3	Direct printing	N	N	N	N	N	N	N	N	N	N	N	N	N	U	N	N	N	26b
9.4.3.1	Process-integrated VOC oxidation	N	N	N	N	N	N	N	U	N	N	N	N	N	N	N	N	N	27a
9.4.2.2	Solvent-free lubricants	N	N	N	N	N	N	N	U	N	N	N	N	N	N	N	N	N	27b
9.4.2.3	Self-lubricating coatings	N	N	N	N	N	N	N	U	N	N	N	N	N	N	N	N	N	27c
9.4.2.1	High-solids enamel coating	N	N	N	N	N	N	N	U	N	N	N	N	N	N	N	N	N	27d
11.4.2.1	Use of low-IPA or IPA-free additives in dampening solutions	N	N	N	N	N	N	N	N	N	U	N	N	N	N	N	N	N	28a
11.4.2.3	Waterless offset	N	N	N	N	N	N	N	N	N	U	N	N	N	N	N	N	N	28b
11.4.4.2	Use of VOC-free solvents or solvents with low volatility for automatic blanket cleaning	N	N	N	N	N	N	N	N	N	U	N	N	N	N	N	N	N	28c
11.4.3.2	Web offset dryer integrated with off-gas treatment	N	N	N	N	N	N	N	N	N	U	N	N	N	N	N	N	N	28d
11.4.3.1	Extraction and treatment of air from the press room or the press encapsulation	N	N	N	N	N	N	N	N	N	U	N	N	N	N	N	N	N	28e
13.4.1.1	Use of retention inks	N	N	N	N	N	N	N	N	N	N	N	U	N	N	N	N	N	29a
13.4.3.1	Automatic cleaning systems connected to the toluene recovery system	N	N	N	N	N	N	N	N	N	N	N	U	N	N	N	N	N	29b

NB:
U: reported to be used at the time of writing; N: reported as not used at the time of writing; NI: no information.
Source: [262, ESVOC et al. 2019]

21.3 Models for estimating environmental and economic effects (cost-benefit)

21.3.1 TFTEI reports, the ERICCa_VOC tool and the EGTEI background documents

[147, TFTEI 2016] [210, TFTEI 2017] [227, TFTEI 2017]

TFTEI[52] has developed a series of reports aiming to assess the economic and environmental effects of emission abatement measures. Currently (2018) available are the reports for:

- the flexible packaging printing sector; and
- car manufacturing (see links in the following table).

In addition, TFTEI has developed a methodology (ERICCa_VOC) for cost estimation of abatement options for VOCs for installations in the flexible packaging printing sector and car manufacturing with a solvent input of more than 200 tonnes per year (IED Annex I installations). However, the design and costs of VOC reduction measures are similar for many other sectors with comparable operating conditions. Therefore the developed tool is expected to be broadly applicable. The methodology provides cost data for primary measures (substitution of products with a high solvent content, with some limits (as costs for primary measures are sector- and plant-specific)) and the secondary measures thermal oxidation and adsorption with solvent recovery. For secondary measures, the tool can be used for any type of activities and size of plants (even consumption lower than 200 t/year), independently from primary measures. Costs are estimated for different regulatory objectives based either on the solvent management plan methodology or not.

The 'ERICCa_VOC' tool is available at the following link:
http://tftei.citepa.org/images/files/costs_reduction_techniques_large_users_solvents/ERICCa_VOC_0.49.xlsx.

The emission reduction cost methodology is explained in the relevant report:
http://tftei.citepa.org/images/files/costs_reduction_techniques_large_users_solvents/TFTEI-VOC-cost_calculation_methodology_2017_02-01.pdf

The background documents and associated synopsis sheets developed by EGTEI from 2003 to 2006 for several activities emitting VOCs are also linked in the following table. It is noted that these documents are provided only for information as they are now considered outdated according to TFTEI.

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[52] At its 33rd session in December 2014, the Executive Body (EB decision 2014/2) of the United Nations Economic Commission for Europe (UN-ECE) Convention on Long-Range Transboundary Air Pollution (LRTAP) approved the upgrade of the Expert Group on Techno-Economic Issues (EGTEI) to Task Force on Techno-Economic Issues, TFTEI. The establishment of the former Expert Group on Techno-Economic Issues (EGTEI) was decided by EB, in December 2001, as a follow-up of the proposal from the French Ministry for an Ecological and Solidary Transition. More information on TFTEI can be found at the following link: http://tftei.citepa.org/en/.

Table 21.2: Table of EGTEI synopsis sheets, TFTEI reports and EGTEI background documents relevant to this document

STS BREF Chapter	Sector/activity	URL to related TFTEI report	IED Annex VII(2) activity code
2	Coating of vehicles	Final report on car manufacturing: http://tftei.citepa.org/images/files/costs_reduction_techniques_large_users_solvents/TFTEI-VOC-car-industry-final.pdf	Annex VII(3)
11	Flexography and non-publication rotogravure printing	Final report on flexible packaging printing sector: http://tftei.citepa.org/images/files/costs_reduction_techniques_large_users_solvents/TFTEI-VOC_packaging%20printing_2017_03_23.pdf	3
EGTEI background document (developed in the period 2003-2006)			
10	Heatset web offset	http://tftei.citepa.org/images/files/voc_emission_reduction_techniques_costs/bd_heat_set_offset_170503.pdf	1
12	Publication rotogravure	http://tftei.citepa.org/images/files/voc_emission_reduction_techniques_costs/bd_publication_gravure_170603.pdf	2
9	Winding wires	http://tftei.citepa.org/images/files/voc_emission_reduction_techniques_costs/bd_wire_coating_311003.pdf	9
7	Manufacture of adhesive tape (EGTEI: Adhesive application in industry)	http://tftei.citepa.org/images/files/voc_emission_reduction_techniques_costs/bd_adhesive_application_081203.pdf	16
2	Coating of trucks and vans	http://tftei.citepa.org/images/files/voc_emission_reduction_techniques_costs/bd_trucks_and_vans_coating_150703.pdf	Annex VII(3)
2	Coating of truck cabs	http://tftei.citepa.org/images/files/voc_emission_reduction_techniques_costs/bd_truck_cabin_coating_150703.pdf	Annex VII(3)
2	Coating of buses	http://tftei.citepa.org/images/files/voc_emission_reduction_techniques_costs/bd_buses_coating_150703.pdf	Annex VII(3)
3	Coating of trains	See: Other coating industries	8
3	Coating of ACE (agricultural, construction and similar equipment)	See: Other coating industries: http://tftei.citepa.org/images/files/voc_emission_reduction_techniques_costs/bd_paint_general_industry_aggregated_v3_141204.pdf	8

4	Coating of ships and yachts		8
5	Coating of aircraft		8
3	Coating of other metal surfaces		8
6	Coil coating	http://tftei.citepa.org/images/files/voc_emission_reduction_techniques_costs/bd_coil_coating_160603.pdf	7
10	Coating and printing of metal packaging	This industry is not covered by a specific EGTEI background document. Part (e.g. rigid metal packaging) is addressed in the background document 'Other coating industries'. Other parts of the industry are related to flexible packaging	3 and 8 (in part)
3	Coating of other plastic surfaces	See: Other coating industries: http://tftei.citepa.org/images/files/voc_emission_reduction_techniques_costs/bd_paint_general_industry_aggregated_v3_141204.pdf	8
14	Coating of wooden surfaces	http://tftei.citepa.org/images/files/voc_emission_reduction_techniques_costs/bd_wood_coating_300603.pdf	10
15	Wood preservation	http://tftei.citepa.org/images/files/voc_emission_reduction_techniques_costs/bd_preservation_wood_v2_170304.pdf	12
16	Mirrors	See: Other coating industries: http://tftei.citepa.org/images/files/voc_emission_reduction_techniques_costs/bd_paint_general_industry_aggregated_v3_141204.pdf	8

21.3.2 Regional environmental costing model (MKM, MilieuKostenModel)

Description

In Flanders, Belgium, an environmental costing model (MilieuKostenModel or MKM) has been developed in parallel with the EGTEI work. With this tool, it is possible to obtain an overview of potential abatement measures, their costs and emission reduction potential, and to find cost-efficient or lowest-cost solutions.

The interactions and trade-offs for complex situations are taken into account in the MKM by means of mixed integer programming. The model can be used to optimise (e.g. the lowest-cost solution to reduce emissions, or the marginal cost curve for a particular pollutant) and to simulate (e.g. the impact of more stringent environmental objectives on the lowest-cost solution, or what is the impact of the reduction of polluting activities) for one or multiple pollutants at the same time.

A background report describes the definitions used such as environmental costs and cost-efficiency, and the methodology to analyse the cost-efficiency of abatement measures.

MKM was devised to determine the costs of environmental policy and to contribute to a more efficient environmental policy by indicating how environmental targets can be realised in a cost-effective way. The brief was to:

- develop a coherent database with environmental measures, their reduction potential and costs;
- develop a tool to allocate emission reduction efforts between different target groups in a cost-effective way;
- develop a tool to take into account multiple pollutant effects;
- develop a tool to analyse the cost-effectiveness of policy instruments;
- develop an instrument that can be linked to other models such as ecological models, economic models (e.g. RAINS).

Depending on the data available, emission sources are identified on an aggregated level (e.g. sector or industry level) or individual source level (e.g. individual companies). The format of the database makes it possible to describe emission sources as individual installations or as ‘reference installations’. A ‘reference installation’ is a representative category of installations for which the same emission abatement measures are available and for which a particular abatement measure has similar abatement results and costs. For each pollutant, emissions are linked to an activity that is the source of the pollution, e.g. amount of solvent consumed. Consequently, the MKM can be used to predict emissions based on the evolution of the activities or emission factor. Also, it is possible to compare data with the input of other models, e.g. RAINS, and link the MKM with, for example, input-output tables or general equilibrium models.

In addition to emission data, energy consumption, operational hours, capacity, etc. can be entered in the database for each (reference) installation.

For each abatement measure, the following information can be entered in the database: investment costs, operational costs, lifetime, capacity, reduction efficiency.

The development of the model is focused on one criterion: cost-effectiveness. Nevertheless, other criteria can play a significant role in determining the environmental policy such as environmental effectiveness and feasibility. It is important to mention that the environmental costing model (MKM) is not a tool to carry out an investment analysis for a specific company. The model is a tool to support the Flemish Government in estimating the costs of the

environmental policy for different target groups. Such information can be used, for example, to allocate emission reduction efforts between target groups.
Measures and techniques discussed in this document that were analysed with this model are, for example for the coating sector:

- painting techniques/systems, i.e. high-solids (see Section 17.7.2.1), water-based (see Section 17.7.2.2), powder coating (see Section 17.7.2.3) and UV-cured paint (see Section 17.7.2.3);
- off-gas treatment techniques, i.e. adsorption to activated carbon (see Section 17.10.6.2), thermal oxidation (see Section 17.10.5.2) and biological treatment (biofilters) (see Section 17.10.7).

More measures are described in this document to reduce VOC emissions, but not all can be analysed with this model.

The following industries can be consulted in the database of the MKM: coating, printing, degreasing, adhesives and automobiles. As an example of the output of the tool, the results for the coating sectors are shown in Table 21.3 and Table 21.4.

*Note: these data are supplied from the MKM and the footnotes should be referred to.

Reference literature
The MKM page: https://emis.vito.be/nl
The background report: (Meynaerts E., Ochelen S., Vercaemst P., Milieukostenmodel voor Vlaanderen – Achtergronddocument, 2003).
[48, VITO 2005] [78, TWG 2005]

Table 21.3: Average costs and VOC reduction potential of all the measures analysed by the model

Technique	**Operational cost of paint (EUR per kg)**	**Energy cost (EUR per hour)**	**Residues (EUR/kg)**	**VOC content of paint (presumed to be wt-%)**	
Conventional	3.11	6.7	0.3	NI	
High-solids	3.5	6.4	0.3	< 30 %	
Water-based	8.43	7.21	0.2	7.50 %	
Powder coating	15.39***	2.9	0	0 %	
UV paint	3.78***	3.76	0	3.50 %	
	Investment cost (thousand EUR per 1 000 m^3/h)	**Activated carbon (EUR per kg)**	**Operational cost**	**VOC reduction (%)**	**VOC emission concentration**
Activated carbon*	5-10	1.2	EUR 0.5-2.30 per m^3/h with initial VOC conc. of 1-10 g/m^3	85 %	5-100 mg TOC/m^3
Thermal oxidation**	5-40	NA	EUR 0.45-4.50 per 1 000 m^3/h (extra energy)	95-99 %	< 20-50 mg TOC/m^3

* Reduction option when VOC emissions are between 8 and 20 tonnes a year, 85 % reduction.
** Reduction option when VOC emissions are > 20 tonnes a year, 95 % reduction.
*** Sections 17.7.2.3 and 17.7.2.6 give costs of EUR 3.01-5.38/kg for both radiation-cured and powder coating paints.
Source: [48, VITO 2005]

Table 21.4: **Possible cost-effective measures for the reduction of VOC emissions per industry**

Industry	**Number of employees**	**Possible in-process measures (1)**			**Possible end-of-pipe measures**	
Metal surfaces	1-19	60 % high-solids	*40 % water-based*	50 % powder		
	20-199	80 % high-solids	*40 % water-based*	50 % powder		
		100 % high-solids		60 % powder		Incinerator
						Incinerator*
	200-499	80 % high-solids		50 % powder		
					Activated carbon*	Incinerator
						Incinerator*
	500-999	80 % high-solids		50 % powder	Activated carbon*	
		80 % high-solids				Incinerator
	1 000-1 000+	80 % high-solids				
		100 % high-solids	Water-based			
Metal packaging – barrels	20-99					Incinerator*
	100-199					Incinerator*
	500-999	Optimise cleaning agents				
Furniture	10-499			80 % powder (for those who still use wet coatings)		
	5-199		60 % water-based	*40 % powder*	Activated carbon*	
Ships	10-499	60 % high-solids				
Trains	10-1 000+	70 % high-solids		*30 % powder*	Activated carbon*	Incinerator*
Others	1-49	60 % high-solids		30 % powder		
	50-99		30 % water-based	30 % powder		
	100-199	60 % high-solids		30 % powder		
	200-499	No additional measures				
	500-999				Activated carbon	

Industry		Number of employees	Possible in-process measures (1)			Possible end-of-pipe measures	
WOOD	**Furniture**	1-9	30 % high-solids	30 % water-based			
		10-19	30 % high-solids	30 % water-based			
		20-49	30 % high-solids	30 % water-based	UV paint	Activated carbon*	_Biofilter*_
				water-based	UV paint		
		50-99	30 % high-solids	30 % water-based	10 % UV	Activated carbon*	_Biofilter*_
		100-199	30 % high-solids	30 % water-based	10 % UV		
		200-499	30 % high-solids	30 % water-based	10 % UV	Activated carbon*	Incinerator*
	Cabinet work	1-499	30 % high-solids	40 % water-based	10 % UV		Incinerator
	Others	5-199	30 % high-solids	40 % water-based	10 % UV		
Plastic		1-4	50 % high-solids	*30 % water-based*			Incinerator*
		5-9	50 % high-solids				Incinerator*
		10-19	50 % high-solids				Incinerator*
		50-99	50 % high-solids	*40 % water-based*			
		100-199		*50 % water-based*			
		200-499	50 % high-solids	*40 % water-based*			Incinerator*
		500-999	50 % high-solids		UV paint		Incinerator

(1) The percentages of the possible measures relate to maximum technical uptake, they are not based on cost benefit.
* Not enough data were collected in the survey to draw a conclusion. In these cases, a general rule was used: oxidisers are technically applicable when VOC emissions are > 20 t/yr and adsorption to activated carbon and biofilters are technically applicable when VOC emissions range from 8 t/yr to 20 t/yr. However, Section 17.10 of this document shows choice is related to air volume and concentration, not total consumption.
Measures in italics were rejected and were not taken into account in the model as they have higher costs and lower efficiencies compared to other measures.
Source: [48, VITO 2005]

21.4 Measuring fugitive emissions – direct method

[16, Aminal et al. 2002] [38, TWG 2004] [97, TWG 2006]

Step 1: Identify all sources of fugitive emissions within the plant

All solvent vapours that are not routed to the abatement system escape to the air and contribute to the fugitive emissions. Most industries considered in this document have many sources of fugitive emissions. The following is a case study in some 10 flexographic printing (flexible packaging) plants in Flanders, Belgium, and the Netherlands. However, the principles described in the following steps are readily transferable to other industries. Most plants will have a number of sources and most of these will only result in small or extremely small emissions. In most cases, there are just one to three sources in a plant which make a substantial contribution to the fugitive emissions. More than one emission factor may need to be determined for a source, to improve the accuracy or for convenience.

A flexible packaging plant has many sources of fugitive emissions. The sources identified so far are listed below, although most plants will only have a few of these. In some cases, there may be more sources, or another classification may be more convenient.

Sources of fugitive emissions for flexographic printing are:

- press room ventilation during printing;
- dryer ventilation during make-ready;
- dryer ventilation while waiting;
- local exhaust between press units;
- cleaning department;
- ink mixing department;
- solvent content of water-based inks, paints and adhesives;
- solvents used in production machines not connected to the incinerator;
- residual solvent in products;
- solvents discharged in water;
- solvent emissions from waste water treatment plants;
- vapour losses from tanks, etc.

Double-counting should be avoided. For example, if the ink is mixed next to the press then the evaporated solvent will be removed by the local exhaust between press units and the room ventilation and does not need to be quantified separately.

Step 2: Study the ventilation system and ensure that it works as expected

In production areas in particular, the design of the ventilation system determines which fugitive emission sources are present, and how the emitted quantities must be estimated or measured. The ventilation systems do not normally work as assumed in the plant. Either the system was built in a different way to that remembered or recorded, and/or the system control settings were completely changed during the course of time. A ventilation system that actually operates as expected is very rare.

Some examples that were actually encountered in practice are as follows:

- The actual duct system was different from the drawing. Fans and ducts had been installed or removed, and the modifications had not been documented accurately.

- Automatic positive and negative pressure controls did not operate as designed. Printing plants which expected to be working above atmospheric pressure were actually working at subatmospheric pressure, and the other way round.
- Some components of the ventilation system were shown to have more functions than expected. A fan for aqueous paints on one of the printing units was also found to be connected to the local exhaust between the press units.
- Significant airflows were shown to exist between different parts of the building.

As long as the operation of the ventilation system is not perfectly in order, there is no point in measuring or estimating fugitive emissions that are affected by it. If the settings of the ventilation system need to be adjusted later, the estimation and measurements will be of no use. Hence, the first action should be to assure complete understanding of the ventilation system in the production areas. The ducting and fans need to be compared with the drawings. The maintenance status should be checked. Poor maintenance and cleaning can reduce the airflow by as much as 50 %. It is good practice to correct any substandard maintenance before carrying out any measurements.

When comparing the design with the current system, questions must be asked such as the following:

- Have filters and drive belts been replaced according to suppliers' maintenance schedules?
- Are the fan blades and heat exchangers clean?
- Where are the exhausts?
- Where are the inlets for fresh air?
- Which exhausts are connected to the same duct?
- Which fan serves what part of the system?
- When are dampers and valves automatically opened or closed?
- What automatic controls are incorporated?
- What measurements are provided for them?
- What are the theoretical flow rates of the fans?
- How are the control systems supposed to operate?
- What is the difference between summer and winter control modes?

In most cases, there is a clear difference between theory and practice. It has then to be decided what is actually required and the ventilation settings need to be adjusted accordingly. It then has to be verified if the ventilation system actually produces the required results in the different stages of the production process (e.g. make-ready, printing, cleaning). In practice, this may be relatively easy to do. For example, the direction of the airflow through doors, windows and other openings can be easily established using a thin, narrow strip of plastic film. Fugitive emissions can only be determined once the ventilation system is adjusted as required by plant management. Obviously, management will also need to ensure the improved regime is maintained.

Step 3: Make a substantiated estimate for each source, in the form of an emission factor multiplied by a production parameter

The emissions of every source with emissions that are not negligible have to be estimated. In this step, the order of magnitude needs to be established. Later it will be decided if the emissions are high enough to warrant additional measurements. Obviously, the estimates should have a reliable basis, but at this stage the number of measurements should be minimised. The aim is to only use data already available within the plant, and data which are easily measured.

Below are some examples of useful information that is already available in the plant, or which can easily be measured:

- fan capacities, as specified by their manufacturer;
- information about occupational exposure to solvents;
- measurements of residual solvent in products, carried out for customers;
- quantity of bulk solvents, inks, paints and adhesives received;
- simple experiments in the ink mixing department;
- simple solvent balances for the cleaning department, etc.;
- concentration measurements with a PID at local exhausts;
- verification of the direction of the press room ventilation flow.

The example in Table 21.5 relates to a plant with an annual input of 1 000 tonnes of solvent. The example clearly shows how only two out of the eleven sources account for over 70 % of the fugitive emissions.

Table 21.5: Emissions related to sources from a plant processing 1 000 tonnes of solvents

Source	Emissions in kg	% of input	% of fugitive
Press room ventilation during printing	9 000	0.90	8.0
Dryer ventilation during make-ready	5 400	0.54	4.8
Dryer ventilation while waiting	22 500	2.25	20.0
Local exhaust between press units	56 550	5.66	50.3
Cleaning department	8 750	0.88	7.8
Ink mixing department	7 500	0.75	6.7
Solvent content of water-based inks, etc.	2 500	0.25	2.2
Residual solvent in products	200	0.02	0.2
Solvents discharged in water	-	-	-
Solvent emissions from waste water treatment plant	-	-	-
Vapour losses from tanks, etc.	67	0.01	0.1
Total	**112 467**	**11.26**	**100.1**

At this stage, another option would be to reduce the emissions from the major sources or to eliminate them completely before doing any additional measurements. For example, if sufficient incinerator capacity were available, the local exhaust between press units or the exhaust of the cleaning department could be connected to the incinerator. This would eliminate these sources of fugitive emissions completely.

Step 4: Determine which of the sources need more accuracy

The estimates made in Step 3 are not particularly accurate. However, they clearly indicate that the magnitude of the fugitive emissions varies greatly between sources. Vapour losses from tanks are very small, while the local exhaust between the press units is particularly important.

Now the accuracy of the calculated total fugitive emission needs to be determined. The emission parameters which need more accuracy must be selected. This is done by a worst-case approach: the maximum possible error for each source is estimated, and the resulting maximum potential fugitive emissions from the source in question are calculated. The total of all these maximum potential emissions is the ‘worst case’.

Most emission estimates made in Step 3 were calculated by multiplying two or more fairly inaccurate figures. For example, a theoretical airflow may have been multiplied by an indicative concentration measurement and an estimated number of running hours. In such a case, the inaccuracy in each of the parameters needs to be estimated separately and this information is used to calculate the potential maximum emissions from each source, as if the largest possible potential error did indeed occur. The result is the maximum emissions possible from the source in question.

The maximum emissions possible from all the different sources are then added up to calculate the maximum overall fugitive emissions, as if the initial emission estimates for each and every source had been too low. This is a very conservative approach. It is equally likely that the emission estimates were not too low, but too high. In that case, the actual fugitive emissions would be lower than the estimates. In reality, errors to both sides will be made and the actual emissions will be closer to the initial estimate than would be assumed on the basis of the calculation of the potential maximum emissions.

The example in Table 21.6 shows the estimation of the maximum error for each source. Note, however, that a large part of the inaccuracy is due to the limited amount of information about ventilation flows and solvent concentrations.

Table 21.6: Example of a possible outcome of the calculation of inaccuracies

Source	Fugitive emissions as % of input	Max. error factor	Max. % of input
Press room ventilation during printing	0.90	2.25	2.03
Dryer ventilation during make-ready	0.54	1.50	0.81
Dryer ventilation while waiting	2.25	2.00	4.50
Local exhaust between press units	5.66	2.25	12.72
Cleaning department	0.88	2.00	1.75
Ink mixing department	0.75	1.50	1.13
Solvent content of water-based inks, etc.	0.25	1.25	0.31
Residual solvent in products	0.02	1.25	0.03
Vapour losses from tanks, etc.	0.01	1.00	0.01
Total	**11.26**		**23.29**

The worst-case figures obtained in this way can still easily amount to double the original estimate. Some sources will be so small that they would not affect the outcome, irrespective of how precisely they are measured. In this example these are:

- solvent content of water-based inks, paints and adhesives;
- residual solvent in products;
- vapour losses from tanks.

There is no point in investigating these sources in any greater detail. Two of the sources on the list are clearly much more important than the others:

- local exhaust between press units;
- dryer ventilation while waiting.

These sources require further investigation, but together they account for over 70 % of the fugitive emissions.

Note: this is only an example. In practice, different sources may be the ones with high or low emissions.

Step 5: Improve the inaccurate estimates for large sources

The scope, depth and detail of the further investigations will depend on the objectives. In most cases, the inaccuracy of only two or three sources will have to be reduced to obtain a significant improvement of the outcome in the worst-case approach.

The further investigation needs to be tailored to the specifics of the converting plant. As stated earlier, further investigation is only necessary for sources of fugitive emissions that are both relatively large and uncertain.

This step (Step 5) describes how the inaccuracy of most of the initial estimates can be reduced. In cases where airflow and solvent concentration are being multiplied, an obvious option for improvement of the estimates is to actually measure the concentration. This can be done relatively easily by using passive samplers. Where the solvent losses from a source can be determined with scales, the number of weighings could be increased to improve accuracy. As an example, results of the improvement of the accuracy are given in Table 21.7.

Table 21.7: An example showing results of the improvement of accuracy

Source	Emissions in kg	% of input	% of fugitive emissions
Press room ventilation during printing (positive pressure)	9 000	0.90	8.0
Cleaning department	8 750	0.88	7.8
Ink mixing department	7 500	0.75	6.7
Solvent content of water-based inks, etc.	2 500	0.25	2.2
Residual solvent in products	200	0.02	0.2
Solvents discharged in water	-	-	-
Solvent emissions from waste water treatment plant	-	-	-
Vapour losses from tanks, etc.	67	0.01	0.1
Subtotal of sources not investigated further	**28 017**	**2.81**	**21.1**
Dryer ventilation during make-ready	8 000	0.80	6.0
Dryer ventilation while waiting	24 750	2.48	18.6
Local exhaust between press units	72 200	7.22	54.3
Subtotal of sources investigated in detail	**104 950**	**10.50**	**78.9**
Total fugitive emissions	**132 967**	**13.31**	**100**
Previous result (before additional investigation)	**112 467**	**11.25**	
NB: Subtotal not investigated further as a percentage of fugitive emissions should be 25 %.			

In this example, the additional investigation has greatly increased the accuracy of 3 of the 11 sources. The worst case now only differs a few per cent from the actual estimate. As an example, the results of the new estimates of the accuracy are given below.

Example: Increased accuracy as shown in Table 21.8 below.

Table 21.8: An example showing results of the increased accuracy

Source and notes	Estimated % of input	Factor max. residual error	Max. % of input improved estimate
Dryer ventilation during make-ready	0.80	1.20	0.96
Dryer ventilation while waiting	2.48	1.20	2.97
Local exhaust between press units	7.22	1.20	8.66
Other sources (unchanged)	2.80		5.24
Total	**13.30**		**17.83**
Previous result	**11.25**		**23.28**

Please note that here only the potential errors that result in increased emissions are being calculated. Errors resulting in reduced emissions are, however, equally likely.

If the fugitive emissions have to be determined more accurately still, other emission sources can be considered for further investigation. In this example, the cleaning department and press room ventilation are likely candidates. One third of the remaining difference between the actual estimation and the worst case (4.5 %) in this example is associated with the cleaning department, and one fifth with the room ventilation.

Step 6: Establish a record-keeping system from which the annual production parameters can be easily derived

Simplicity starts with choosing the right parameters. Where possible, they should be based on information that is already being collected. However, it should be determined if the figures obtained from other records do in reality accurately reflect the parameter which the emission factor refers to, and caution is needed. Examples of potential discrepancies between the existing records and the required parameters are as follows:

- Waiting hours and other stops as recorded in the production department may occur both during make-ready and during printing. For the calculation of fugitive emissions, however, only the periods in which the printing units contain ink, but are not actually producing, matter.
- Production hours (as needed to calculate the emissions from the exhausts between the press units) may not, according to production records, include waiting hours and other stops during printing. However, for the calculations, the full period during which the unit contains ink needs to be established.
- If some of the ink is not mixed in the ink mixing department but at the press, the resulting solvent losses will go to the press room ventilation and local exhausts. This may lead to double-counting.

Step 7: Calculate the annual emissions from each source by multiplying the production parameters and related emission factors

This step does not need further explanation.

Step 8: Include the results in the annual solvent management plan and compare the fugitive emissions with the limit value

This step does not need further explanation.

Step 9: Determine new emission factors if there is a significant change in the range of equipment, operations or ventilation

New emission factors must be determined if there are significant changes in the plant. A significant change may be a change in the ventilation system of the production areas, purchase of new machines, sale of old machines, a substantial change in the product range, or changes in the operating methods.

Determining the emission factors is not, in practice, a one-off activity. Once the plant becomes accustomed to dealing with fugitive emissions, the awareness of these emissions will also increase. This in turn will lead to improvements in the records, a repeat and recheck of measurements, and a wish to improve the accuracy of less important emission factors. Furthermore, options will be identified to reduce fugitive emissions. This will also lead to new emission factors.

21.4.1 Application to the printing sector

Description
This method was tested in two Flemish flexible packaging plants, a very large packaging gravure plant and a medium-sized flexographic plant. It is based upon direct measurements of the fugitive emissions. The capture efficiency is the percentage of the evaporated solvents that are exhausted with the waste gases. The remainder escapes as fugitive emissions.

Introduction and terminology of the alternative (direct) method

Sources of fugitive emissions: Fugitive emissions in a printing plant have many different causes. They arise during printing, cleaning, mixing of inks, transferring of solvents, etc. Each of these activities is a ‘source’ of fugitive emissions. It is possible to allocate the fugitive emissions in a plant to some 10 or 20 different ‘sources’.

Emission factor: The more frequently an activity is undertaken, or the longer it takes, the greater the fugitive emissions will be. Mixing 20 drums of ink will produce twice as many fugitive emissions as mixing 10 drums. Printing for 4 hours results in greater fugitive emissions than printing for 2 hours.

An emission factor can be determined for each source. This factor indicates the quantity of fugitive emissions for each time or every hour that the activity is carried out.

Emission factors need to be determined only once. They are specific to a machine and a working method. If neither the machine nor the working method changes, the emission factor also remains unchanged.

Production parameter: In order to calculate the emission, the emission factor needs to be multiplied with a production parameter. This production parameter is a measure of the activity of the source of fugitive emissions in question. The larger the production parameter, the bigger the fugitive emissions.

Examples: For cleaning operations, the number of times the cleaning unit is used could be employed as the parameter, and for mixing ink the volume of ink that was mixed.

Effective records need to be kept to produce the production parameters.

In short, the method amounts to the following:

- Estimate or measure the relevant emission factors and set up a record-keeping system for the annual production parameters. This has to be done only once.

- Calculations of fugitive emissions have to be carried out each year. This is done by multiplying the production parameters for the year in question by the emission factors.

Obviously, the most difficult step is to determine the emission factors. This is done in two or more stages. The first step is to make a well-substantiated estimate. This is done for all the different sources of fugitive emissions. No further action is required for the large number of sources that show very low emissions. The second step is only carried out for a small number of larger sources, where more accurate measurements are taken.

Accuracy

The production parameters can be determined accurately. Preferably, these parameters are figures that are already part of the production records, or that have to be collected anyway for other parts of the solvent management plan.

Examples of such parameters are the number of operating hours of production equipment, the number of orders processed on each machine, the volume of ink purchased, and the number of tonnes of ink mixed. The parameters are always measures of the activity: the higher the parameter, the higher the associated fugitive emissions must be.

The emission factors are a measure of the emissions per unit of activity. For example, the loss of solvent per kilo of mixed ink, or the loss of solvent through the local exhaust between the press units per operating hour.

The accuracy level of the emission factors is variable. The more extensive the measurements and the investigation are, the more accurate the factors will be. The different sources of fugitive emissions do not all need the same level of accuracy.

Accuracy can also be increased by using more than one emission factor for an activity. Instead of using one emission factor for all ink mixing operations, one could distinguish between mixing large and small batches of ink, mixing on hot or cold days, and mixing by hand or by machine. In other words, either one or five different factors could be determined. In the latter case, the accuracy will be greater.

To determine more than one emission factor per activity or increasing their accuracy will however also increase the amount of work. It is not productive to spend a lot of time on a minor source which hardly contributes to fugitive emissions. It is, therefore, advisable to start by estimating the order of magnitude of the emissions from each source, and then afterwards determine which of the sources need the most accurate emission factors.

The required accuracy for a source depends on two different issues:

1. The magnitude of the overall fugitive emissions: if the overall fugitive emissions are considerably below the limit value then the potential error is allowed be relatively large.

Example: At a limit value of 20 % (for the IED), an actual emission of between ‘5 % and 10 %’ would be acceptable, but an actual emission of between ‘15 % and 30 %’ would not be. In the latter case, the accuracy needs to be increased.

2. Contribution of the source to the overall emissions: if the accuracy of the overall figure has to be improved then one should focus on the sources which are both relatively large and have a low accuracy.

Example: Given a limit value of 20 % and actual emissions of 15 % to 30 %, with a contribution from the ink mixing department of 1 % to 2 % and a contribution of the local exhaust between press units of 10 % to 20 %, it would obviously be beneficial to improve the accuracy of the second source.

Achieved environmental benefits

The accuracy in monitoring fugitive emissions is considerably improved. The insight gained into the origin and cause of the fugitive emissions contributes to the reduction of these emissions.

Technical considerations relevant to applicability

Applicable to flexible packaging plants applying a destructive abatement technique.

Example plants

The method has been tested in flexible packaging printing plants.

Reference literature

[38, TWG 2004]

21.5 Solvent mass balance (SMB)

21.5.1 Solvent mass balance for vehicle paint shops

[143, ACEA 2017]

21.5.1.1 Scope of the solvent mass balance

It is very important to define precisely the scope of each solvent mass balance undertaken and to ensure that this scope is also consistent with the scope for the approved total emissions of the installation.

The starting point for the definition of the scope is generally the description in Annex VII, Part 3 of the IED for installations of the vehicle industry: '...all process stages carried out at the same installation from electrophoretic coating, or any other kind of coating process, through to the final wax and polish of top coating inclusive, as well as solvent used in cleaning of process equipment, including spray booths and other fixed equipment, both during and outside of production time.'

Practical experience has shown however that there are numerous additional aspects which have to be considered. These include the following:

- The need to prepare several solvent mass balances for technically independent installations in the same factory.
- Preparation of a joint solvent mass balance for several similar installations (e.g. paint shops of various types) or different activities (e.g. types, bonding processes in car body construction and final assembly, parts cleaning installations, or solvent use in cleaning of facilities).
- Exclusions of process stages that are not part of the IED installation, for example:
    - protective shipping wax applied to the finished vehicle prior to dispatch;
    - paint repair of completely assembled vehicles at the end of the assembly line;
    - process steps, if solvent-free material is used (example: cavity wax).
- Coating of components and service parts in the vehicle painting system which usually do not pass through all the process steps and leave the coating process after the electrocoating or primer stages as individual parts, rather than full vehicle units.
- Spray coating of bodies which were electrocoated elsewhere.
- In some cases, modifications in body/product and surface counting are appropriate. A common example is painting of service parts in a vehicle paint shop, which are usually passed out from the installation after the e-coat or primer. Another example is painting of small production parts in a vehicle manufacturing site which are destined for fitting at a different site rather than the site of manufacture.

With regard to the design of the installation-specific SMB, care should be taken that input data, such as the solvent input, the surface area of the coated products, and the determination of all output mass flows, are consistent with the installation-specific scope of the SMB and reflect partial operations for service parts etc.

21.5.1.2 Basic equations

No two installations are the same, therefore SMBs need to be adjusted to the site and are not directly comparable between installations.

General rules and used terms are defined in Part 7 of Annex VII to the Industrial Emissions Directive. The definitions and equations defined there can be summarised as:

$I = I1 + I2 = \sum_{i=1}^{9} Oi$ Equation 1

$E = O1+O2+O3+O4+O9$ direct method Equation 2

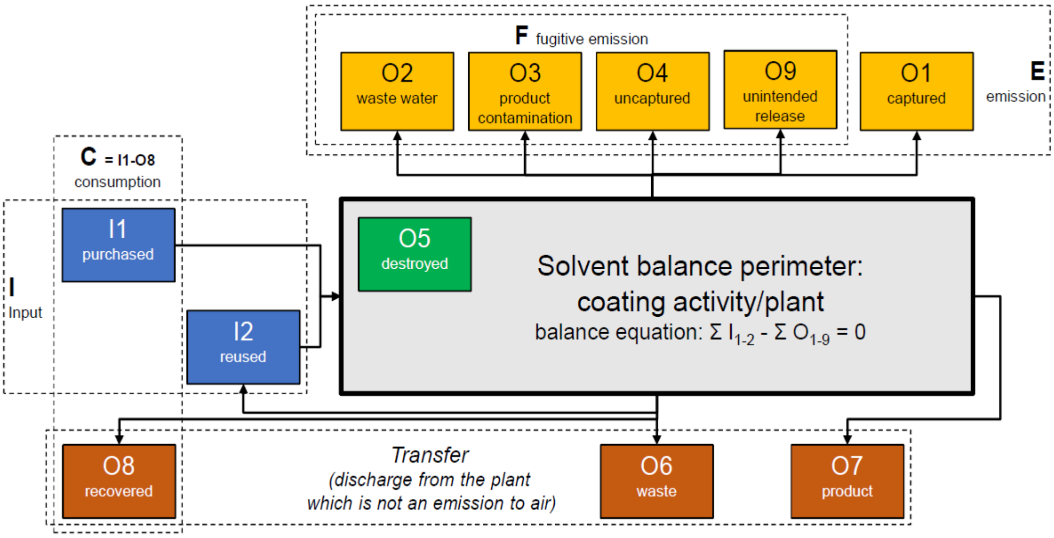
$E = I1-O5-O6-O7-O8$ indirect method Equation 3

$Er = \frac{E}{A}$ Equation 4

where:

A surface area;
O1 O1.1 + O1.2.

(Very often, for practical reasons, the treated (O1.1) and untreated (O1.2) captured emissions are determined and reported separately.)



Source: [143, ACEA 2017]

Figure 21.3: Solvent mass flows in a paint shop

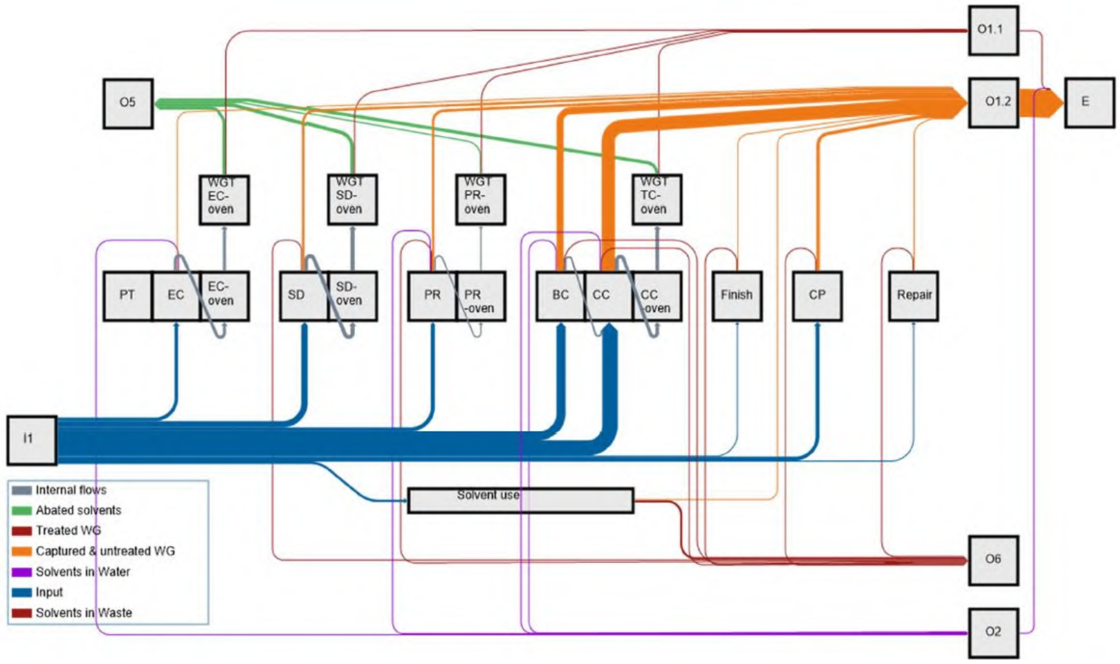
In the figure above, all mass flow types are shown, which are mentioned in Part 7 of Annex VII to the IED. Only a few are relevant or must be determined explicitly to calculate total emissions E or to demonstrate compliance with emission limits.

21.5.1.2.1 Relevant mass flows of organic solvents

Typical mass flow figures of organic solvents in a paint shop with water-based primer and base coat, which is the dominating coating concept in European paint shops (WB paint shop family), are shown in Figure 21.4. Other coating concepts like solvent-based primer and/or solvent-based base coat, integrated processes without primer or solvent-free cavity preservation may give other relations between the different mass flows.

In order to avoid disproportionate costs and manpower, only those solvent mass flows which have a major impact on the total solvent emission should be investigated. The remaining flows might be included in SMB calculations using fixed standard values (e.g. presented here) or even set to zero. However, this will depend on the individual situation of an installation, especially if the calculated emission value is close to the ELV. In such cases, a more detailed investigation is required.

Following these two principles and taking into account practical experiences (see Figure 21.4), the mass flows defined in equations 1 to 3 can be ranked according to their relevance as shown in Table 21.9.



Source: [143, ACEA 2017]

Figure 21.4: Solvent mass flows in a paint shop line (example)

Table 21.9: Relevance of different mass flows

Abbreviation	Mass flow	Explanation (a, b, c, indicates decreasing relevance)	Relevant if … method is applied
Mass flows of primary importance Numerical determination for each SMB calculation. Uncertainties associated with the determination of these parameters will have a high impact on the total uncertainty of the result.			
I1	Input of solvents	VOCs as solvents in paints; diluents and rinsing agents for application; cleaners for plant cleaning.	Indirect
O1.2	Captured and untreated emissions	Application zones without exhaust air treatment: a. CC, BC, PR, b. SD, CP, c. Finish, mix rooms.	Direct
O5	Solvents destroyed by abatement techniques	Usually by incineration in off-gas treatment, but any other process must be considered, provided it is performed within the boundaries of the solvent mass balance and that it leads to the final conversion of organic solvents into other substances.	Indirect
O6	Solvents as waste	a. Collected solvent/paint from colour changing and purging (PR, BC, CC). b. Waste paint. c. Waste plastisols (underbody protection, seam sealing). d. Other wastes with solvent contaminations.	Indirect
O8	Recovered solvents	Either: • Stock differences of solvents/paints at the beginning and end of each solvent balance period. • Storage of captured solvents for reuse in the same installation after internal or external reconditioning. [53] O8 changes to I2 if solvents are introduced in the coating process for the same reference period.	Indirect
Mass flows of secondary importance Case-by-case decision if a quantitative determination (measurement) is required for each SMB calculation. Depending on the compliance situation with the ELV, the use of empirical values or estimates may be sufficient.			
O1.1	Captured and treated emissions	Under normal operating conditions of the respective off-gas treatment equipment, the contribution to the total emission is very small. However, determination of O5 requires determination of clean gas emissions, and sometimes the determination of emission concentrations is required to demonstrate compliance with point-source-specific emission limits.	Direct or indirect
O2	Waste water	Mainly from discharge of circulation water from paint overspray scrubbers, minor amounts from EC waste water.	Direct
O3	Product contamination	Only relevant if solvent-based cavity wax is used; small amounts of solvents may remain in the wax film and will evaporate during the final assembly. All paint layers are completely cured in the paint shop dryers before the vehicles are delivered to the final assembly line.	Direct
O4	Uncaptured emissions into air	Open or semi-closed workplaces: a. finish, CP, SD,	Direct

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[53] In some MS, solvents which are transferred as 'waste for recovery' to a waste treatment facility are counted under O6, except if these solvents are returned to the same installation.

Abbre-viation	Mass flow	Explanation (a, b, c, indicates decreasing relevance)	Relevant if … method is applied
		b. waste water treatment and waste handling places.	
O9	Unintended releases	Unusual and irregular emissions like spillages or accidents.	Direct
I2	Recycled solvent	Recovered from captured solvents, reconditioned, and reused in the same installation. Only in rare cases (use as cleaning solvent).	Indirect
Mass flows that are not relevant in motor vehicle paint shops (0 %)			
O7	Solvents as product	Vehicle paint shops do not produce goods with solvents.	

21.5.1.2.2 Choice of direct or indirect method

In some paint shops waste gases are emitted from a few joint stacks (2-8), but in many installations each single waste gas flow is connected to its own stack, resulting in more than 30, sometimes up to 70, stacks of different sizes.

Equations 2 and 3 define two alternative routes for the calculation of total VOC emissions.

The **direct method** (eq. 2) requires the determination of the emissions from each relevant waste gas flow (*O1*) either captured and treated (*O1.1*) or captured and untreated (*O1.2*). This is usually achieved by analytical determination with periodic or continuous measurements (see Section 21.5.1.4). Additionally, the fugitive emissions from open or semi-closed areas of the paint shop (*O4*) and the solvent transfer in waste water (*O2*) must be determined.

By using the **indirect method** (eq. 3) the amounts of solvents which are introduced in the installation (*I1*) and are not emitted but rather destroyed in off-gas treatment facilities (*O5*) or collected and disposed of as waste (*O6*) are determined. The direct emission measurement at individual stacks may not be needed. Likewise, the technically very complicated determination of the fugitive emissions from open or semi-closed areas of the paint shop or the determination of solvents in waste water can be omitted.

Both methods are equivalent
Both methods are generally equivalent from a legal perspective (as both are described in IED Annex VII, Part 7). The operator of an installation is free to choose a method that fits best with his/her specific local conditions, as long as compliance with the ELV can be demonstrated with sufficient reliability and it meets the requirements of the local permitting authority.

However, the direct method is often not employed for the following reasons:

- The number of stacks and thus the number of monitoring points is usually large. Direct measurements at many emission sources are very expensive and the measurement uncertainties of each individual measuring result add up.
- Uncaptured emissions are not easily measurable.

Generally, the indirect method is the most established one (even in other sectors) and gives a higher accuracy because the determination of the emissions by stacks shows strong fluctuations and would require continuous measurements.

21.5.1.3 Input of solvents (I1)

If the SMB is established using the indirect method (eq. 3), the determination of solvent input (solvents in paints and other coating materials, solvents used as thinners or cleaners) is essential. However, it is expedient to record and document solvent consumption data ($C = I1 - O8$) for all installations, because it triggers the classification of the installation according to the different levels of legal requirements of the IED (Annex I, activity 6.7).

The determination of the solvent input, which covers all materials used for the coating process as well as for cleaning of the equipment and paint cabins and its allocation to the various coating subprocesses, is carried out in two steps: determination of material consumption (see Section 21.5.1.3.1) and determination of the solvent content of coating materials (see Section 21.5.1.3.2).

21.5.1.3.1 Material consumption

Table 21.10 shows a typical situation in a vehicle paint shop with a widely used coating concept. For other coating concepts (integrated processes without primer, or topcoats without clear coat), different results will be found. If two or more suppliers are contracted for the same material type, the number of different materials will rise accordingly.

Table 21.10: Typical diversity of coating materials in a passenger car paint shop

Subprocess	Material	Number of different materials
EC	Electrocoats.	2-10
SD	Body sealing and coating plastisols. Sprayable sound-damping materials.	< 10
PR	Primer, also called surfacer or filler. Sometimes different colours are applied.	1-10
BC	Base coat, very many colours and effect types (uni, metallic, pearl, etc.) Consumption is dominated by a small number of high runner colours.	50-400 (all colours) < 10 (high runners)
CC	Clear coat (incl. 2K hardeners).	< 10
Finish, paint repair	Primer, base coats, clear coats, hardeners and thinners. Colours must match BC.	> 400
CP	Cavity preservation.	< 10
Cleaning and rinsing	Solvents used as thinners or cleaning agents, used in different subprocesses.	< 10

Generally, a material database with 200 to more than 1 000 different materials and their respective consumption data is required for the determination of the input into the paint shop in general and its use in the various subprocesses in detail. In SMB calculations, thinners and cleaners are usually assigned to a common subprocess ‘Cleaning and rinsing’ and their use is not allocated to the specific paint applications.[54]

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[54] For the establishment of the solvent balance, it is then necessary to determine the quantity of solvents emitted into the air during the application. For this purpose, the quantity of substances collected and disposed of as solvent waste must be determined. The difference to the quantities used, taking into account an additional quantity of paint in the old solvents, is used to determine an overall emission factor for ‘cleaning and rinsing’.

21.5.1.3.2 Solvent content of coating materials

At best, material suppliers provide comprehensive statements about the solvent contents, which are to be kept on file by the operator. These reports should be provided by the material suppliers on a monthly or annual basis.

Some manufacturers have established company-owned databases with detailed information including verified and confidential composition data on all tested and approved process materials. If supplier reports are not available, solvent content information may be received from these sources.

Thirdly, the solvent content provided by the safety data sheet (VOC content in m %) can be used. It should be kept in mind that in Section 3 of EU safety data sheets, component concentrations represent frame formulations used for deriving the hazard classification. Individual on-site deliveries might have different (lower) solvent contents.

Note that for compliance with the requirements of IED Article 59.5 it is important to check the content of the applied solvents regarding CMR substances or other hazardous organic substances. It is recommended to ask the suppliers for a written confirmation and to check additionally the components data in Section 3 of the safety data sheets.

The IED does not prescribe a specific way to publish solvent contents in coating materials [55]. Usually the values are given in mass percentage. However, solvent contents in vehicle refinishing products must be declared as *'grams/litre (g/l), in the formulation of the product in its ready to use condition'* (Decopaint Directive, Article 2.6). Some paint suppliers also use this definition for general coating materials. Therefore, if 'ready-to-use' solvent concentrations are taken to calculate the solvent input, the amount of solvents which are added on site to adjust the paint to the given solvent content must not be counted as input.

The paint suppliers calculate the solvent contents from the recipe data of their products. Direct analytical measurement of VOC contents in paints, as described in EN ISO 11890-1 and -2 as well as in EN ISO 17895, is not usual.

Table 21.11 shows typical ranges of solvent contents in various paint systems.

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[55] With regard to declaring solvent contents in coating materials there are two relevant pieces of European legislation: (a) the IED which defines VOCs according to their vapour pressure, and (b) Directive 2004/42/EC (Decopaint Directive) which defines VOCs according to their boiling point. Substances with a boiling point or vapour pressure close to the respective threshold values (0.01 ± 0.005 kPa) or (250 ± 20 °C) may be classified as VOCs only in one of the two Directives. VOC data based on the Decopaint Directive should only be used after careful cross-checking. However, for vehicle coatings these differences are rarely relevant as the main components are considered as VOCs in both Directives. If in doubt, the supplier should be contacted.
It is the responsibility of the paint supplier to publish VOC concentration data together with units and the reference to the respective directive, including a statement as to whether the given value represents a 'ready-to-use' value or the real solvent content of the sold material. In some MS, national legislation has introduced specific terms with different units for solvent contents (mass percent, g/l, g/l excluding water, etc.).

Table 21.11: Typical solids and solvent content of coating materials

Substance type	Solids content (%)	Organic solvent content (%)
Electrocoat		
- Dip tank, ready-for-use	16.0 - 20.0	1.0 - 2.0
- Replenishment: resin	-	2.5
- Replenishment: pigment paste	-	9.0
Underbody protection, Seam sealing		
- Underbody coating	95 - 98	2 - 5
- PVC underbody coating	97.2 - 97.6	2.4 - 2.8
- Final underbody wax	79.8	20.2
- Seam sealant	95 - 98	2 - 5
Liquid applied sound deadener	79 - 99	0 - 3
Solvent-based primer	50 - 65	35 - 50
Water-based primer	45 - 55	5 - 12 5.5 - 5.9
Solvent-based topcoat (1)		
- 1K	45 - 60	40 - 55
- 2K	55 - 70	30 - 45
Water-based topcoat (1)		
- 1K	45 - 55	5 - 13
- 2K	45 - 50	12 - 18
Solvent-based base coat		
- Standard (2)	18 -22 (40)	(60) 78 - 82
- High-solids (2)	35 -45 (50)	(50) 55 - 65
High runners	30 - 53	47 - 70
- Special colours	30 - 62	38 - 70
- Ultra-high-solids (3)	-	-
- Integrated processes WB1/2	-	-
Water-based base coat		
- Standard base coat (2)	16 - 22 (40)	12 - 17
- Integrated processes (WB1+WB2) (2)	16 - 30 (40)	10 - 10
Solvent-based clear coat	47 - 54	46 - 53
		43 - 49
- 1K high-solids	55 - 60	40 - 45
- 2K high-solids	55 - 65	35 - 45
Cavity preservation wax	(4)	
- Hot wax	100	0
- Standard solvent wax	50	50
- High-solids solvent wax	48	20
- Standard water-based wax	35	0
- Advanced water-based wax	39	0

(1) Coats without additional clear coat layer.
(2) Values in parenthesis apply for low-opacity colour shades, such as white.
(3) Not used for coating of passenger cars.
(4) Wax, additives, fillers, mineral oil.
Data source: VDI 3455:2013, Emission control - High-volume car body painting plants, Röder, T., Modern cavity protection, in: Automotive Circle (ed.) 2016 – Strategies in Car Body Painting, Bad Nauheim, 2016, data from paint suppliers. Concentration ranges represent the variations found in the most used materials of each class.

21.5.1.4 Measurement of emissions in exhaust gases

21.5.1.4.1 FID measurements

A standard approach is to measure solvent emissions with flame ionisation detection (FID). This procedure is described in EN 12619:2013. The operation of FID is based on the detection of ions formed during combustion of organic compounds in a hydrogen flame. The generation of these ions is proportional to the concentration of organic species in the sample gas stream.

FID measurements are usually reported as ‘propane equivalents’, meaning as the quantity of propane which would produce the same signal (response). FID measurements are often labelled ‘total organic carbon’ (TOC), ‘total hydrocarbons’ or ‘total hydrocarbon content’ (THC), although a more accurate name would be ‘total volatile hydrocarbon content’ (TVHC) as hydrocarbons which have condensed out are not detected. The FID operating range is not completely congruent with the definition of VOCs; in particular, FID cannot differentiate between solvent and non-solvent.

In fact, the measured FID signal depends not only on the carbon content of the components present, but also on the type of carbon bonding in the molecule, and instrument-specific sensitivities must be taken into account. Because of these factors, a response factor *Rf* must be determined and used to modify the propane equivalent signal:

$$Rf = \frac{c_{propane\ eq}}{c_{Substance}} \qquad \text{Equation 5}$$

where:

$c_{Propane\ eq}$ FID reading in either ppm C or mg C/m^3;

$c_{Substance}$ concentration of the measurand in the waste gas in either ppm or mg/m^3.

Response factors for commonly used volatile compounds are usually available from the instrument supplier. In Table 21.12 ranges of response factors for commonly used solvents are presented.

This measurement approach is well established and well accepted. It is easy to use, cost-effective and can provide information over a representative time interval. However, the FID measurement results, given in carbon atom concentration units (TOC in ppm or mg C/m^3), must be converted into solvent concentration in mg/m^3.

21.5.1.4.2 Conversion factors

For conversion from FID results (provided as total carbon) to solvents (requested for solvent mass balances), it is necessary to know the chemical identity of the main gaseous organic components contained in the waste gas flow. Very often 80 % of the total mass consists of less than five different components. These key substances can be determined by additional sample collection (adsorption using solid adsorbent, desorption and separation, identification and quantification of single components with gas chromatography (CEN/TS 13649:2014)), but, due to technical limitations of the analytical methods, typically not all relevant compounds will be captured, analysed and quantified. Alternatively, the composition of the waste gas flow can be calculated using the composition date of the solvent or paint mixture. However, the composition of the liquid (paint, solvent) and vapour (waste gas) phase might be different, as the evaporation rates and partial vapour pressures of the volatile substances concerned are different. Theoretical models are available but are only applicable after laborious verification.

For converting the FID signal of total carbon concentration c_{TOC} into the VOC concentration c_{VOC} (or the mass flow $\dot{M}_{\mathrm{VOC}}$), which is the monitoring target, a conversion factor f_S must be determined:

$$f_S = \frac{c_{\mathrm{VOC}}}{c_{\mathrm{TOC}}} \cong \frac{\bar{M}_{\mathrm{VOC}}}{\bar{M}_{\mathrm{C}}} \qquad \text{Equation 6}$$

where:

$\bar{M}_{\mathrm{VOC}}$	mean molar mass of the VOC mixture;
$\bar{M}_{\mathrm{C}}$	mean molar carbon mass of the VOC mixture;
S	index for the plant segment to be monitored.

If this additional information on major constituents is not available to derive conversion factors, the reference values listed in Table 21.12 may be used to convert TOC into solvent concentration. Table 21.12 provides a list of conversion factors (conversion from mg C to mg substance) and response factors (used for calculating solvent concentrations from FID measurements to TOC concentrations) for common solvents and paints.

As the compositions of organic solvents in coating materials or paint thinners are different, the emissions from the following plant segments (S) can be expected to have different conversion factors:

EC:	application of electrocoat;
SD:	application of sealers, underbody coats and sprayable sound dampeners;
PR/BC:	application of primer or base coat paints (as long as both coating types are either solvent-based (SB) or water-based (WB), both paint systems will have matching conversion factors);
CC:	application of clear coat;
waste gas:	clean gas from thermal treatment systems;
spot repair:	mixture of primer/base coat and clear coat.

Table 21.12: Conversion factors and response factors for common solvents and paints

Substances	Carbon content (%)	Conversion factor	$U_{95\%}$	Response factor	$U_{95\%}$
Solvent mixtures					
Aliphatic hydrocarbons	80	1.2			
Substituted aromatic hydrocarbons	90	1.1			
Oxygenated hydrocarbons	60	1.7			
Alcohols (C1 to C5)	37-65	1.70		0.79	0.18 (1)
Organic acids (C1 to C4)	40-54	1.85-2.50		0.69	
Ketones (C3 to C6)	62-72	1.38-1.61		0.76-0.83	0.16 (1)
Esters (C3 to C6)	49-62	1.61-2.04		0.68-0.83	0.16 (1)
Glycol ethers (C4 to C6)	45-61	1.64-2.22			
Glycol ether esters (C6 to C8)	55-60	1.67-1.82			
Aliphatic hydrocarbons (C4 to C10)	83-86	1.16-1.20		0.94-1.00	0.05 (1)
Aromatic hydrocarbons (C6 to C8)	90-92	1.09-1.11		0.93-1.00	0.05 (1)
Solvents in paints (2)					
WB family paint shops (generic factor for all types of coats and solvents used)	70	1.4			
Water-based paint	68	1.47	0.06		
Solvent-based paint	72	1.39	0.06		
SB 2K clear coat	82	1.22	0.06		
Paints in integrated process paint shops	53	1.88			
Paints in integrated process paint shops	78	1.29			
EC dip tank waste gas		1.67	0.05	0.72	0.02
EC dryer oven exhaust gas		2.3	0.07	0.72	0.02

(1) Numbers describe the range of individual response factors, determined with different FID systems. The uncertainty in each response factor determination is much smaller (~ 0.003).

(2) C content of coating materials is given only as C content of the organic solvents (excluding water and solids content).

21.5.1.4.3 Monitoring

Both continuous and periodic monitoring are well-established approaches for developing solvent mass balances.

Continuous monitoring

Continuous monitoring of solvent emissions from point sources is usually done with automated, officially approved flame ionisation detectors (FIDs). The attached emissions calculator and the software used must also comply with the evaluation standards. Internal calibration of the equipment is carried out at regular intervals.

Measured values (in ppm propane equivalent) shall in principle be used to derive 30-minute mean values and converted to the respective half-hour averages of mg/m^3 solvent. Usually the raw data are converted into class frequencies of emission concentrations of different levels and only these data are used as input to further calculations. The emissions monitoring software identifies system malfunctions and shutdown idle times. Therefore, the reported data cover only valid measurements at normal operating conditions during which solvent emissions can occur.[56] Compared to annual measurements, the continuous determination of TOC concentrations is more expensive by a factor of 8 to 10.

Periodic monitoring

Periodic monitoring is usually carried out with the FID method, described in EN 12619. The primary result is a stream of ‘ppm TOC’ raw data. These are transformed into solvent concentrations as described in Section 21.5.1.4.2 (conversion factors).

Only in exceptional cases is monitoring carried out by taking samples and off-site gas chromatography (GC) analysis of the collected organic substances (CEN/TS 13642).

21.5.1.5 Calculation of mass flows from emission concentration measurements

Measured emission mass flows from stacks are always determined from the simultaneous measurement of substance concentrations and the flue-gas volume. If the determination of solvent mass flows is part of the measuring task, the necessary parameters for the calculation of the exhaust gas volume flow are simultaneously determined, in addition to the actual pollutant measurement. Therefore, solvent mass flows which are determined either continuously or periodically are usually based on matching pairs of substance concentration and waste gas flow figures. It should be noted that the volumetric flow rate measurement is an important contributor to the uncertainty of the overall mass release calculation.

21.5.1.5.1 Emission factors

One way to cope with this intrinsic disadvantage of periodic monitoring is to supplement each sampling and monitoring campaign for a specific release point by recording the throughput of coated bodies (product units) and/or coating material (solvents) in the application process which is connected to the respective release point p. Then an emission factor ef_p, can be derived, which represents the relation between measured emission mass flow (e.g. kg/h) and the throughput of products or coating material/solvent:

$$ef_p = \frac{E_p}{n_p} \quad \text{or} \quad ef_p = \frac{E_p}{I_p} \qquad \text{Equation 7}$$

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[56] In practical operation, it has been shown that, after the completion of painting processes, the release of solvents does not abruptly return to zero. In particular, dissolved solvents are further released (stripped) from wet scrubbers over a longer period (1-2 h). This must be respected in the configuration of the emission calculation software.

where:

E_p emission mass flow from the stack p during the monitoring exercise, in kg/h;

n_p production volume (number of coated bodies) in u/h;

I_p material or solvents consumed in kg/h in the upstream application process during the monitoring exercise.

The advantage of this method is that a more realistic result of the annual emission is attained, especially if the factory operates with changing production levels.

21.5.1.5.2 Captured solvents (O1)

Only if the direct method (eq. 2) is used for the calculation of the solvent mass balance must direct emissions be measured or assessed for all emission sources with captured solvents.

However, raw gas and clean gas solvent concentrations at off-gas treatment units need to be measured if the abatement efficiency is determined.

The solvents contained in the clean gas from off-gas treatment units usually contribute about 1.5 % to 3.0 % of the total paint shop emissions. Emission monitoring will therefore focus on providing proof of the correct operation of the off-gas treatment system at all operating conditions rather than on determining the emission mass flows exactly.

In the case of thermal oxidisers, combustion temperature control is the standard procedure for function control. Target values are set for each individual combustion chamber in such a way that all emission limits to be taken into account (for example, TOC, CO, NO_X) are maintained with the lowest possible fuel consumption. It is recommended that these calibration measurements be carried out after commissioning or after technical modifications to the system or in the upstream coating process and that they are repeated at regular intervals.

$O1.1$ can be calculated for each point source p in several ways (see also VDI 3455:2013):

- Using the result of the most <u>recent calibration measurement</u>

$$O1.1_p = c_p \times \dot{V}_p \times t_p \qquad \text{Equation 8}$$

where:

c_p solvent emission concentration of the last periodic measurement of point source p;

$\dot{V}_p$ average flue-gas flow;

t_p operating time of the off-gas treatment unit p.

These measurements should be carried out after commissioning or after technical modifications to the system or in the upstream coating process and may be repeated every 3 to 5 years.

- Using emissions factors

As described in Section 21.5.1.5.1 (Emission factors, eq. 7), the emissions from a point source can be calculated if the relation between a suitable activity, like consumption of solvents in a coating process, and the resulting emission is known. In the case of emissions from an off-gas treatment system, the emission factor ef_p can be expressed as a combination of a transfer factor tf_S and the abatement efficiency af_p:

$$O_{1.1,p} = I_S \times tf_{SP} \times (1 - af_P) \qquad \text{Equation 9}$$

where:

I_S	input of solvents into the paint shop segment S, upstream of the abatement system;
tf_{SP}	transfer factor between the paint shop segment S and the off-gas treatment system P;
af_P	abatement efficiency of the gas treatment system P.

Instead of using solvent input data, the calculation can also be based on body count data (see Section 21.5.1.5.6). These measurements should be carried out after commissioning or after technical modifications to the system or in the upstream coating process.

- Using emission limit values

Instead of a measured solvent concentration, an emission limit value can be introduced in eq. 8. As real emission must not exceed emission limit values, the result derived by this method is a conservative estimation of the actual solvent emission, provided the proper functioning of the off-gas treatment system can be demonstrated by continuous operation monitoring (e.g. combustion temperature).

- Using continuous measuring

Continuous monitoring of solvents in purified waste gas is rarely used. The IED requires continuous monitoring only if the clean gas output at the respective stack is higher than 10 kg/h TOC. At an assumed emission concentration of 50 mg/m^3 TOC, this threshold value is reached only with exhaust gas flow rates of 200 000 m^3/h.

As described above, there are a number of equally valid methods which can be used, and the chosen method to determine mass emissions for stacks is the site/installation's decision.

21.5.1.5.3 Destroyed solvents (O5)

The amount of abated solvents only needs to be determined if the SMB is calculated with the indirect method.

O5 includes all solvents which have been introduced in the process and are transformed by chemical reactions to substances which are no longer volatile organic compounds. In vehicle paint shops these reactions are usually thermal oxidation in off-gas treatment facilities. Catalytic oxidation or biological degradation are possible but unusual alternatives.

Solvents which are captured in the STS installation and transferred across the SMB border as solvents (as waste solvent or contained in wastes, in water, as products or product contamination, etc.) cannot be counted as *O5*.

The amount of $O5_{P}O5_{P}$ (per treatment system P) is the difference between the solvent quantity that enters the treatment system from one or more application segments with the raw flue-gas and the mass flow in clean flue-gas. The mass flows in the raw gas and clean gas of the treatment system can be either simultaneously measured (eq. 10) or calculated using transfer and abatement factors (eq. 11):

$$O5_P = O1.1_{SP}^{in} - O1.1_P \quad \text{Equation 10}$$

$$O5_S = I_S \times tf_{SP} \times af_P \quad \text{Equation 11}$$

where:

$O1.1_{SP}^{in}$	solvents in flue-gas input from paint shop segment S to the off-gas treatment equipment P;
tf_{SP}	transfer factor of solvents from a paint shop segment S to the off-gas treatment system P;
af_P	abatement factor of the off-gas treatment system P (see below).

If the average capacity utilisation of the paint shop deviates significantly, the values determined for *O5* with eq. 10 may have to be recalculated. In these cases, O5 can be determined for example by the use of transfer and emission factors according to eq. 11.

Because *O5* is a very important quantity for the indirect method, for each installation an appropriate way for determining reliable values for it has to be found. Generally, this has to be agreed with the competent authority. If transfer factors are not known or cannot be measured with sufficiently reliability, repeated spot measurements of the raw gas solvent mass flow might be appropriate to derive reliable annual $O1.1_{SP}^{in}$ data. In the case of central abatement units, where waste gases from several application cabins or dryer ovens are collected, continuous measurement may be a cost-effective alternative.

21.5.1.5.4 Abatement efficiencies

The abatement efficiency af_P of an off-gas treatment facility is defined as:

$$af_P = (1 - \frac{\dot{m}_{TOC,}^{out}}{\dot{m}_{TOC}^{in}}) \quad \text{Equation 12}$$

where:

$\dot{m}_{TOC,}^{in/out}$	input and output mass flow of total organic carbon.

Under normal conditions, the directly measured TOC concentrations can also be used for this formula, since the standard volume flows before and after the off-gas treatment facility are practically constant. Indeed, the exhaust gas volume flow is increased by about 1 % by the addition of natural gas (fuel), as well as by the evaporation of liquid substances and the formation of new organic compounds during the cross-linking of the coating resins plus about 1 % uncontrolled entries of air into the system operated with a slight vacuum. Overall, however, this influence is negligible for usual off-gas treatment abatement efficiencies > 90 %.

If reliable data on abatement efficiencies of the operated off-gas treatment are not available, data from Table 21.13 can be used. See also information on abatement efficiency in Table 21.28 and Table 21.29.

Table 21.13: Reported abatement efficiencies of off-gas treatment systems used in vehicle paint shops

Off-gas treatment system	Abatement efficiency (%)	Comments
RecTO	98.13	Average value reported from 38 paint shops. The 50 % mid-range is 97.4-99.5 %.
RTO-2bed	90.73	Average value reported from 4 paint shops. The max.-min. range is 99.5-66.1 %.
RTO-3bed	93.87	Average value reported from 4 paint shops. The max.-min. range is 98-87.8 %.
RTO-RAD	96.03	Average value reported from 4 paint shops. The max.-min. range is 99.1-90 %.
TO	97.12	Average value reported from 19 paint shops. The 50 % mid-range is 94.5-97.1 %.

Source: [155, TWG 2016]

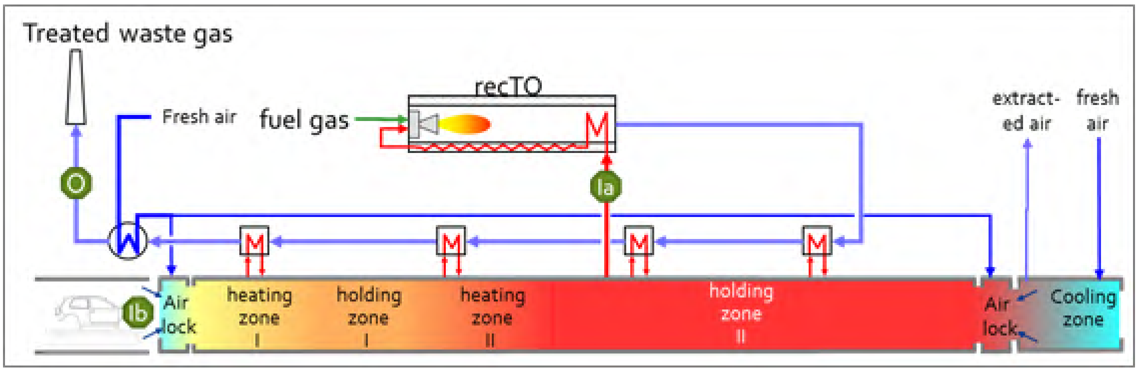
Very often, off-gas treatment units are connected to one or more dryer ovens or are an integrated part of the dryer system (like most recuperative oxidisers which are also used for oven heating). In this case, the measuring of $O1.1_{SP}^{in}$ can be done at two locations (Figure 21.5):

1a. The measuring point is located between the dryer and the off-gas treatment system. This is the usual place and the sampling procedure is the standard probing in flue-gas ducts.
The measurement result will also include organic substances which evaporate only at elevated temperatures (oven temperatures > 130 °C) and volatile organic reaction products of the paint resin curing reaction (especially if melamine resins are used, e.g. in e-coat 8 % to 15 % of the solids are transformed into gaseous products).

1b. The measuring point is located between the paint application cabin and the attached dryer oven. Test bodies are equipped with several metallic foils (approximately 0.1 m to 0.3 m) and painted and dried as usual. The films are each weighed before coating, and before and after the drying run. For water-based paints, the water content of the damp lacquer layer must also be determined.
The procedure measures the transfer of solvents in the wet coating layer into the oven. These solvents are subsequently treated in the off-gas treatment system. However, the solvent quantity introduced into the dryer via the air intake from the spray booth through the airlock to the dryer is not recorded by this method. The direct measurement of this flow would require very complex sampling procedures.

Procedure 1b is a standard method in the United States but is not used in Europe for the following reasons:

- difficult to carry out;
- high measurement uncertainty;
- additional airborne inputs from the application zone are not recorded.



Ia: measurement of solvents in the oven exhaust gas.
Ib: measurement of solvents carried over into the dryer oven with the wet paint film.
O: measurement of the treated waste gas.
Source: VDI 3455:2013 modified by [143, ACEA 2017]

Figure 21.5: Measuring points to determine abatement efficiency in off-gas treatment units in a dryer oven off-gas treatment combination

21.5.1.5.5 Solvents in waste (O6)

The amount of waste solvents or solvents in waste only need to be determined if the SMB is calculated with the indirect method.

Waste types
An assessment of information in the STS questionnaires shows that the following solvent-carrying waste types are relevant in vehicle paint shops [144, ACEA 2017].

Waste paint
Waste paint is understood as expired paint material or paint which is to be disposed of for other reasons. Its composition resembles the composition of the new material; however, small amounts of solvents may be added on site for viscosity adjustment.[57] Usually the solvent content of the waste is proportional to the solvent content of the new paint: water-based paints below 30 %, 2K CC about 50 % and solvent-based paints usually above 50 %. In most cases, waste paint is collected and disposed of as a mix of all types of paint. Then the reported solvent contents in waste paint will differ from the solvent contents of the different paint systems used.

Plastisols including sealers and adhesives
Plastisols, like seam-sealing materials, adhesives or underbody coats, are usually applied after electrocoating and before spray-painting operations. Chemically, they are macromolecular materials (PVC, PU-, rubber or epoxy resins, etc.) with different amounts of plasticisers, sometimes with a VOC-like volatility. Plastisol wastes are either expired material in containers, plastic foils with droppings or stoppers with sticking sealants or underbody coats.

Used solvents
Used solvents are usually thinners or organic cleaning agents mixed with different amounts of paint. They are generated and collected at paint change or bell cleaning processes. Three subtypes of used solvents with different solvent contents can be distinguished:

‘H’: high solvent concentration: clear coat applications or if solvent-based paints are used.

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[57] If paint is withdrawn by the original paint supplier for reuse, it is not subject to the rules of waste legislation, but for the calculation of the solvent mass balance these quantities have to be added to O6 rather than subtracted from I1.

‘M’: medium solvent concentration: storage of ‘H’- and ‘L’-type solvent wastes in the same tank.
‘L’: low solvent concentration: usually butylglycol-water mixtures with water-based primer or base coat.

Paint sludge
Paint overspray from spray-painting operations is introduced in off-gas treatment systems to reduce the (paint) particle concentration in the exhaust air. The precipitated paint particles are removed from the water reservoir of wet scrubber systems by coagulation and sedimentation. The primary paint sludge is further dewatered using different techniques, which yield pasty (> 80 % water) or solid (< 40 % water) waste.

Until recently venturi scrubbers or equivalent wet scrubber systems were used in all large vehicle paint shops. In new installations, dry particle filters are now usually installed instead and paint particles are either captured in ground limestone or adsorbed in cardboard filter boxes.

Limestone
Ground limestone is used as pre-coat material for particle filters. Used material carries dry paint droplets and small amounts of solvents.

Other solvent-containing waste
All other solvent-containing wastes are placed in this group. Examples are: packaging material, filters, spent waxes, wiping cloths.

Usually, waste management covers all activities of the factory and waste transfer figures are available only as factory-wide data. If other activities with solvent use are undertaken at the same site, it may be difficult to assign the correct mass flow to the paint shop for which the SMB has to be established.

Table 21.14: Solvent-containing wastes

Waste	**Solvent concentration (wt- %)**		**Contribution to *O6* (g/m^2)**		**Comments**
	Median	**Range**	**Median**	**Range**	
Waste paint	**28**	12-50	**0.3**	0.2-0.6	
Plastisols, sealers, adhesives	**2.2**	1.2-4-1	**0.1**	0.0-0.3	
Used solvents High solvent Medium solvent Low solvent	 **92** **53** **10**	 88-99 50-55 3-17	**5.7**	2.9-11.6	Contribution to *O6* shows a large variation
Paint sludge	**2.0**	0.6-3.8	**0.3**	0.1-0.6	
Limestone	**0.2**		**0.2**		Only 1 sample
Other solvent-carrying waste	**1.5**	0.5-29	**< 0.1**	0.0-0.3	

Source: Data from STS Questionnaires [144, ACEA 2017] and additional information from STS TWG. The ranges are given as 50 % mid-range.

Determination of solvent contents in waste
In some cases, solvent contents in waste are measured by the waste disposal enterprise, but only for solvents which are disposed of for reuse is this done on a regular basis. The input analysis of the waste disposal enterprises is focused on other parameters.

As can be seen from Table 21.14, parameter *O6* is usually dominated by the amount of used solvents which are recovered or disposed of. Frequently, the origin of the solvent waste is known, e.g. colour change or bell purging, so the composition of the solvent waste can be estimated from the composition of the ingredients involved (x % solvent + y % paint), and the associated uncertainty of such an estimate might be below 10 %.

There appears to be no generally applicable analytical method for solvents in waste. For pasty wastes or sludges, an analytical method adapted to the standard EN ISO 11890-1 (determination of solvents in liquid paints) is used in some cases. The solvent content is determined from the mass loss when drying a waste sample at 110 °C for 1 hour. Alternatively, solvent contents are determined by analytical determination of single volatile substances using GC methods. Such a procedure is recommended for the determination of solvents in liquid paints if the solvent concentration is supposed to be below 15 % (EN ISO 11890-2).

Representative sampling of solid and pasty waste is a particularly important aspect. Many types of waste are inherently inhomogeneous. Furthermore, it is expected that a sample taken from the surface of a longer-stored waste will have a different solvent composition to a sample from the centre of the waste.

In addition to the sampling-related and process-specific uncertainties of the applied analytical method, it should also be borne in mind when evaluating the results of the measurements that the results referred to as ‘volatile organic compounds’ might not fulfil the IED criteria for ‘organic solvent’.

The expected reliability of the measured solvent contents of pasty waste or sludge is very low. However, as can be seen from Table 21.14, the expected contribution to O6 of these types of waste is usually very small so even high uncertainties do not have a significant effect on the overall result.

If installation-specific data are not available, solvent content data from this table can be used. However, due to the large spread of these average values, it is recommended to determine the solvent content of a waste fraction if its contribution expressed in g/m^2 exceeds 3 % of the total emission of the installation

Solvents in waste water (O2)

Relevant solvent contents are only to be found in the circulating water of wet separators for paint overspray, in dryer oven condensates, and in waste water from the electrophoretic dip coating. Wet overspray separators are usually run as closed-loop systems and reach service lives of more than 1 year. Paint sludge and solvent are continuously discharged from the wash water and disposed of as paint sludge (*O6*).

Solvent-containing waste water therefore occurs only irregularly or with low continuous flows. Solvent contents between 2.2 g/l and 3.2 g/l are reported. Hence, the contribution to the total emission is very low.

New facilities with dry overspray filtration do not produce waste water with solvents.

If organic solvents in water are treated in a waste water treatment plant (WWTP) which is operated on the same site, the abated quantity is *O5*, and only the remaining quantity which leaves the installation is *O2*.

To determine the solvent content, different measuring methods are used, which have been developed for the monitoring of organic contaminants in waste water. When evaluating the results of these measurements, it should be noted that the term ‘VOC’ used in water analysis cannot be equated with ‘VOC’ defined in the IED. Actually, there is no approved standard to measure solvents as defined in the IED.

21.5.1.5.6 Reference area (A)

Annual total surface area

The surface area of any product considered in the mass balance calculation is defined as follows: The total surface area of the product coated in the installation in the respective year or reporting period, including new vehicles and any other new parts which will ultimately be applied to vehicles.

The total surface area A is obtained from the surface area of coated products which are transferred from the paint shop to the final assembly or into use elsewhere (e.g. coated service parts and coated production parts for non-local sites).

When painting the same body for a second time (second run), its surface will only be counted once for the surface calculation. Where product quantity is not assessed between the paint shop and final assembly, finished product numbers leaving final assembly can be applied instead.

In some cases, modifications in body/product and surface counting may be appropriate. A common example is painting of service parts in a vehicle paint shop, which are usually passed out from the installation after the e-coat or primer. Another example is painting of small production parts in a vehicle manufacturing site which are destined for fitting at a different site to the site of manufacture.

Calculation of the body surface

The surface area which must be determined for the calculation of the relative solvent emissions E^r is determined using CAD calculation systems.

In vehicle production, the design details of each individual part of the body shell are managed in CAD systems. There are different systems, but all can calculate the part surface. The construction state of the body shells, which are fed into the paint shop, can be taken from bills of materials (BOM) or assembly protocols.

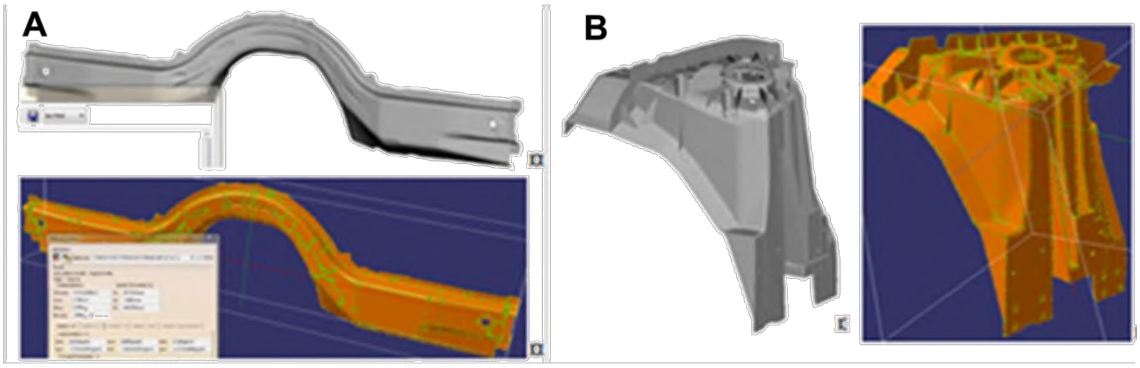
The body surface is determined in two steps:

- Definition of the models and model variations to be calculated. Since even for body in white shells there are up to several hundred production variants, a representative selection of one to approximately five model variants must be made - with regard to the number of parts and different surfaces.
- Determination of the total surface area of the corresponding individual parts by combining CAD and BOM data. For practical reasons, the determination can be limited to the most important parts, e.g. 90 % of the total mass of the body shell. The total surface can then be determined by extrapolation.

Table 21.15: Example of CAD surface areas of vehicle parts

CAD System	Steel sheet		Cast part	
	ANSA®	CATIA®	ANSA®	CATIA®
Surface 1 side 2 sides	0.395 m^2 0.790 m^2	0.799 m^2	0.379 m^2 0.758 m^2	0.682 m^2
Differences	1 %		11 %	

NB: The ANSA® system provides only the area of one side. In the case of press parts, the total surface area can be calculated by duplication with sufficient accuracy. For complex bodies such as castings, only systems such as CATIA® should be used which calculate the complete surface area of the item.
Source: [142, ACEA 2016]



NB: a) Steel sheet, b) Cast part.
Source: [142, ACEA 2016]

Figure 21.6: Example of CAD surface areas of vehicle parts

The surface area of a body in white shell can be calculated with an enhanced uncertainty of < 2 %.

The different types or modifications of vehicles and their respective surface area (in m^2/unit) that are processed in the respective paint shop should be listed in the SMB report in a table with the type of vehicle produced together with the produced numbers and surface area. Finally, the average surface area is determined by adding the surface areas of all vehicles produced divided by the total number of vehicles produced.

The following statistics were derived on averaged surface areas reported for 73 passenger car (including LCV) paint shops in the EU for 2012 [142, ACEA 2016]:

average reference surface area:	97 m^2;
50% mid-range:	88 m^2 to 107 m^2,
maximum:	160 m^2.

The numbers refer to the average value for all different vehicle types painted in respective installations.

The calculation of the vehicle surface with CAD and BOM data is rarely used in truck chassis and bus paint shops, because there are too many individual variants with large differences in surface area but a low production volume for each variant. With the approval of the competent licensing authorities, alternative calculation formulas are applied, each of which is tailored to the design of the chassis or the coach body as well as to the extent of the coating activities.

21.5.1.6 Uncertainty considerations

21.5.1.6.1 Enhanced uncertainty

Inevitably, even the best measurement result is uncertain. This is true also for calculated number total emissions from solvent mass balance calculations, as measured or estimated data are used in this exercise.

Several sources of uncertainty can be identified for the respective elements of the solvent mass balance:

1) Uncertainty of input I1: Uncertainty in determining I1 stems from inaccuracies in determining the exact amount of used paints. In large paint shops this uncertainty is considered

very small. In addition, another source of uncertainty is the variation in the solvent content of different paints provided by the paint supplier. Measures to reduce uncertainty of I1:

- Tracking material consumption per colour.
- Tracking the amount of solvent used for viscosity adjustment as well as tracking VOC content per colour.

2) Uncertainty of emitted and destroyed solvents (*O1* and *O5*): The uncertainty associated with VOCs in waste gases is influenced by the destruction efficiency of the afterburner, the amount of solvent diverted to the afterburner and the running time of the equipment. The uncertainty of the measurement of VOCs is an additional factor.
Measures to reduce uncertainty of *O1* and *O5*:

- The solvent mass balance should take account of breakdown of control equipment.
- Use of accredited laboratories to measure VOCs.

3) Uncertainty of solvent in waste *O6*: Uncertainty of *O6* stems from the variation in solvent content of the waste batch and the analytical method.
Measures to reduce uncertainty of *O6*:

- Analysis of solvent content in waste, where O6 has a significant impact on the solvent mass balance.
- Use of accredited laboratory for waste analysis.

Solvent in waste water *O2* is usually a very small amount and solvent in product *O7* is not relevant in a solvent mass balance for a vehicle paint shop.

21.5.1.7 SMB records / reporting

The SMB report should present all results and contextual information which are necessary to follow the calculation steps and verify the results and assumptions or estimates made. With regard to these considerations, it is recommended that the following elements are either included in the SMB report or retained as supplements for discussions with the competent authority:

- Simplified layout of the installation including:
  - relevant process steps and secondary installations (mix room, WWTP, waste handling areas (if relevant);
  - off-gas treatment equipment (process type, technical data);
  - stacks (release points of VOCs into the air: position, dimensions, upstream processes);
  - release points of waste water (with VOCs), destination of waste water after it leaves the paint shop.
- Description of the calculation process (equations used).
- Description of data sources.
- Contextual information for each calculation parameter applied, like off-gas treatment efficiencies, emission factors, conversion factors:
  - definition;
  - date of last determination;
  - reference to the respective measurement report (must be kept available for the competent authority);
  - statement as to why the parameter used is applicable (e.g. ‘paint shop design, material and application method not changed since last determination’);
  - consideration of the uncertainty of the result.

- As annexes:
    - raw data used;
    - measurement reports, if direct measurements were used for the establishment of the solvent balance.

21.5.2 Solvent mass balance for the coil coating sector

[177, ECCA 2017] [212, TWG 2018] [264, TWG 2019]

For a general description, see Section 17.3.1.

21.5.2.1 Introduction

The solvent mass balance (SMB) calculation for a coil coating line is a method for estimating the following:

a) The annual input of solvent into the installation (expressed in tonnes/year).
b) An estimation of the fugitive emissions (expressed in tonnes/year).
c) The amount of fugitive emissions as a percentage of the solvent input.

The information contained in the following sections is provided as guidance for those wishing to carry out SMB calculations within the coil coating industry. It does not describe how to monitor waste gas emissions or how to verify compliance of these waste gas emissions with their applicable emission limit value. The uncertainties associated with the method are discussed in Section 21.5.2.3.

21.5.2.2 Solvent mass balance equation for coil coating

The solvent mass balance equation contains a number of mass flow terms:

Fugitive emissions = $O2+O3+O4+O9 = I1+I2 - (O1+O5+O6+O7+O8)$ Equation (1)

and $(O2+O3+O4+O9)/(I1+I2) < \text{ELV}$ (emission limit value) for an installation to be in compliance.

These terms and their relevance to the coil coating sector are described in Table 21.16.

By defining the relevance of each term, it is possible to simplify the overall equation. According to IED definitions (Part 7 of Annex VII), for a coil coating line, parameters O2, O3 and O9 are zero. For the sake of simplicity, O7 may also be considered as zero as it is not relevant for coil coating.

Therefore Equation (1) becomes:

Fugitive emissions $F = 0 + 0 + O4 + 0 = I1+I2 – O1 – O5 – O6 - O8$

with $O8 = 0$ when the recovered solvent is not sold into other applications.

Therefore, Equation (1) becomes $\mathbf{F = O4 = I1+I2 – O1 – O5 – O6}$ or

$\mathbf{F = I_{total} – O1 – O5 – O6}$

where:

I_{total}	the amount of solvent that enters the plant over the period considered for the solvent mass balance. Both the new and recycled solvent is mainly contained in the paint but is also contained in the materials used for cleaning the equipment.
O1 & O5	the amount of solvent within the captured air. Much of the VOCs in the captured airflow is abated with treatment efficiencies of the order of 99.7-99.8%.
O6	VOCs contained in collected waste. Cleaning a machine (roller coaters) involves using solvent and rags. Part of the dirty solvent can be reused, part is a liquid waste.

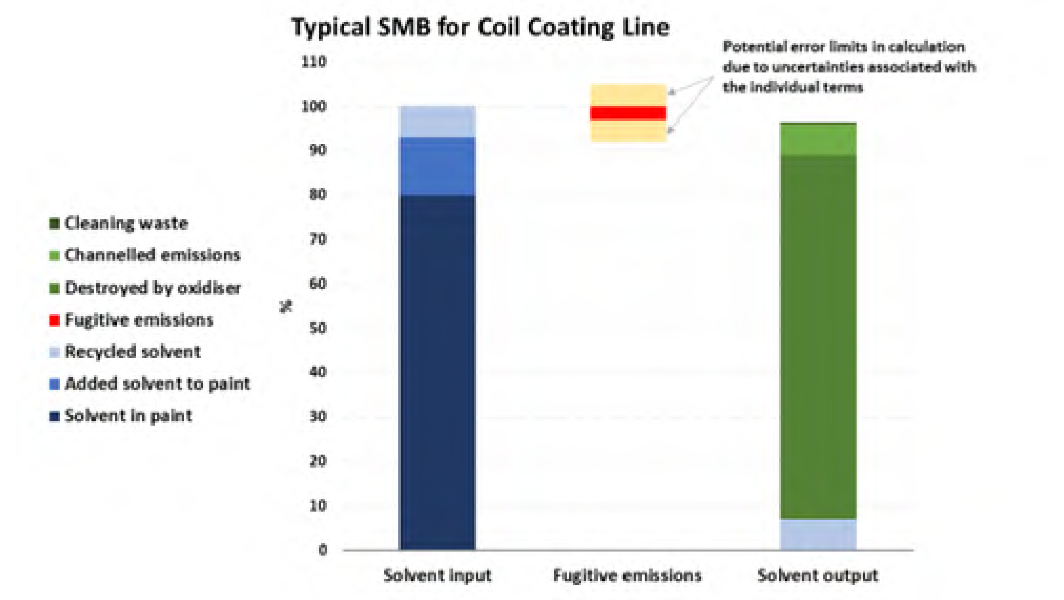
For a well-managed coil coating line, $\mathbf{I_{total} \sim (O1 + O5 + O6)}$

Table 21.16: Mass flows for the solvent mass balance and their relevance for the coil coating sector

Parameter	Mass flow	Relevant	Explanation
Input of VOCs as solvent			
I1	The quantity of organic solvents or their quantity in mixtures purchased which are used as input into the process in the time frame over which the mass balance is being calculated.	**Yes**	Coil coating paints typically contain between 30 % and 70 % solvent depending on the system (Table 6.4). Solvents are also purchased for cleaning the equipment.
I2	The quantity of organic solvents or their quantity in mixtures recovered and reused as solvent input into the process. The recycled solvent is counted every time it is used to carry out the activity.	**Yes**	Some coil coating plants recover solvent from cleaning and mixing processes which is then reused during later production runs.
Output of VOCs into the air			
O1	Emissions in waste gases. O1.1 Contained and cleaned. O1.2 Contained and not cleaned.	**Yes**	O1.1: Emissions to air from external or integrated thermal oxidiser. O1.2: Exhaust air from untreated waste stream, e.g. air cooling of strip. O1.1 is a key component of every coil coating SMB. The use of O1.2 depends on the configuration of the coil coating line.
O2	Solvent in waste water.	No	The only water to come into contact with the prepainted metal is at the quench units after curing. All VOCs have been removed by that stage in the process. The IED defines this term as zero for coil coating.
O4	Fugitive emissions released to the outside environment via windows, doors, vents and similar openings.	**Yes**	Very difficult to measure directly. Coil coating units are usually fully enclosed to minimise fugitive emissions.
O9	Organic solvents released in other ways.	No	For example: accidents, spillages, leakages. The IED defines this term as zero for coil coating.
Destroyed VOCs			
O5	Organic solvents and/or organic compounds lost due to chemical or physical reactions, including those which are destroyed, by incineration or other waste gas or contained (as long as they are not counted under O6, O7 or O8).	**Yes**	All coil coating lines operate thermal oxidisers and energy recovery schemes to maximise the destruction of solvent VOCs and to optimise energy usage within the installation. Abatement efficiencies in the oxidisers are of the order of 99.8 %.
Other outputs of VOCs			
O3	The quantity of organic solvents which remains as contamination or residue in product output from the process.	No	For coil coating, the amount of solvent left in the final product is negligible and should be ignored in the SMB. Also, according to IED Annex VII, Part 2, No 1, footnote 1, the solvent residue in the finished products is not to be considered as part of fugitive emissions.
O6	VOCs contained in collected waste.	**Yes**	Cleaning of the applicator equipment requires solvents and rags. Part of the dirty solvent can be reused, part is liquid waste. Dirty rags are a solid waste. Both dirty solvent and used rags are generally stored in empty paint drums.

Para-meter	Mass flow	Relevant	Explanation
O7	Organic solvents or organic solvents contained in mixtures, which are sold or are intended to be sold as a commercially valuable product.	No	Not an activity associated with the coil coating industry.
O8	Organic solvents contained in mixtures recovered for reuse but not as input into the process (if not counted under O7).	Depends on individual situations.	Some companies may dispose of some recovered solvent into non-coil coating applications. The default situation for coil coating is that all recovered solvent is reused in the process.

The typical proportions of these terms in a coil coating SMB are shown below.



Source: [177, ECCA 2017] [264, TWG 2019]

Figure 21.7: Example of a typical SMB for a coil coating line

The calculation of fugitive emissions within the coil coating sector involves the subtraction of the summation of some large terms (O1, O5, O6) from one large term (I_{total}) to derive a relatively small number. This may lead to significant levels of uncertainty in the calculated value for fugitive emissions as a result of uncertainties in the various terms in the SMB.

21.5.2.3 Sources of uncertainty in I1 for the SMB calculation for coil coating

Parameter I1 is a key quantity (kg) in the overall calculations for the SMB methodology. I1 is calculated as follows:

$$I1(kg) = \Sigma\ (V_{\text{paint reference}}\ x\ C_{\text{paint reference}}) + V_{\text{cleaning solvent}}$$

where:

$V_{\text{paint reference}}$	total volume of paint purchased for the painting activity;
$C_{\text{paint reference}}$	solvent concentration of the paint reference;
$V_{\text{cleaning solvent}}$	total volume of solvent purchased for cleaning.

Parameter I2 (recycled solvent) is less important due to the small quantities involved and the fact that the amount added to thin the paints is easily measured, giving a low level of uncertainty on this term.

21.5.2.3.1 Uncertainty in calculating the volume of paint ($V_{\text{paint reference}}$)

The difficulty in defining the volume of paint used within the reference period comes from the difficulty of having a perfect inventory of material in a business where thousands of drums are used annually, sometimes returned and reused, and where hundreds of different paint types are required to meet market demand.

The main sources of uncertainty in calculating V_{paint} are given in Table 21.17.

Table 21.17: Main sources of uncertainty in calculating $V_{\text{paint reference}}$

Topic	Area	Typical volume	Sources of uncertainty
Paint storage (multiplicity of storage locations)	Main storage facility	1 000 drums	Content of the drums, particularly those that have been partially used.
	Tanks for bulk products, e.g. primer	40 m^3 of paint per tank, possibly 3 tanks per location	Accuracy of measurement of the paint volume in the tank.
	Preparation area 'paint kitchen'	10-15 drums	Amount of solvent mixed with paint prior to application.
	Application room	< 5 drums	Amount of paint left in drums after application.
Stock management	Daily deliveries	20-50 drums per day	Inconsistency of data entry into stock management system.
	Leftover paint	20-50 drums per day	Volume of unused paint that is returned to the system.
Paint consumption	Paint yield	Per barrel	The solvent content of the paint is usually reported as ± 5 %.
	Coil length	Per order	The actual length of the coil is slightly different from the expected one: measuring its length is only possible with an uncertainty of ± 0.05 %.
	Painted length	Per order	Painted length can be significantly different to the coil length due to quality issues with the substrate.
	Paint thickness	Per order	The accuracy of the tools for measuring thickness is ± 1 µm. With most paint systems, the accuracy of the paint thickness is therefore ± 5 % for a nominal 20 µm coating.
Source: [177, ECCA 2017] [264, TWG 2019]			

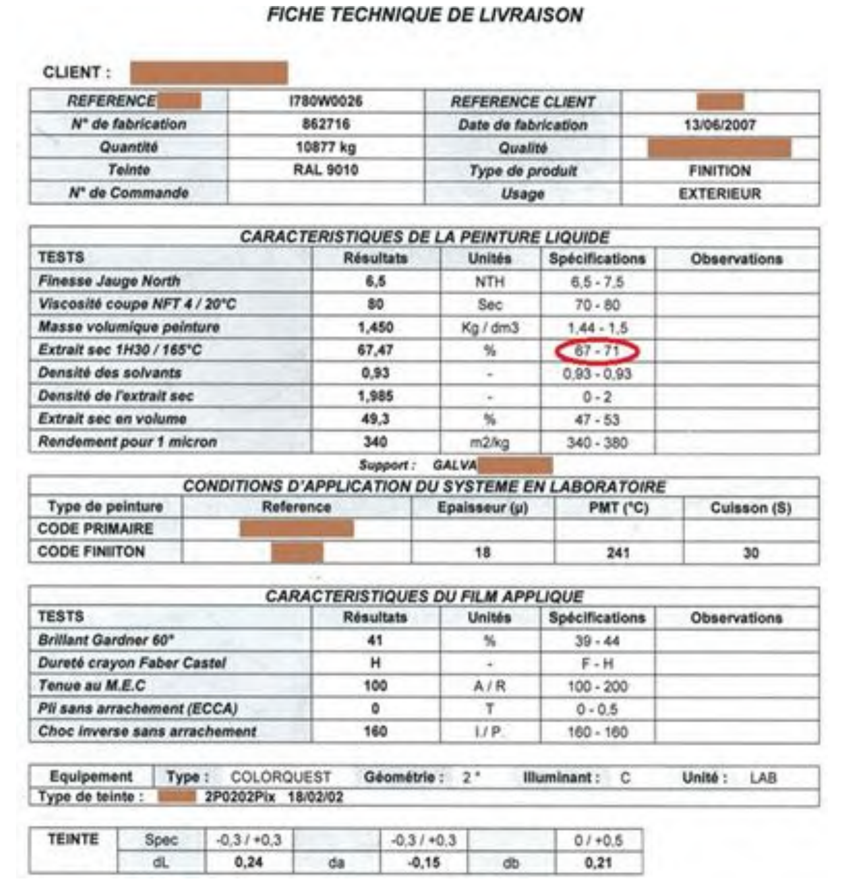
The uncertainty linked to miscalculating the number of drums being stored at the facility is relatively low and a conservative estimate is ± **0.1 %**. There is a higher uncertainty linked to the volume of paint contained in the drums than to the number of drums. The impact of the inaccurate measurement/estimation of the volume of paint in the drums on the uncertainty of $V_{\text{paint reference}}$ is of the order of ± **0.8 %**. Calculating the paint consumption from the paint yield, the painted surface and the coating thickness is impossible with an accuracy better than ± **8 %**. Overall, these factors give a maximum uncertainty for the calculation of $V_{\text{paint reference}}$ of ± **1 %**.

21.5.2.3.2 Uncertainty in calculating the volume of solvent in the paint ($C_{\text{paint reference}}$)

There are two main sources of uncertainty in determining the volume of solvent in the paint used by the coil coating line during the reference period for the SMB. These are the following:

(a) Inaccuracy of the technical data sheets for each paint

The following figure illustrates the uncertainty in the solvent concentration of the paint detailed in the following technical data sheet.



FICHE TECHNIQUE DE LIVRAISON

CLIENT : [redacted]

REFERENCE[redacted]	I780W0026	*REFERENCE CLIENT*	[redacted]
N° de fabrication	862716	*Date de fabrication*	13/06/2007
Quantité	10877 kg	*Qualité*	[redacted]
Teinte	RAL 9010	*Type de produit*	FINITION
N° de Commande		*Usage*	EXTERIEUR

CARACTERISTIQUES DE LA PEINTURE LIQUIDE

TESTS	Résultats	Unités	Spécifications	Observations
Finesse Jauge North	6,5	NTH	6,5 - 7,5	
Viscosité coupe NFT 4 / 20°C	80	Sec	70 - 80	
Masse volumique peinture	1,450	Kg / dm3	1,44 - 1,5	
Extrait sec 1H30 / 165°C	67,47	%	67 - 71	
Densité des solvants	0,93	-	0,93 - 0,93	
Densité de l'extrait sec	1,985	-	0 - 2	
Extrait sec en volume	49,3	%	47 - 53	
Rendement pour 1 micron	340	m2/kg	340 - 380	

Support : GALVA[redacted]

CONDITIONS D'APPLICATION DU SYSTEME EN LABORATOIRE

Type de peinture	Reference	Epaisseur (µ)	PMT (°C)	Cuisson (S)
CODE PRIMAIRE	[redacted]			
CODE FINIITON	[redacted]	18	241	30

CARACTERISTIQUES DU FILM APPLIQUE

TESTS	Résultats	Unités	Spécifications	Observations
Brillant Gardner 60°	41	%	39 - 44	
Dureté crayon Faber Castel	H	-	F - H	
Tenue au M.E.C	100	A / R	100 - 200	
Pli sans arrachement (ECCA)	0	T	0 - 0,5	
Choc inverse sans arrachement	160	I / P	160 - 160	

Equipement | Type : COLORQUEST Géométrie : 2 ° Illuminant : C Unité : LAB

Type de teinte : [redacted] 2P0202Pix 18/02/02

TEINTE	Spec	-0,3 / +0,3		-0,3 / +0,3		0 / +0,5
	dL	0,24	da	-0,15	db	0,21

Source: [177, ECCA 2017] [264, TWG 2019]

Figure 21.8: Example of a technical data sheet for the coil coating sector

The range of solvents on the data sheet is to allow the paint to be thinned to the correct viscosity to run on the production line. The amount of added solvent will vary from drum to drum. There are also some raw materials which have a range for their solvent content listed on their data sheets. This is due either to a need to maintain a certain chemical activity for the material or because it is impossible to remove all the solvent during its manufacture.

In the example above, the technical specification indicates a dry content by weight within the range of 67-71 %. The solvent content in this case is then known with an uncertainty of ± 2.9 %. As this data sheet is typical of most paints used in the coil coating sector, a reasonable estimate of this uncertainty in the solvent content of the paint reference is **± 2.5 %**.

(b) Absence of a complete database of paints used

A typical year of production on an average coil coating line usually corresponds to ≈ 500 paint references and a paint consumption of 3.5 kilotonnes. It is typical of many coil coating lines to extrapolate the solvent content of some representative paints across the total volume of paint. For example, 45 paint references correspond to more than 80 % of the total paint consumption. The operator uses the weighted average value of the dry solid content of these 45 paints and assumes that this value can be extrapolated to the total amount. The standard deviation of the solvent content in the 45 first reference paints is > 5 with a mean value of 37.5. A reasonable estimate of the uncertainty on the dry content when extrapolating to the total paint volume is then ± 2.7 %.

In summary, the solvent content of each paint reference is known with an uncertainty of ± 2.5 %. The method of extrapolating the solvent content from the value of 80 % of the total amount gives an extra uncertainty of ± 2.7 %.

Overall, these factors give a maximum uncertainty for the calculation of $C_{\text{paint reference}}$ of **± 5 %**.

21.5.2.3.3 Uncertainty in calculating the volume of cleaning solvent ($V_{\text{cleaning solvent}}$)

Methyl ethyl ketone (MEK) is recognised as the 'universal' cleaning solvent, although in some cases where some speciality paints are processed other solvents are also used by some lines. The typical annual consumption of MEK for a coil coating line is in the range of 150-200 t. The MEK is generally delivered in 1 m^3 containers and if there is an uncertainty in the stock variation of one container, then the uncertainty of $V_{\text{cleaning solvent}}$ is then ± 0.5 %.

The main uncertainties associated with these three parameters are given in the following table.

Table 21.18: Main sources of uncertainty in calculating I1 for the solvent mass balance

Parameter	Activities	Uncertainty
$V_{\text{paint reference}}$	Paint stored in different locations – stores, tanks, preparation room, coater houses etc. Daily usage of paint and movement in and out of storage facilities. Consumption depends on a number of variables including paint thickness, surface finish and specific events such as development trials and quality problems.	± 1 %
$C_{\text{paint reference}}$	Inaccuracy of technical data sheets – late addition of solvents to paint formulations by supplier to meet local requirements of coil coating line. Incomplete solvent database – potentially inaccurate given the use of solvent additions during production and very resource-intensive to maintain.	± 5 %
$V_{\text{cleaning solvent}}$	~200 tonnes of MEK (methyl ethyl ketone) purchased each year.	± 0.5 %

Source: ECCA [212, TWG 2018]

The overall uncertainty associated with an estimation of I1 and hence of I_{total} during a solvent mass balance calculation for a coil coating line may be as high as ± 5.6 %.

21.5.2.3.4 Sources of uncertainty in calculating parameters O1 and O5 for the SMB for coil coating

The main source of uncertainty in determining parameters O1 and O5 is the assumption concerning the efficiency of the oxidiser system used by the coil coating lines. The reported abatement efficiencies within the data collection for coil coating were above 98 %, with many above 99 % and some reporting > 99.8 %. There are also other uncertainties associated with O5 which result from the fact that it is impossible to determine how much solvent is consumed in the curing oven prior to abatement.

Most coil coating lines have installed extraction facilities and implemented containment techniques within their paint kitchen and application room in order to minimise the amount of untreated solvent that escapes to air.

21.5.2.3.5 Sources of uncertainty in calculating parameter O6 for the SMB for coil coating

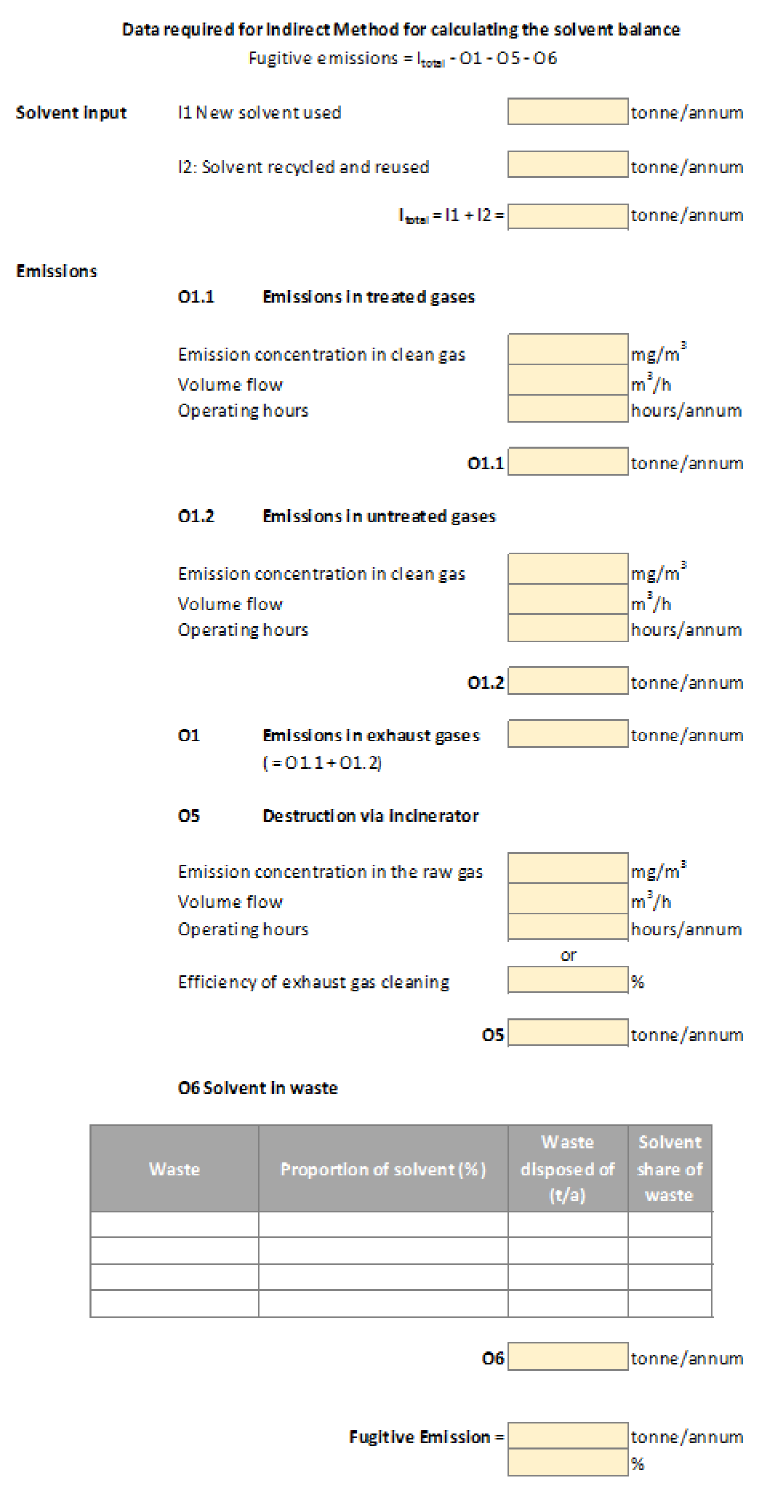
The relatively small volumes involved (< 1 % of the total solvent output from the line) in the waste from the line means that this term is a minor contributor to the overall uncertainty in the SMB. The main uncertainty is a combination of the amount of solvent in each cleaning rag and the number of rags used during the reference period.

21.5.2.4 BAT for reducing fugitive emissions

There are numerous BAT (see Table 21.19 and Table 21.20) than can be deployed to minimise fugitive emissions and quantify the various terms within the SMB that is used to calculate the percentage of fugitive emissions.

21.5.2.5 SMB records and recording

The operator of a coil coating installation is free (as described in IED Annex VII, Part 7) to choose a method for calculating the SMB that is most appropriate to their specific local conditions. It must however reliably demonstrate compliance with the ELV and be shown to meet the requirements of the local permitting authority. The indirect method for calculating the SMB is most commonly used in the coil coating industry. The data requirements for completing this calculation are shown in the following example.



Data required for indirect Method for calculating the solvent balance

Fugitive emissions = I_{total} - O1 - O5 - O6

Solvent input I1 New solvent used ☐ tonne/annum

I2: Solvent recycled and reused ☐ tonne/annum

I_{total} = I1 + I2 = ☐ tonne/annum

Emissions

O1.1 **Emissions in treated gases**

Emission concentration in clean gas ☐ mg/m^3

Volume flow ☐ m^3/h

Operating hours ☐ hours/annum

O1.1 ☐ tonne/annum

O1.2 **Emissions in untreated gases**

Emission concentration in clean gas ☐ mg/m^3

Volume flow ☐ m^3/h

Operating hours ☐ hours/annum

O1.2 ☐ tonne/annum

O1 **Emissions in exhaust gases** ☐ tonne/annum

(= O1.1 + O1.2)

O5 **Destruction via incinerator**

Emission concentration in the raw gas ☐ mg/m^3

Volume flow ☐ m^3/h

Operating hours ☐ hours/annum

or

Efficiency of exhaust gas cleaning ☐ %

O5 ☐ tonne/annum

O6 Solvent in waste

Waste	Proportion of solvent (%)	Waste disposed of (t/a)	Solvent share of waste

O6 ☐ tonne/annum

Fugitive Emission = ☐ tonne/annum

☐ %

Source: [177, ECCA 2017]; [264, TWG 2019]

Figure 21.9: Example of data requirements for the calculation of fugitive emissions for the coil coating sector

The SMB report should present all results and contextual information which enable the calculation steps to be followed and to verify the results and assumptions or estimates made. It is recommended that the following elements should either be included in the SMB report or retained as a supplement for discussions with the competent authority.

(a) Simplified layout of the installation including:

  - (i) relevant process steps and secondary installations (paint storage, paint kitchen, waste handling areas (if relevant);
  - (ii) off-gas treatment equipment (process type, technical data);
  - (iii) stacks (release points of VOCs into the air: position, dimensions, upstream processes).

(b) Description of the solvent balance perimeter, particularly where the coil coating line is part of a larger facility, e.g. integrated steelworks.
(c) Description of the calculation process (and equations used).
(d) Description of data sources.
(e) Contextual information for each applied calculation parameter:
  - (i) definition;
  - (ii) date of last determination;
  - (iii) reference to the respective measurement report;
  - (iv) statement as to why the parameter used is applicable.

(f) Quantitative or qualitative consideration of the uncertainty of the result.
As annexes:
  - (i) raw data for calculations;
  - (ii) measurement reports, if direct measurements were used for the establishment of the solvent balance.

21.5.2.6 Improving the SMB methodology

The existing approach for calculating the SMB (and hence fugitive emissions) is based on using terms which are derived from a number of different sources and calculated over different time frames. For example, the amount of solvent used in the paints can be a single annual calculation based on the reconciliation of stock levels whereas the percentage of VOCs emitted from the ovens can, in some cases, be either a continuous or a periodic measurement. Other terms may just be a snapshot in time and extrapolated for the full year.

The overall approach could potentially be improved by developing a set of detailed measurements over a relatively short period, e.g. 2 days for all of the terms in the SMB. This would offer greater consistency of measurement and probably reduce the uncertainty in the overall calculation of fugitive emissions. The selected time period for the detailed measurement could then be considered representative for the whole year and used to decide whether the line operator is compliant with the emission limits.

The deployment of such an approach for the SMB would need to be agreed by the line operator and the local regulating authorities.

Table 21.19: BAT checklist for helping to reduce and quantify I1 in the SMB calculation

SMB parameter		BAT	
I1	$\mathbf{V}_{\mathbf{paint}}$ (volume of paint)	**BAT 5** - to prevent or reduce fugitive emissions during storage and handling of solvent-containing materials and/or hazardous materials	**5(b)** - sealing or covering of containers and bunded storage area
			5(c) - minimisation of storage of hazardous materials in production area
			5(d) - techniques to prevent leaks and spillages during pumping
			5(e) - techniques to prevent overflows during pumping
			5(g) - containment for spills and/or rapid take-up when handling solvent-containing materials
		BAT 7 - to reduce the raw material consumption and the overall environmental impact of the coating application processes	**7(a)** - roller coating
		BAT 6 - to reduce solvent and other raw material consumption and to reduce VOC emissions	**6(a)** - centralised supply of VOC-containing materials (e.g. inks, coatings, adhesives, cleaning agents)
			6(e) - colour grouping
		BAT 10 - to monitor total and fugitive VOC emissions by compiling, at least once every year, a solvent mass balance	**10(b)** - implementation of a solvent tracking system
	$\mathbf{C}_{\mathbf{paint}}$ (concentration of solvent)	**BAT 3 -** to reduce the environmental impact of the raw materials used	**3(a)** - use of raw materials with a low environmental impact
			3(b) – optimisation of the use of solvents in the process
		BAT 4 - to reduce solvent consumption, VOC emissions and the overall environmental impact of the raw materials used	**4(a)** - use of high-solids solvent-based paints and coatings
			4(c) - use of radiation-cured coatings and paints
			4(g) - use of laminate films
			4(h) - Use of substances which are not VOCs or are VOCs of a lower volatility
	$\mathbf{V}_{\mathbf{cleaning\ solvent}}$	**BAT 9** - to reduce VOC emissions from cleaning processes	**9(c)** - manual cleaning with pre-impregnated wipes
			9(d) - use of low-volatility cleaning agents
		BAT 22 - to reduce the quantity of waste sent for disposal	**22(c)** - recovery/recycling of solvents

Table 21.20: BAT checklist for helping to reduce and quantify O1, O5 and O6 in the SMB calculation

SMB parameter	BAT	
O1 (solvent in waste gases) and **O5** (solvent destroyed)	**BAT 6 -** to reduce solvent and other raw material consumption and to reduce VOC solvent emissions	**6(c)** - supply of VOC-containing materials (e.g. inks, coatings, adhesives, cleaning agents) at point of application using a closed system
	BAT 11 - to monitor emissions in waste gases and in accordance with EN standards	**If TVOC load < 10 kg/h** – annual monitoring in accordance with EN 12619
	BAT 14 - to reduce total emissions of VOCs from production and storage areas	**14(b)** - air extraction as close as possible to the point of application of VOC-containing materials
		14(c) - air extraction as close as possible to the point of preparing paints/coatings
		14(d) - extraction of air from the drying/curing processes
		14(e) - minimisation of fugitive emissions from the ovens either by sealing the entrance and the exit of the curing ovens or by applying subatmospheric pressure in drying
		14(f) - extraction of air from the cooling zone
		14(g) - extraction of air from storage of raw materials, solvents and solvent-containing wastes
		14(h) - extraction of air from cleaning areas
	BAT 15 - to reduce VOC emissions in waste gases	**15(b)** - adsorption using activated carbon or zeolites
		15(d) - sending off-gases to a combustion plant
		15(i) - thermal oxidation
		15(e) - recuperative thermal oxidation
		15(f) - regenerative thermal oxidation with multiple beds or with a valve-less rotating air distributor
		15(g) - catalytic oxidation
O6 (solvent in waste)	**BAT 9** - to reduce VOC emissions from cleaning processes	**9(c)** - manual cleaning with pre-impregnated wipes
		9(d) - use of low-volatility cleaning agents
	BAT 22 - to reduce the quantity of waste sent for disposal	**22 (b)** - recovery/recycling of solvents

21.5.3 Solvent mass balance for the heatset web offset printing sector

21.5.3.1 Solvent mass balance for the heatset web offset printing sector (INTERGRAF)

[224, INTERGRAF 2018]

Introduction

The SMB for the heatset web offset printing sector (Heatset SMB) provides a method for the following:

a) Calculation of the annual input (expressed in t/yr).
b) Reliable estimation of the fugitive emissions (expressed in t/yr).
c) Calculation of the fugitive emissions as a percentage of the input.

The Heatset SMB described below aims to both simplify and standardise the making of SMBs in the heatset web offset printing sector. It does not describe how to monitor waste gas emissions or how to verify compliance of these waste gas emissions with their applicable emission limit value.

VOC emissions in heatset web offset printing

In heatset web offset printing the following sources of VOC emissions can be distinguished:

1. Inks

- Offset inks contain oils that are not VOCs at room temperature. They however evaporate in the dryer and at the drying temperature they are considered VOCs. After evaporation they are transported to the oxidiser, where they are to a very large extent destroyed. A small proportion may escape destruction in the oxidiser and will be emitted (waste gas emission).
- A proportion of the oils remain in the ink on the paper web. The web is cooled and the oils are no longer VOCs. The residue in the printed product is not considered part of the fugitive emissions (see also IED Annex VII, Part 2, Heatset web offset printing, ‘special provisions’).
- Evaporation of the VOCs in inks takes place in the dryer. They do not contribute to the fugitive emissions. The quantity of these VOCs needs to be known however in order to determine the annual input and the percentage of fugitive emissions.
- Unless the ink supplier provides a different value, it may for the purpose of the Heatset SMB be assumed that the VOC content of heatset inks is 35 %.

2. Fountain solution additives

- Fountain solutions contain wetting agents. These are, in most cases, VOCs. These VOCs partly evaporate from the rollers on their way from the fountain to the paper web (fugitive emissions).
- They are also partly absorbed in the paper web and transported to dryer. After evaporation they are destroyed in the oxidiser. A small proportion may escape destruction (waste gas emission).

3. Automatic cleaning

The cleaning agents used for automatic cleaning are often VOCs mixed with water. Both water and VOCs partly evaporate on their way through the press (fugitive emissions).
Depending on the system used, the remainder is either:

- absorbed in the paper web, transported to the dryer and after evaporation destroyed in the oxidiser; a small proportion may escape destruction (waste gas emissions); or
- collected as liquid waste (no emission); or
- absorbed in tissue which is disposed of as waste (no emission).

4. Manual cleaning

Manual cleaning is not very frequent since in heatset web offset printing no colour changes are necessary. Cleaning agents for manual cleaning contain VOCs.

- During manual cleaning a proportion of the VOCs in the cleaning agents will evaporate (fugitive emission).
- The remainder will be collected and disposed of as waste (no emission).

5. Press room air to off-gas treatment

- The off-gases from dryers are oxidised. The oxidation process is very effective. Only a very small amount of VOCs escapes destruction and is emitted (waste gas emission).
- Dryers take their inlet air from the press room. This air will contain fugitive emissions of VOCs that have evaporated from cleaning agents and dampening solution. The dryer air is transported to the oxidiser and the VOCs contained in that air are destroyed. This reduces the actual fugitive emissions. Since the press room is also separately ventilated to the atmosphere, this concerns a limited percentage of the fugitive emissions.

Conservative simplification

Complicated parameters

Some of the parameters that would be necessary for an accurate SMB in heatset web offset printing are difficult to establish:

- The proportion of VOCs in the waste of the cleaning agents. Some of the waste cleaning agents are mixed with water, some are contained in tissue and others in cleaning wipes.
- The proportion of the VOCs in the dampening solution and cleaning agents that is absorbed in the paper web, destroyed in the oxidiser and therefore not emitted as fugitive emissions.
- The proportion of fugitive VOC emissions that is transported to the oxidiser through the inlet air of the dryer.

Conservative sector parameters

Where the actual fugitive emissions are expected to be lower than the applicable fugitive emission limit, it may be possible to demonstrate compliance without measurements, substantiated estimates, etc. For this purpose, the following conservative parameters can be used:

- proportion of VOCs in waste: 0 %;
- proportion of fugitive VOC emissions in dampening solution: 90 %;
- proportion of fugitive VOC emissions in cleaning agents: 85 %;
- proportion of fugitive VOC emissions in dryer inlet air: 0 %.

Calculation method

The following procedure is recommended to determine the fugitive emissions and check compliance with the limit value. The method is designed to use, wherever possible, only information that is, or should be, readily available such as annual quantities used of inks, dampening additives and cleaning agents and information provided by suppliers on the VOC content of their products.

Determine annual input

The annual input is the sum of the VOC content of the inks, dampening additives and cleaning agents used in the applicable year.

For all these products, their contribution to the input is calculated by multiplying the quantity of the product used by its VOC content (percentage) as provided by the supplier. For inks, the VOC content at drying temperature may not be available. In that case, the inks may be assumed to contain 35 % VOCs.

Conservative estimation of fugitive emissions

The fugitive emissions are calculated using the conservative parameters:

- Assume VOCs in waste: zero.
- Fugitive emissions from dampening solutions:
    - Multiply the amount of VOCs in dampening additives by 90 %.
- Fugitive emissions from cleaning agents:
    - Multiply the amount of VOCs in cleaning agents by 85 %.
- Assume no VOCs in dryer inlet air.

The total of these calculated emissions is a conservative estimate of the fugitive emissions.
It should be noted that since the oils in inks are not VOCs at room temperature, they do not contribute to the fugitive emissions.

Check estimated fugitive emissions against ELV

The fugitive emissions are calculated as a percentage of annual input and compliance checked against the applicable emission limit value. If the value is compliant, no further action is necessary, other than recording the calculations and possibly reporting the result.

Non-compliance and BAT

Where the estimated fugitive emissions are considerably higher (for example several per cent of input) than the BAT-AEL, it is likely that BAT is not applied throughout the plant.

The main possible cause for excessive fugitive emissions in heatset web offset printing is the application of isopropanol (IPA) in too high a percentage in the dampening solution. Where the usual IPA percentage is more than 4 % or 5 % (w/w), it is unlikely that fugitive emissions lower than the limit value can be obtained. Another possible cause is the application of cleaning agents with a high solvent content.

Where this is the case, it is recommended to first reduce or substitute the amount of IPA consumed or reduce the solvent content of the cleaning agents, before dedicating any effort to increasing the accuracy of the SMB.

Non-compliance and improved accuracy

Where there is non-compliance of the fugitive emissions, but this non-compliance is not excessive, it is recommended to improve the accuracy of the estimated emissions. Recommendations on how to increase the accuracy are given below.

Increasing accuracy

Where compliance with the fugitive emission limit value cannot be demonstrated with the parameters used in the conservative simplification for the estimation of fugitive emissions, it will be necessary to measure or estimate some of the emission parameters. This will lead to a lower estimation of the fugitive emissions.

In order of increasing difficulty, the parameters for which the accuracy may be increased are:

- VOCs in waste;
- VOCs transported to the oxidiser;
- fugitive VOC emissions from dampening solution;
- fugitive VOC emissions from cleaning agents.

Proportion of VOCs in waste
The VOC content of waste that is disposed of is not considered to be emitted. Where an accurate estimation of the amount of VOCs in waste is available, this may be subtracted from the fugitive emissions as determined with the conservative simplification. A considerable reduction of the estimation of the fugitive emissions may result.

A substantiated estimate of the VOC content of one or two of the largest waste streams can often be made. These will generally include the waste of cleaning agents for the rubber blanket. Information may be obtained from the company that treats the waste. Where the total weight of the waste stream is determined accurately, a substantiated estimation of the solvent content may be used.

It is recommended to focus on one or two large waste streams. It may be necessary to keep those streams separate from other streams for a considerable period of time in order to determine the total quantity and the VOC content with sufficient accuracy.

Where used cleaning agent is transported to the dryer by the paper web, there may not be a substantial amount of solvent-containing waste and this method may not lead to a substantially lower estimation of the fugitive emissions.

Proportion of fugitive VOC emissions that are transported to the oxidiser
A method for establishing the quantity of fugitive emissions transported to the oxidisers is described in Section 11.4.3.1. It requires thorough knowledge of the actual ventilation system of the dryers, the press room and the press encapsulation.

Proportion of fugitive VOC emissions in dampening solution
A considerable proportion of both the water and the additives in the dampening solution never reaches the paper web. It evaporates during the process of producing an ever thinner layer of water that can be emulsified into the ink or brought onto the plate directly.

Obviously, for the offset process to work, some of the dampening solution must reach the plate and therefore the paper web. It is however rarely known in what proportion. Very little literature addresses this question. Therefore the sector proportion of 90 % evaporation can be assumed to be conservative. It will be difficult to substantiate any estimations that differ from this conservative estimate.

It may however be possible to estimate how much of the water in the dampening solution evaporates, by establishing the difference between the amount of water fed to the press and the increase in the humidity of the paper web during printing before the dryer. This difference must have evaporated.

If this amount is known, the extent to which the VOC content evaporates faster or slower than the water and in what concentration it reaches the paper web can also be established. With the amount of water reaching the paper web and the VOC concentration at that point, the quantity of VOCs that have not evaporated and the quantity of VOCs that have been emitted as fugitive emissions can be calculated.

It will be important to take the temperature into account.

It is not known whether this estimation method has been attempted in practice.

Proportion of cleaning agents emitted fugitively
A distinction must be made between cleaning agents used while the press is running and the cleaning agents used while the press is idle.

When the press is idle, no cleaning agents are transported to the paper web, evaporated in the dryer and destroyed in the oxidiser. In this case, the fugitive emissions are equal to the difference between the amount of VOCs used and the amount disposed of as waste.

Cleaning while the press is running may result in a proportion of the cleaning agents reaching the paper web, depending on the cleaning system used. Where the system is such that cleaning agents are evacuated by the paper web, it will be more difficult to accurately estimate the amount absorbed by the paper than in the case of the dampening solution, since cleaning is an intermittent process.

Reference literature

- Assessment of printed product recyclability, European Recycled Paper Council, Issue 2 January 2017.
- Emission control Heatset web offset presses, VDI 2587, November 2001.
- Commission Decision of 16 August 2012 establishing the ecological criteria for the award of the EU Ecolabel for printed paper.

21.5.3.2 Solvent mass balance for the heatset web offset printing sector (DE)

[DE comment #198 in [212, TWG 2018]]

Basic principle
The basic formula of the solvent mass balance (in kg/year) is that all inputs (I) are equal to all outputs (O):

$\sum \text{Input} = \sum \text{Output}$

The following table shows the different inputs (I) and outputs (O) for organic solvents.

Note: the discharge of the collected exhaust gas from the room ventilation (press hall) is considered here for this sector as fugitive emissions because it is not treated and it is therefore similar to other fugitive emissions such as from doors, windows, etc. – see definition of O4 under IED Annex VII, Part 7, No 2.

Table 21.21: Mass flows for the solvent mass balance and their relevance for the heatset offset printing sector

No	Mass flow	Relevance	Explanation
Input of VOCs as solvent			
I1	The quantity of organic solvents or their quantity in mixtures purchased which are used as input into the process in the time frame over which the mass balance is being calculated.	Yes	VOCs as solvent in printing inks, in dampening solution, in cleaning agents.
I2	The quantity of organic solvents or their quantity in mixtures recovered and reused as solvent input into the process. The recycled solvent is counted every time it is used to carry out the activity.	Low	Under certain circumstances for example the cleaning agents can be recovered and reused for cleaning again.
Output of VOCs into the air or the waste water			
O1	Emissions in waste gases. O1.1 Contained and treated. O1.2 Contained and not treated.	Yes	O1.1: Emissions to air from external or integrated thermal oxidiser. O1.2: Exhaust air from air conditioning plant, air extraction from encapsulation of machines.
O2	Solvent in waste water.	Low	Emptying and cleaning of the dampening solution mixing apparatus and dampening solution cooling device as well as of the dampening solution container.
O4	Fugitive emissions released to the outside environment via windows, doors, vents and similar openings.	Low	Generally not directly measurable, due to the almost fully encapsulated construction of the installations, and generally very low
O9	Organic solvents released in other ways.	Low	e.g. accidents, spillages, leakages.
Destroyed VOCs			
O5	Organic solvents and/or organic compounds lost due to chemical or physical reactions (including those which are destroyed, by incineration or other waste gas or waste water treatments, or contained, as long as they are not counted under O6, O7 or O8).	Yes	Thermal oxidation of the VOC exhaust gases from the dryer.
Other outputs of VOCs			
O3	The quantity of organic solvents which remains as contamination or residue in product output from the process.	Limited	A part of the mineral oil hydrocarbons in the inks remains in the paper. According to IED Annex VII, Part 2, No 1, footnote 1, the solvent residue in the finished product is not to be considered as part of fugitive emissions.
O6	VOCs contained in collected waste.	Yes	e.g. VOCs in ink waste, filter materials, cleaning cloths.
O7	Organic solvents, or organic solvents contained in mixtures, which are sold or are intended to be sold as a commercially valuable product.	No	
O8	Organic solvents contained in mixtures recovered for reuse but not as input into the process, as long as not counted under O7.	Low	e.g. recovered cleaning agents that have not been input in the relevant time frame.

Table 21.22: Determination of the input I1 according to the annual solvent consumption and the VOC content of the input materials

Substance	**Annual consumption** in	**VOC content** in weight % (at temperature of application)	**VOC input** in
Printing inks	kg/year	About 30-40 % mineral oil hydrocarbons	kg/year
Isopropanol	l/year	100 %	kg/year
Further organic additives in dampening solution	l/year	e.g. 30 % 2-butoxyethanol	kg/year
Cleaning agents for offset rubber blankets	l/year	e.g. 90 % aliphatic hydrocarbons	kg/year
Basic cleaning agents, cleaning agents for ink rollers	l/year	e.g. 98 % aliphatic hydrocarbons	kg/year
Total I1		kg/year	

For the elaboration of a comprehensive solvent mass balance, some of the listed inputs and outputs must be determined from raw data like the annual quantities of input I1, VOCs contained in treated waste gases (O1), VOCs destroyed (O5) or VOCs in the collected waste (O6).

The following steps give support in the determination of the input and output quantities.

Determination of input I1

For the determination of I1, the annual quantities of consumption of the input materials and of their VOC content are required (see Table 21.22).

The annual consumption quantities can, as a rule, be taken from the existing IT systems for administration of the financial and logistical data. If necessary, the data from the manufacturers (of the printing inks and/or auxiliaries) can be accessed.

The VOC contents of the input materials in Table 21.22 are given as an example and can be taken from the safety data sheets or technical documents of the manufacturers. The input quantities of isopropanol, the further dampening auxiliary agents as well as of the cleaning agents are typically given as volumes and thus have to be calculated into weight (kg) by the density.

If the technical process and design parameters of a dryer are available, the maximum permissible input quantity into the dryer can be used according to the data of the manufacturer of the dryer. A realistic value in practice is 2.2 g printing ink per m^2 (doublex) at an evaporation rate of 95 %. By the known parameters, machine velocity and nominal web width, the solvent input per time can be calculated.

Determination of input I2 and if necessary O8

The recovery of solvents usually takes place by the distillation of polluted cleaning agents. The quantity of the recovered cleaning agents has to be determined and summed up over the time frame of the solvent mass balance. I2 are considered only such quantities that are reused again during the time frame of the solvent mass balance.

VOCs that are recycled but not reused in the installation are considered as O8. In heatset offset printing, the following cases could be relevant for O8:

- Internal recycling of cleaning agents, e.g. by distillation without reusing the recovered quantity during the time frame of the solvent mass balance.

- Recovery of mineral oils from the waste gas of the dryer as long as the purpose of recovery is reuse but not for the same activity.

Determination of contained treated waste gases O1.1

O1.1 is defined as emissions in contained treated waste gases in kg/year:

$$O1.1 = \left(\frac{Cclean}{10^6}\right) * fs * \frac{dV}{dt} * t$$

where:

C_{clean}	Emission mass concentration for total carbon (C_{total}) in clean gas in mg C/m^3 (e.g. the average value of the last periodic emission measurement by an authorised emission measurement institute).
fs	Conversion factor from total carbon (C_{total}) into the VOC molecular weight. For simplification, in the case of thermal oxidisers fs = 1 can be assumed (conservative assumption).
dV/dt	Waste gas volume in m^3/h (according to the measurement report of the authorised emission measurement institute).
t	Operation time of the off-gas treatment unit in h/year.

Determination of contained untreated waste gases O1.2

The determination of O1.2 is not required if the fugitive emissions are determined according to the indirect method for the solvent mass balance because O1.2 is considered for this sector as fugitive emissions. If it is necessary to determine O1.2 in special individual cases, the following direct method can be applied:

$$O1.2 = \left(\frac{C_{exhaust}}{10^6}\right) * fs * \frac{dV}{dt} * t$$

where:

O1.2	Emission in contained untreated waste gases in kg/year.
$C_{exhaust}$	Emission mass concentration for total carbon (C_{total}) in contained untreated waste gas in mg C/m^3.
fs	Conversion factor from total carbon (C_{total}) into the VOC molecular weight. This factor shall be determined by the authorised emission measurement institute that has measured the exhaust gas volume. A factor of approximately 1.5 can be assumed as a worst-case assumption.
dV/dt	Exhaust gas volume in m^3/h of the contained untreated waste gas.
t	Operation time of the printing unit in h/year.

Other fugitive outputs O2, O4 and O9

The discharges of VOCs into the waste water (O2), and VOCs emitted by windows, doors, vents and similar openings are all considered fugitive emissions. Common to all these outputs is the generally high effort and large uncertainty in their determination. It is good practice in heatset web offset printing to determine the fugitive emissions using the indirect method of IED Annex VII, Part 7, No 3(b)(i). In this case, the single fugitive outputs O2, O4 and O9 need not be determined directly.

VOCs in products to be sold

A part of the hydrocarbons (about 5 wt-%) in the printing inks is discharged onto the paper and is not very volatile at ambient temperatures. Compared to other activities of IED Annex VII, the VOC residue in the final product is not considered as fugitive emissions for heatset web offset printing.

In the case of an evaporation factor of FV > 1, a part of the rubber blanket cleaning agent remains in the product O3.

VOCs destroyed in the off-gas treatment (O5) and VOCs in waste (O6)
The applied solvents have different volatility and already partially evaporate in the area of the printing units. By the encapsulation of the machine and extraction by the room ventilation plant, this part of the exhaust gases is collected but emitted as O1.2 without any cleaning. Another part is collected by the dryer, discharged to the off-gas treatment unit and destroyed (O5). A further part, especially of the cleaning agents, will be contaminated, collected and disposed of as waste (O6).

VOCs sold as product (O7)
Organic solvents that are sold as a product do not play any role in the heatset web offset printing sector.

Calculated values for the solvent mass balance

Solvent input I = I1 + I2
The solvent input is relevant for the determination of the emission limit value for the fugitive emissions (F). According to the IED (Annex VII, Part 2, No 1), the emission limit value (ELV) for fugitive emissions is 30 wt-% of the solvent input I.

Solvent consumption SC = I1 – O8
According to this formula, organic solvents that are recovered for their reuse or that are contained in the mixtures recovered for reuse (O8) can be subtracted for the calculation of the solvent consumption (SC). But for the heatset offset printing sector this is generally not the case and would only be relevant for specific cases.

Fugitive emissions F
According to IED Annex VII, Part 7, No 3(b)(i), fugitive emissions can be determined in two ways: direct method (a) or indirect method (b) using the following formulas:

a) $F = O1.2 + O2 + O4 + O9$
b) $F = I1 - O1.1 - O3 - O5 - O6 - O7 - O8$

The determined fugitive emission (F) has to be compared with the emission limit value for the fugitive emissions (ELV(F) = 30 % of solvent input I according to IED Annex VII, Part 2, No 1).

Total emission E
The total emission is calculated by the sum of VOCs in the contained treated waste gases (O1.1) and fugitive emissions (F): $E = F + O1.1$.

Exemplary solvent mass balance for a heatset offset printing installation

Table 21.24 shows an exemplary solvent mass balance for a heatset web offset installation.

The following assumptions have been made:

- The heatset offset installation consists of three printing machines.
- The oldest of the machines still works with isopropanol as a dampening agent. The two newer machines are using isopropanol-free dampening agents.
- For the balance, it is assumed that very volatile organic compounds like isopropanol mostly evaporate and only a small part (10 %) is destroyed in the off-gas treatment system.
- The low-volatile organic compounds getting on the paper web (especially the mineral oils of the printing inks but also the applied rubber blanket cleaning agents with flame points

> 60 °C) enter the gas phase predominantly in the dryer and are thus discharged to the off-gas treatment system.

- A smaller part of the hydrocarbons in the printing inks is absorbed by the paper.
- For the different cleaning and washing agents, assumptions have to be made on their release depending on the type of each agent.
- For the rubber blanket cleaning, the collection of a larger quantity by the dryer with discharge to the off-gas treatment system can be assumed. For the highly volatile cleaners, their consideration as untreated channelled emissions (output O1.2) is the worst-case assumption.
- In the case of low-volatile cleaning agents, a relevant discharge as collected waste seems reasonable. As proof, waste disposal documents can be asked for.

Table 21.23: Guide values for the solvent mass balance

Material	Composition of the VOC input of the installation
Printing inks based on mineral oil hydrocarbons (VOC 30-45 wt-%, on average: 35 wt-%)	• 99 wt-% is discharged to the dryer on the paper web, of which about 95 wt-% is volatile in the dryer and will be destroyed in the off-gas treatment unit (O5 besides the remaining O1.1). • About 5 wt-% remains in the paper and is not volatile after cooling (O3). • < 1 wt-% is discharged into the waste, e.g. by polluted cleaning cloths or at the basic cleaning of the colour troughs. • < 0.1 wt-% already evaporates in the area of the printing units and is emitted as contained untreated waste gas.
Isopropanol (100 wt-% VOCs)	• 89 wt-% is emitted in the area of the printing units and is discharged as exhaust gas of the room ventilation plant (O1.2). • About 10 wt-% gets to the off-gas treatment unit by the dryer (O5 besides the remaining O1.1). • Small quantities (< 1 wt-%) are disposed of with the waste (O6).
Organic dampening agent concentrates	The following simplified assumptions can be made for the organic dampening concentrates: • About 5 % of the organic dampening concentrates are emitted in the area of the printing units and are discharged as exhaust gas of the room ventilation plant as fugitive emissions (O1.2). • About 10 % of the organic dampening concentrates get to the off-gas treatment unit by the dryer and are destroyed (O5 besides the remaining O1.1).
Rubber blanket cleaning agents (100 wt-% VOCs because of the drying temperature of about 150 °C)	Depending on the construction of the rubber blanket cleaning unit, the following different factors for retention are relevant: • < 1 wt-% is already emitted in the area of the printing units and is discharged as exhaust gas of the room ventilation plant (O1.2). • About 35-60 wt-% gets to the off-gas treatment unit by the dryer (O5 besides the remaining O1.1). • About 5-30 wt-% stays in the paper web depending on the evaporation factor of the cleaning agent (O3). • About 35-55 wt-% is contaminated cleaning agents or cleaning cloths and are disposed of as solvent-containing waste (O6). If required, exact information on the single ratio can be obtained by the manufacturer of the cleaning system for the consideration of construction- and cleaning-agent-specific values. In the case of an evaporation factor *FV* = 1, 100 % of the solvent that is fed to the dryer by the paper web evaporates; in the case of an evaporation factor *FV* = 2, 50 % evaporates and 50 % remains in the paper (O3).
Basic cleaning, cleaning agents for manual cleaning of rolls	Substances with a vapour pressure < 0.01 kPa at 20 °C do not need to be considered for the fugitive emissions. Substances with a vapour pressure > 0.01 kPa at 20 °C are generally entered as fugitive emissions unless the operator verifies that they are disposed of, e.g. in the waste O6 by the waste balance under the assumption of 5 g VOCs per cleaning cloth.

Table 21.24: Exemplary solvent mass balance for a heatset offset printing installation

Material input	**Consumption**	**VOC content** in %	**Density** in kg/l	**I1** in kg	**O1.1** in kg	**O1.2** in kg	**O3** in kg	**O5** in kg	**O6** in kg
Printing ink	2 000 000 kg	36.0	1.000	720 000	650	0	4 590	710 530	4 230
				100.0 %	0.09 %	0.0 %	0.64 %	98.68 %	0.59 %
Isopropanol, Manufacturer A	30 000 l	99.5	0.785	23 432 kg	12 kg	20 972 kg	0 kg	2 332 kg	117 kg
Balance in %				100 %	0.05 %	89.5 %	0.0 %	9.95 %	0,5 %
Dampening agent, Manufacturer A	35 000 l	24.0	1.100	9 240	46	8 316 kg	0 kg	832 kg	46 kg
Balance in %				100.0 %	0.5 %	90.0 %		9.0 %	0.5 %
Dampening agent, Manufacturer B	25 000 l	23.7	1.000	5 925	30	5 333	0	533	30
Balance in %				100.0 %	0.5 %	90.0 %		9.0 %	0.5 %
Dampening agent, Manufacturer C	15 000 l	9.0	1.050	1 418	7	1 276	0	128	7
Balance in %				100.0 %	0.5 %	90.0 %		9.0 %	0.5 %
Rubber blanket cleaner, Manufacturer A	20 000 l	85.0	0.840	14 280	29	2 850	0	4 204	7 197
Balance in %				100 %	0.2 %	20.0 %		29.44 %	50.40 %
Rubber blanket cleaner, Manufacturer B	10 000 l	0.0	0.850	0	0	0	0	0	0
Balance in %				100 %	0.2 %	20.0 %		29.44 %	50.40 %
Cleaning agents for rolls, Manufacturer A	7 000 l	99.0	0.791	5 482	0	1 096	0	0	4 385
Balance in %				100 %		20 %			80 %
Cleaner, Manufacturer B	5 000 l	100.0	0.718	3 590	0	718	0	0	2 872
Balance in %				100 %		20 %			80 %
Total				783 366	773	40 561	4 590	718 558	18 884
				I1	O1.1	O1.2	O3	O5	O6
				100.0 %	0.1 %	5.2 %	0.6 %	91.7 %	2.4 %
Fugitive emissions F		**45 151 kg**		**5.8 %**					
Limit value for fugitive emissions F: 30 % of total I		**235 010 kg**							
Total emissions E		**45 924 kg**		**2.3 %**					
NB: The quantities of O1.2 are considered as fugitive emissions (no off-gas treatment takes place).									

Reference literature

Draft Guideline German Association of Engineers VDI - Emission control – Heatset web offset presses, VDI 2587, September 2017, [DE comment #198 in [212, TWG 2018]].

21.5.4 Solvent mass balance for flexography and non-publication rotogravure printing

[198, Germany 2017]

Description

The following procedure is a guide for the compilation of solvent mass balance (SMB) for flexographic and rotogravure printing systems.

21.5.4.1 Determination of fugitive emissions F

Fugitive emissions F can be calculated as follows:

$F = I1 - O1.1 - O5 - O6 - O7 - O8$
(or: $F = I1 - (O1.1 + O5) - O6 - O7 - O8$)

(O1.1 + O5) represents the amount of VOCs in the raw gas of the off-gas treatment system. This can be determined by an operational flame ionisation detector (FID) for continuous detection of total C mass concentration in conjunction with continuous detection of the volume flow in the raw gas:

$(O1.1 + O5) = cCtot * 10^{-6} * fS * V_R * t_R$ in kg/yr

where:

(O1.1 + O5) = amount of VOCs in raw gas in kg/yr;
cCtot = average total carbon concentration in raw gas in mg/Nm^3;
fS = conversion factor of cCtot to solvent (VOCs);
V_R = average waste gas volume flow of the crude gas under normal conditions in Nm^3/h and dry;
t_R = operating time of the off-gas treatment system in h/yr.

The average annual raw gas concentration cCtot must be derived from all measured values. To convert the total carbon concentration cCtot to the substance-specific solvent concentration (cVOC) to be monitored, the latter must be multiplied by the conversion factor fS. This conversion factor fS results from the quotient of the molar mass and the carbon fraction of the solvent used.

The exhaust air volume flow has to be determined continuously using a volumetric flow measurement. The average exhaust gas volume flow VR must be determined from all measured values.

In justified individual cases, alternatively the raw gas quantity may be determined from the measured lower explosive limit (LEL) values of the concentration measuring devices or by means of additional built-in IR sensors.

The measurement errors caused by the sensitivity of the concentration measuring devices to the different solvents must be corrected by calculating an average value for the solvent mixture used with which the measured LEL value is interpreted. The solvents used must be proportionally weighted and the measured LEL value should be interpreted with this correction factor.

The average raw gas mass flow in Nm^3/h is calculated as the quotient of the sum of all determined raw gas mass flows and the number of all investigations in the reference period.

If different solvents are used in the printing process and these cause different cross-sensitivity to the sensors, detectors with small differences in cross-sensitivity are to be used. For example, a sensor calibrated to ethyl acetate can indicate up to 50 % too high a value when using pure ethanol as a solvent. This would lead to too little concentration in the normal operation. At an actual ethanol concentration of 30 % of the LEL, 45 % of the LEL would be measured in this case, resulting in an admixture of actually unnecessary fresh air, e.g. to reach the set point of 35 % of the LEL (this is a tried-and-tested set point because it still has sufficient distance to the warning and shut-off points).

21.5.4.2 Determination of the fraction of the amount destroyed in the off-gas treatment system (O5)

In order to determine the quantity of fugitive emissions F, if not according to Section 21.5.4.1, knowledge of the quantity O5 is required, i.e. the amount of solvents destroyed in the off-gas treatment system:

$F = I1 – O1.1 – O5 – O6 – O7 – O8$

The amount of solvents destroyed by off-gas treatment (O5) can be determined by means of the abatement efficiency (‘efficiency’, better A_R = removal efficiency) of the oxidative off-gas treatment using the following relationship:

$$O5 = \frac{O1.1}{1 - A_R} - O1.1$$

where:

A_R = removal efficiency of thermal oxidation;
O1.1 = emissions from captured and treated off-gases.

Decisive here are the resilient representative determination of O1.1 and the removal efficiency. For this purpose, parallel measurements of the total C mass concentration of the raw and clean gas over a longer period of time may be necessary.

21.5.4.3 BAT for determining the emissions from captured and treated off-gases (O1.1)

The VOC emissions contained in the clean gas of an off-gas treatment system (O1.1) are calculated according to the following equation:

$O1.1 = cCtot * 10\text{-}6 * fS * V_R * t_R$ in kg/yr

where:

O1.1 = VOC mass flow in the clean gas in kg/yr;
cCtot = total carbon concentration in the clean gas in mg/Nm^3;
fS = factor for conversion from cCtot to VOCs;
V_R = average waste gas flow under normal conditions in Nm^3/h and dry;
t_R = operation time of the waste gas cleaning unit in h/yr.

The average total carbon value (cCtot) of the last emission measurement shall be used as the mass concentration. Continuous determination of the total C mass concentration in combination with the continuous determination of the waste gas volume flow would be ideal. Otherwise, representative mass concentrations of clean gas are to be determined during the measurement of the emission. This may possibly also require measurement over a longer period of time (e.g. working day). The mass concentration of the solvents (solvent mixtures) used should be converted using the factor fS. The conversion factor fS is to be formed from the quotient of the molar mass and the carbon content of the solvent used.

The exhaust air volume flow has to be determined continuously using a volumetric flow measurement. The average waste gas volume flow has to be determined from all measured values. Alternatively, it is permissible to determine the volume flow via the frequency converter of the raw gas fan. Alternatively, the emissions in the captured treated waste gas can also be measured directly using flame ionisation detection (FID) or flame temperature analysis (FTA) devices. From the individual values of mass concentration, the average annual mean value is determined according to the method described above.

21.5.5 Common cases for mass balances

[205, Belgium 2005]

In this section, some of the most common cases for mass balances for STS activities are presented.

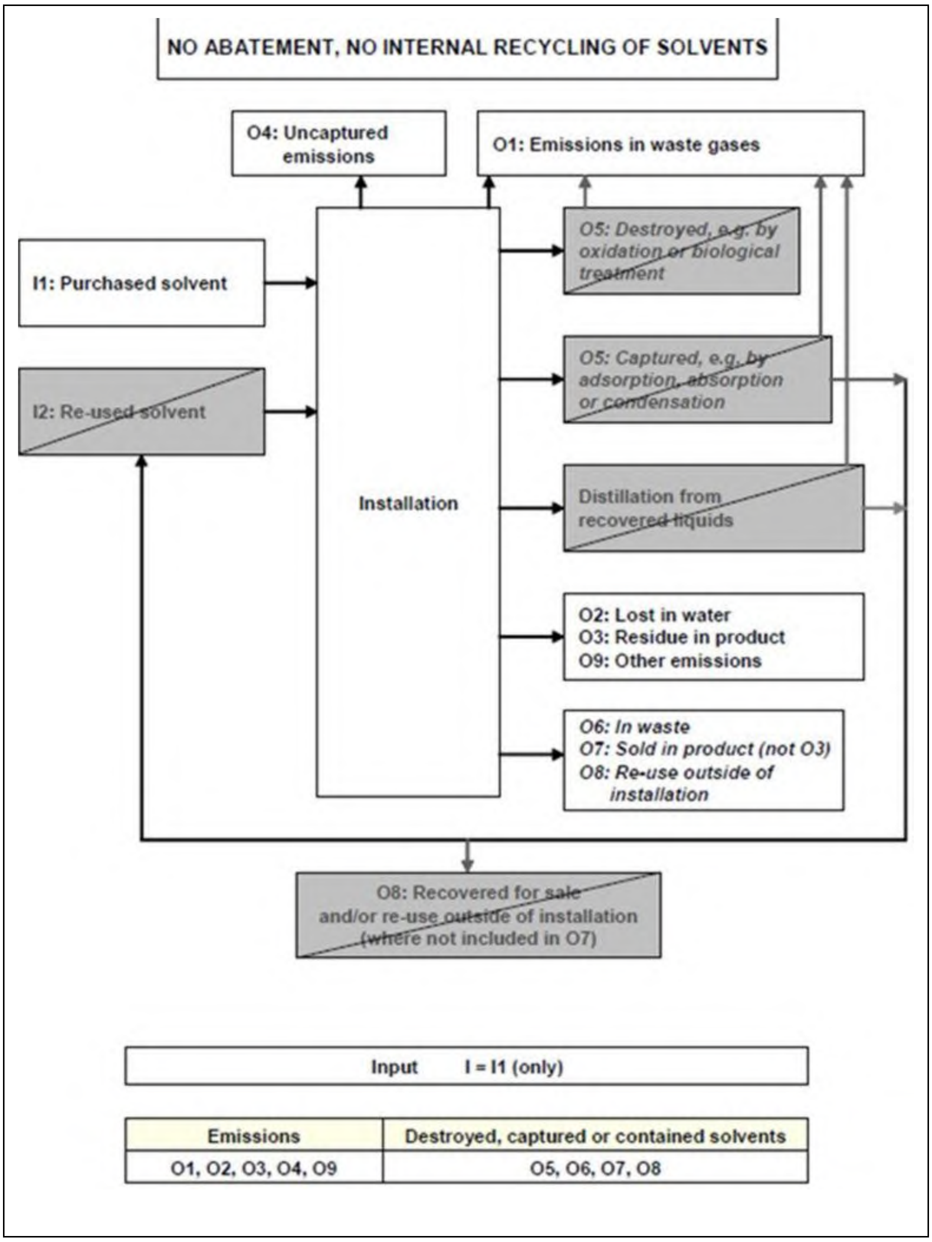


Figure 21.10: No end-of-pipe abatement and no internal recycling

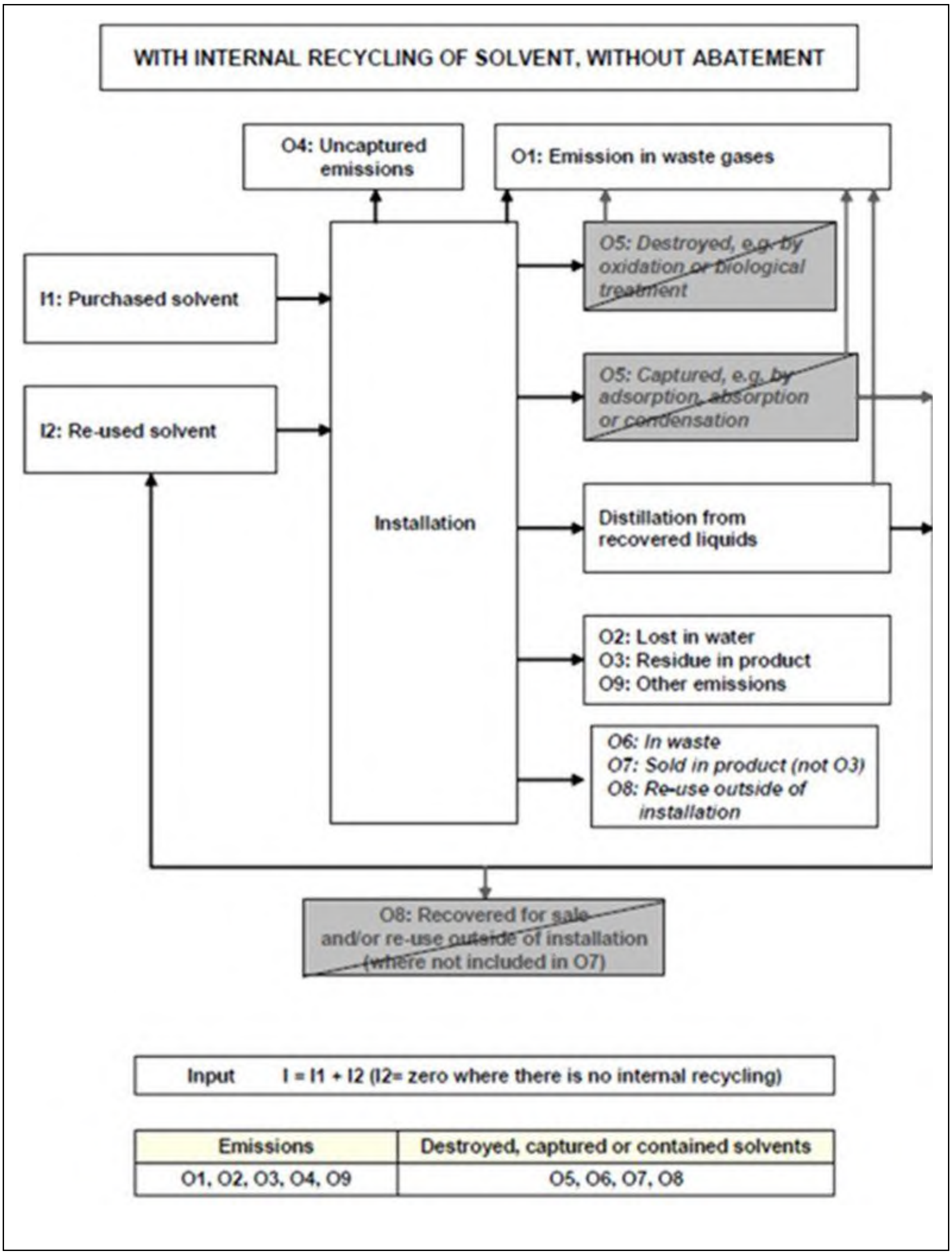


Figure 21.11: No end-of-pipe abatement but with internal solvent recovery and reuse

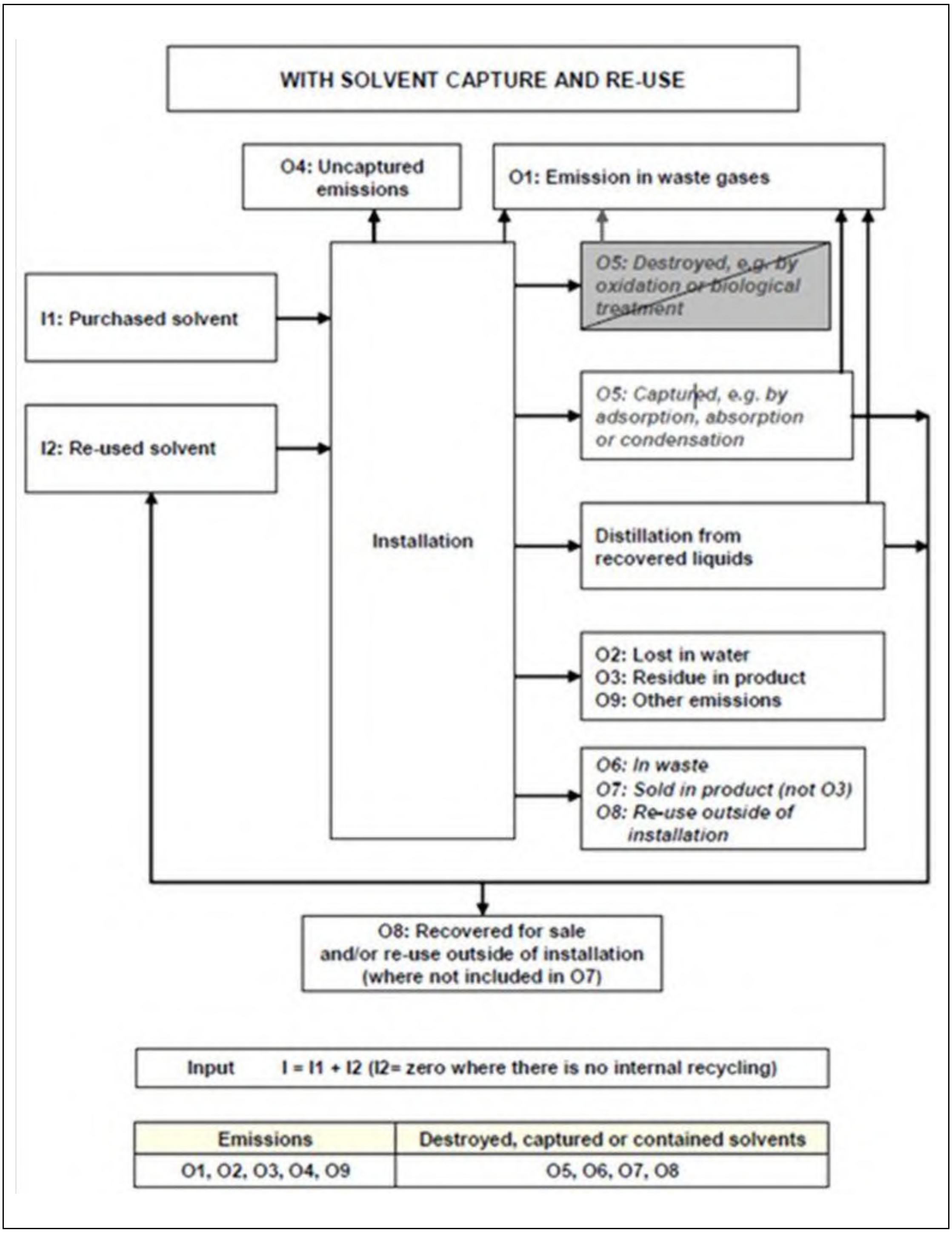
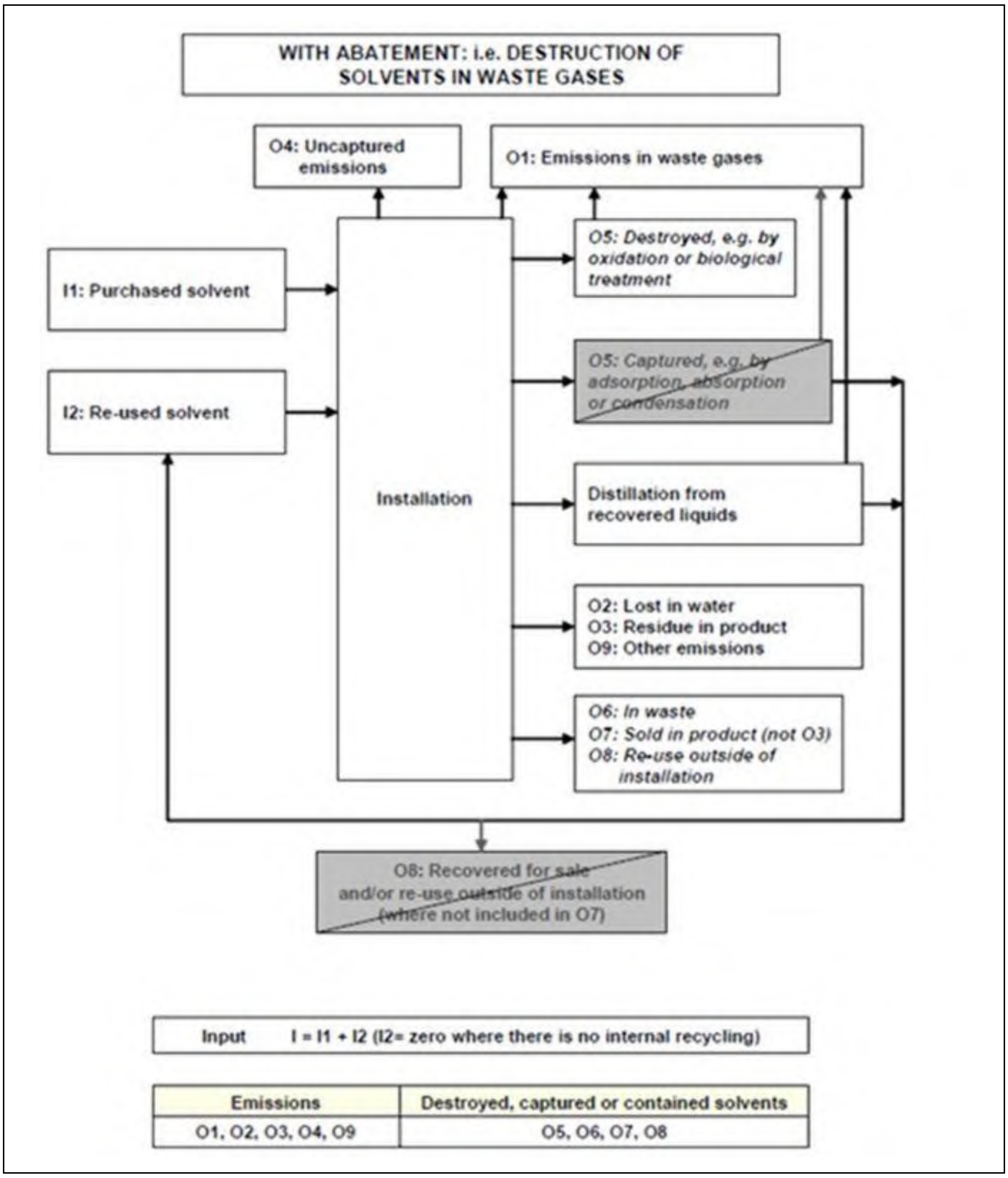


Figure 21.12: With solvent capture and reuse (internally and externally)



Input I = I1 + I2 (I2= zero where there is no internal recycling)

Emissions	Destroyed, captured or contained solvents
O1, O2, O3, O4, O9	O5, O6, O7, O8

Figure 21.13: **Destructive end-of-pipe abatement**

21.6 Abatement efficiency of off-gas treatment techniques

[97, TWG 2006] [131, Verspoor et al. 2006] [155, TWG 2016]

End-of-pipe techniques: Descriptions and considerations for applicability

The descriptions and considerations for applicability below are intended as an overview only. See the relevant sections in Chapter 17 of this document for additional information. The information in this annex on its own cannot serve as the basis for the selection of a suitable abatement technique.

Table 21.25: Off-gas treatment techniques

End-of-pipe technique and description	General characteristics	Use considerations
Thermal oxidation Off-gases are heated by burning natural gas. There is no attempt at heat recovery for a reduction of energy consumption.	The simplest oxidation technique with the lowest capital investment. Autothermic operation only at concentration levels over 25 % LEL. Lowest electrical energy consumption for the main fan. Highest gas consumption. As the simplest technique, it has the lowest maintenance and least downtime. Rapid start-up (0.5-1 h), but it requires a stable operating temperature. Non-organic dust needs to be removed (to dust levels < 3 mg/m^3) before the oxidation unit, although this technique is more tolerant of dust than others.	For intermittent use (a few days a week; very variable airflows; one-shift system, etc.) Where the capital costs are much more relevant than operational costs or in combination with other abatement technologies for multi-purpose units or for air volumes < 2 000 m^3/h. For concentration ranges between 5 and 16 g/m^3, high inlet temperatures of the off-gas and in situations where gas flow and solvent concentrations are relatively constant. Operation at concentration levels above LEL is also possible.
Recuperative oxidation Similar to thermal oxidation but with a heat exchanger that preheats the incoming off-gases with the heat of the exhaust gases. Reduces gas consumption, but the heat exchanger requires a higher investment.	With a heat exchanger of maximum efficiency (about 76 %), autothermic operations are possible at solvent concentrations approaching 10 g/m^3 (ethyl acetate or ethanol) or more. Autothermic concentration depends on the caloric value of the solvent. Electrical energy consumption for the main fan is higher than in the case of thermal oxidation. Gas consumption is lower. A simple oxidation technique, but with a relatively high investment due to the large steel content. Almost immediate start-up (0.5-1 h). Removal efficiency is restricted by the maximum operating temperature which is determined by the mechanical integrity of the heat exchanger. The heat exchanger has a limited lifetime and requires substantial maintenance due to corrosion and thermal stress. Heat exchangers may easily be blocked by accumulation of dust in the tubes, and	For intermittent use (one- or two-shift systems), but where the reduction of gas consumption warrants additional capital cost and electrical energy. Where autothermic operation is possible, but excess energy cannot be used in the installation as an alternative for regenerative oxidation.

	efficiency will be reduced due to the partial fouling, increasing investment and running costs. However, the technique is more tolerant of dust than others, and there are techniques for clearing blockages (air blow, chain cleaning, ball drop, etc.).	
Catalytic oxidation Oxidation temperatures are lower, at about 280-450 °C (instead of some 800 °C) Often equipped with a heat exchanger. Reduces gas consumption, but catalysts and heat exchangers lead to a higher investment. Catalyst may need maintenance and occasional replacement which add to the operational cost and downtime.	When equipped with an efficient heat exchanger (maximum possible around 87 %), autothermic operations are possible at solvent concentrations of some 5 g/m^3 or over (depending on the calorific value of the solvent). The maximum possible temperature of the catalyst limits the inlet concentration to some 8 g/m^3. Electrical energy consumption for the main fan is higher than in the case of thermal oxidation. With solvent concentrations below 25 % LEL, the gas consumption will be lower than in the case of recuperative oxidation. The catalyst makes this a less simple oxidation technique, but still with a relatively low investment. Almost immediate start-up (1 h to preheat the catalyst), but shutting down too frequently may damage the catalyst carrier. Catalyst adds to the need for maintenance and increases downtime. Some solvents or dust particles poison the catalyst and lead to early replacement of the expensive catalyst. Catalyst and carrier need to be adapted to waste gas composition, required temperature and expected removal efficiency. A used catalyst may need to be disposed of as hazardous waste, although the catalyst material can often be recycled. Very sensitive to the presence of dust and droplets in the off-gases. Sensitive to changes in the inlet concentration	Used only where all solvents that are to be oxidised are known not to poison the catalyst and where the inlet temperature is not too high for the catalyst. Where autothermic operation is possible, but excess energy cannot be used in the installation as an alternative for regenerative oxidation.
Regenerative oxidation: 2 beds The oxidising chamber is situated between two ceramic beds. The waste gas passes through one bed before entering the oxidising chamber and leaves through the other. The direction of waste gas flow is alternated every 1 to 5 minutes. One bed preheats the off-gases; the other accumulates the heat from the exhaust. During the changeover solvent-laden off-gases are emitted for a few seconds. Reduces fuel consumption drastically. Increases the need for electrical energy due to the higher air	With a high heat exchanger efficiency (maximum possible 96 %), autothermic operations are possible from solvent concentrations of 2 g/m^3 and over (depending on the calorific value of the solvent, e.g. ethyl acetate 2.2 g/m^3). Preheating after periods of standstill may, however, account for considerable gas consumption. Electrical energy consumption for the main fan is higher than in the case of other oxidisers because of the high pressure drop in the ceramic beds. Where the solvent concentration in off-gases is higher than the autothermic concentration, excess heat is produced. This may be recovered. Where excess heat is not permanently recovered and the concentrations are variable, the efficiency of the heat exchanger may need to be reduced to prevent overheating of the ceramic beds when high	Specifically suitable in continuous or near continuous operations where most of the time the solvent concentrations in the off-gases are over the autothermic concentration and the solvent concentrations do not vary significantly.

resistance in the ceramic beds.	concentrations occur. This leads to a higher autothermic concentration and the need for adding natural gas in periods of low solvent concentrations. The complicated sensors and large valves necessary to repeatedly change the direction of the airflow mean complex equipment and the need for skilled personnel. Higher maintenance costs and more downtime than other oxidation techniques. Every 1 or 2 years there is a need for 2 to 3 days downtime for maintenance. Needs preheating before start-up since the ceramic beds cool down during standstill. (After 36 hours of standstill, 1 to 2 hours are needed for preheating.) Removal efficiency is a few per cent lower than that of the 3-bed system (see below) due to emissions during changeover of the direction of the waste gas stream. Where end-of-pipe emission limits expressed in mg C/m^3 averaged over a short period of time apply, the emissions during changeover of the direction of the waste gas stream may lead to an average outlet concentration that exceeds the limit values if the inlet concentration is higher than about 3 g/m^3. The regenerator blocks rapidly with dust. It is possible to run with some low dust concentrations, but the regenerative beds need a different structure (structured packing (honeycomb instead of saddles) with different cost and efficiency.	
Regenerative oxidation: multiple (3 or more) beds In principle the same as the 2-bed system. The third bed serves to avoid the emission of solvent-laden air during the change of the direction of the waste gas flow. Alternatives with a valveless rotating air distributor are also in use. In that case, the ceramic medium is held in a single rotating vessel divided into multiple wedges.	(Relative to the 2-bed system). Investment some 25 % higher. Lower emissions. Higher preheating cost. Some 10 % higher electricity consumption due to larger fan for purging purposes. Removal efficiency a few per cent higher due to the prevention of emissions during changeover of the direction of the waste gas stream. Online burnout possible for removing sticky particles.	(Relative to the 2-bed system) Most suitable for concentrations of 1-12g/m^3, especially if there is a variation in the concentration over the production time. Most suitable in large continuous operations with solvent concentrations in off-gases well above autothermic concentration. Where the resulting emission reduction warrants the additional investment and operational cost.
Other oxidation techniques (Not included in calculations of removal efficiency)		
Combustion plant (Process heater) The off-gases to be treated are sent to a combustion plant (including CHP) as combustion air and complementary fuel.	A suitable heater must be available and must be operating and able to receive all the off-gases at times when they are produced.	Not to be used for off-gases containing CMR substances. There may also be safety considerations.
Adsorption (to a solid)		
Regenerative carbon adsorption	Desorption must be done in an atmosphere with little or no oxygen. Steam, nitrogen or	Only to be considered when the recovered

The low-temperature off-gases are led through a bed of activated carbon. The solvent adsorbs to the activated carbon. When the carbon is saturated the waste gas flow is switched to a second carbon bed. The saturated bed is desorbed through heating. The heat releases the solvents from the carbon in such a high concentration that it allows condensation of these solvents.	oxygen-free hot air may be used. After condensation of the solvent, complex techniques may be necessary to make the recovered solvents ready for reuse. These techniques depend on the solvent recovered. Some examples: In the case of toluene and xylene, desorption is done with steam and simple condensation will suffice. In the case of ethyl acetate, desorption is done with nitrogen. Dewatering with molecular sieves and several subsequent distillation steps are necessary to remove side products and secondary solvents such as acetic acid, traces of ethanol and low-volatility solvents. Since the adsorption characteristics of solvents differ enormously, the size of the adsorbers (and therefore not only the investment but also the energy and inert gas consumption) is very much determined by the kind of solvent. (Examples: Toluene and xylene need relatively ‘small’ adsorbers. Ethanol needs a 25 % larger adsorber than ethyl acetate.) Some solvents may react with the activated carbon and cause fire. MEK is one of these, but techniques exist to prevent these reactions and recover MEK safely. Some low-volatility solvents may adhere to the activated carbon permanently and quickly reduce the adsorption capacity with early replacement of the activated carbon as a result. Activated carbon also adsorbs water effectively. Waste gas streams with a high moisture content are therefore not suitable. Investment and operational costs are considerably higher than in the case of oxidation. This is more evident where the solvent loads are below 1 000 tonnes per year. Alternatives with moving carbon beds exist, but are not commonly used. Electrical energy consumption for the main fan is higher than in the case of oxidisers because of the higher resistance of the beds of activated carbon. High displacement with low air speeds necessary to prevent blowing out of the activated carbon. The complex equipment requires specifically trained technical personnel. Very reliable operations and very little downtime are the norm. The high cost in comparison to oxidation and the low market value of recovered solvents necessitate the reuse of the solvents in the same installation in order to make solvent recovery a viable option. Break-even point between oxidation and recovery evidently depends on the price of the solvent recovered and the techniques necessary. For toluene and xylene, recovery may be cheaper than oxidation starting at a solvent consumption of 100 t/yr. For ethyl acetate, MEK and	solvent can be reused in the installation or be sold against the market value of ‘fresh’ solvents. (usually the sale of recovered solvent brings no more than 50 % of its original price). Where several hundred tonnes of toluene or xylene are used as the only solvent this technique can always be seriously considered. With other solvents higher annual quantities are necessary to make this a viable option. Especially where there are mixtures of several different solvents, numerous complications may need to be solved before this technique can be used successfully. However, technical solutions exist for most of these practical problems. The end result may be too complicated and expensive.

	ethanol, break-even with oxidation was calculated to be possible starting at approximately 500 to 1 000 tonnes per year. Does not work with high inorganic dust concentrations.	
Polymer adsorption The low-temperature off-gases are led through a moving bed of grains of a special polymer. The solvent adsorbs to the polymer. The saturated polymer is desorbed through heating. The heat releases the solvents from the polymer in such a high concentration that it allows condensation of these solvents.	Desorption is done with hot air. The concentrations are above the higher explosive limit in order to prevent accidents. After condensation of the solvent, complex techniques may be necessary to make the recovered solvents ready for reuse. These techniques depend on the solvent recovered. Since the adsorption characteristics of solvents differ enormously, the amount of polymer necessary is very much determined by the kind of solvent. Since the polymer is the most costly part of the equipment (10 to 20 times the cost of activated carbon), this technique is known to be suitable for only very few solvents. Since the polymers do not adsorb water, the system can be used for off-gases with high moisture content. Also, no dehydration of the recovered solvent is necessary. The equipment is very simple. High displacement fans with low air speeds are necessary to prevent blowing out the polymer. Very reliable operations and very little downtime are possible. Does not work with high inorganic dust concentrations.	No examples of successful application in industries in the scope of this document are known.
Other adsorption techniques (Not included in calculations of removal efficiency)		
Oil scrubbing VOC removal efficiency generally relatively low. Mainly used for abating emissions of inorganics or odours		
Absorption using a suitable liquid (wet scrubbing) Several types exist. In water scrubbing, off-gases are led through a curtain of water or water mist. Particularly suited for the removal of droplets and dust. Waste water treatment is necessary.		Water-soluble VOCs.
Condensation		
Condensation at ambient temperature, no inert gas dryer (Not included in calculations of removal efficiency) Off-gases are cooled down to a temperature above freezing point. Low-volatility solvents	The equipment is very simple and not expensive. No information about operating costs.	No examples of successful application in industries in the scope of this document are known.

condense. High-volatility solvents, however, are not condensed effectively.		
Condensation with inert gas dryer In an enclosed drying system containing an inert gas (mostly nitrogen) the solvent concentration is allowed to rise to several hundred grams per m^3. The inert gas is led through a condenser where a part of the solvents are condensed at approximately room temperature. The inert gas with a reduced solvent content is returned to the dryer. The condenser is often cooled with the liquid nitrogen that is also needed for topping up the dryer system.	The dryers are obviously more expensive than traditional dryers. The operational costs depend to a large extent on the amount of nitrogen used. Nitrogen is used mainly when the dryer needs to be opened, for instance in the case of job changes. Where mixtures of solvent are used, complex techniques may be necessary to make the recovered solvents ready for reuse. Since the dryer needs to be as closed as possible, the technique can only be used for drying thin even substrates that can be led through the dryer without serious leaks at the entry and exit.	The technique is only applicable where there is no need to open the dryer for several days in a row.
Refrigerated condensation The waste gas is cooled to a temperature below 0 °C. Icing occurs and regular de-icing is necessary. For that purpose, there are usually two condensers. A condensation step above 0 °C upstream reduces the water content of the waste gas.	The running costs are high and increase if a lower condensation temperature is necessary.	Mostly for the recycling of more expensive solvents. Low airflows with high concentrations.
Cryogenic condensation Condensation at very low temperature usually with liquid nitrogen.		Mostly for the recycling of more expensive solvents. Low airflows with high concentrations.
	Biological treatment	
Biological treatment (Not included in calculations of removal efficiency) The waste gas is blown through a bed of organic material in which the VOCs are adsorbed and destroyed (metabolised) by bacteria.	The equipment is simple and not expensive, but needs a lot of space in the case of large airflow. Bacteria are easily killed by changing the composition of the waste gas or by lack of feed in the holiday season. This affects the filter efficiency. No information about operating cost.	Waste gas stream with low concentration. Biodegradable and preferably water-soluble components. Odour problems.

Removal efficiencies

Table 21.27 and Table 21.28 below give the removal efficiency of oxidation techniques and solvent recovery with activated carbon. For other techniques, insufficient data were available to produce similar tables.

Removal efficiency depends on:

- the carbon content of the solvent molecule;
- the average inlet concentration;
- the average outlet concentration;
- operating temperature.

The shaded bands in the tables give the range of removal efficiency that can be expected from either oxidation or solvent recovery.

The lower parts of the band correspond to the lower inlet concentrations.

The attainable solvent concentrations in the off-gases for solvent recovery are somewhat higher than in the case of oxidation. The removal efficiencies are therefore somewhat lower.

Effectiveness of the oxidation
The effectiveness of the oxidation of VOCs is dependent on three parameters:

a) Turbulence: The complete movement and mixture of the off-gases in the burner chamber.
b) Time: Minimum residence time of the off-gases in the burner chamber (typically 1 second).
c) Temperature: The burner chamber operating temperature (typically in the range of 720 °C to 850 °C).

Points (a) and (b) are design parameters set by the manufacturer. Point (c) (temperature of the burner) is the only parameter that can be adjusted by the operator. It must be noted, however, that high energy demands and increased NO_X levels will result from elevated running temperatures when attempting to increase VOC removal efficiency.

Inorganic dust
The techniques are sensitive to inorganic dust to varying degrees. Some are very sensitive, others less so, or they can be adapted. Inorganic dust is likely to affect the efficiency of the technique and/or gas throughput (higher airflow resistance) and the amount of maintenance required. Adapting to off-gases with inorganic dusts can therefore have an impact on capital and running costs.

Calculations
The removal efficiency equals 100 % minus the percentage of remaining carbon after the abatement equipment. The percentage of carbon remaining is calculated by dividing the 24-hour average outlet concentration by the 24-hour average inlet concentration. For this calculation, the inlet concentration is expressed in g/m^3 solvent, multiplied by the percentage carbon content of the solvent. The outlet concentration is expressed in mg carbon per m^3.

The 24-hour average outlet concentrations are based on experience in installations that today are subject to end-of-pipe emission limit values. It must be noted that, in order to be certain of compliance, the actual 24-hour average outlet concentrations are always lower than these end-of-pipe emission limit values.

It must also be noted that the actual end-of-pipe concentration may vary widely over the day, depending on the production circumstances in the installation.

Carbon content
The carbon content of a solvent can be determined on the basis of a chemical formula. For reasons of simplicity, four categories are given in Table 21.26 for use in Table 21.27 and Table 21.28.

Table 21.26: Chemical groups of common solvents and their carbon content

Solvent group	Average carbon content (%)	Chemical groups of solvents
Group 1	55.0	Alcohols, glycol ethers, glycol, ether esters
Group 2	65.0	Esters, ethers, ketones
Group 3	85	Hydrocarbons
Group 4. Exceptionally low carbon content compared to other chemicals in their group	37.5	Methanol
	48.6	Methyl acetate

Removal efficiency and BAT

Table 21.27 and Table 21.28 provide information about the range of removal efficiencies associated with oxidation and solvent recovery (activated carbon adsorption). These tables do not imply that compliance with every single value in the ranges can be considered BAT.

The emission ranges attainable by the application of BAT are given in the industry-specific parts of Chapter 18 in this document. These emission ranges associated with BAT always apply to the total of both end-of-pipe emissions and fugitive emissions.

Where the emission range associated with BAT is, for instance, 10 % of solvent consumption, and the fugitive emissions account for 5 % of solvent consumption, the removal efficiency of the abatement equipment must be over 95 %.

The abatement equipment must obviously be chosen in such a way that it will reduce emissions sufficiently to attain the emission range associated with BAT and still leave room for unavoidable fugitive emissions.

Removal efficiency and end-of-pipe emission limit values

The IED, permit provisions and similar national legislation may prescribe end-of-pipe emission limit values. These values may be different for different industries. Attainment of the lower parts of the removal efficiency ranges given in Table 21.27 and Table 21.28 may not lead to compliance with these emission limit values (ELVs). Indeed compliance with some especially low emission limit values may require removal efficiencies higher than the highest value given in the tables. This may, for instance, be the case where solvents such as those mentioned in Article 58 of the IED (carcinogens, mutagens or toxic to reproduction) are used.

Table 21.27: Removal efficiency of oxidation techniques

Oxidation	Removal efficiency	75.0 %	80.0 %	85.0 %	90.0 %	92.5 %	95.0 %	97.5 %	99.0 %	99.5 %	99.9 %
Group 1 solvents	0.5-1.0 g solvent/m^3		🟩	🟩	🟩	🟩	🟩	🟩			
Inlet concentration	1.0-2.0				🟩	🟩	🟩	🟩			
	2.0-6.0						🟩	🟩	🟩	🟩	
	6.0-12.0								🟩	🟩	🟩
Group 2 solvents	0.5-1.0 g solvent/m^3			🟩	🟩	🟩	🟩	🟩			
Inlet concentration	1.0-2.0					🟩	🟩	🟩			
	2.0-6.0						🟩	🟩	🟩	🟩	
	6.0-12.0								🟩	🟩	🟩
Group 3 solvents	0.5-1.0 g solvent/m^3			🟩	🟩	🟩	🟩	🟩			
Inlet concentration	1.0-2.0					🟩	🟩	🟩	🟩		
	2.0-6.0							🟩	🟩	🟩	
	6.0-12.0								🟩	🟩	🟩
Methanol	0.5-1.0 g solvent/m^3	🟩	🟩	🟩	🟩	🟩	🟩				
Inlet concentration	1.0-2.0			🟩	🟩	🟩	🟩	🟩			
	2.0-6.0					🟩	🟩	🟩	🟩		
	6.0-12.0							🟩	🟩	🟩	
Methyl acetate	0.5-1.0 g solvent/m^3	🟩	🟩	🟩	🟩	🟩	🟩				
Inlet concentration	1.0-2.0			🟩	🟩	🟩	🟩	🟩			
	2.0-6.0					🟩	🟩	🟩	🟩	🟩	
	6.0-12.0							🟩	🟩	🟩	

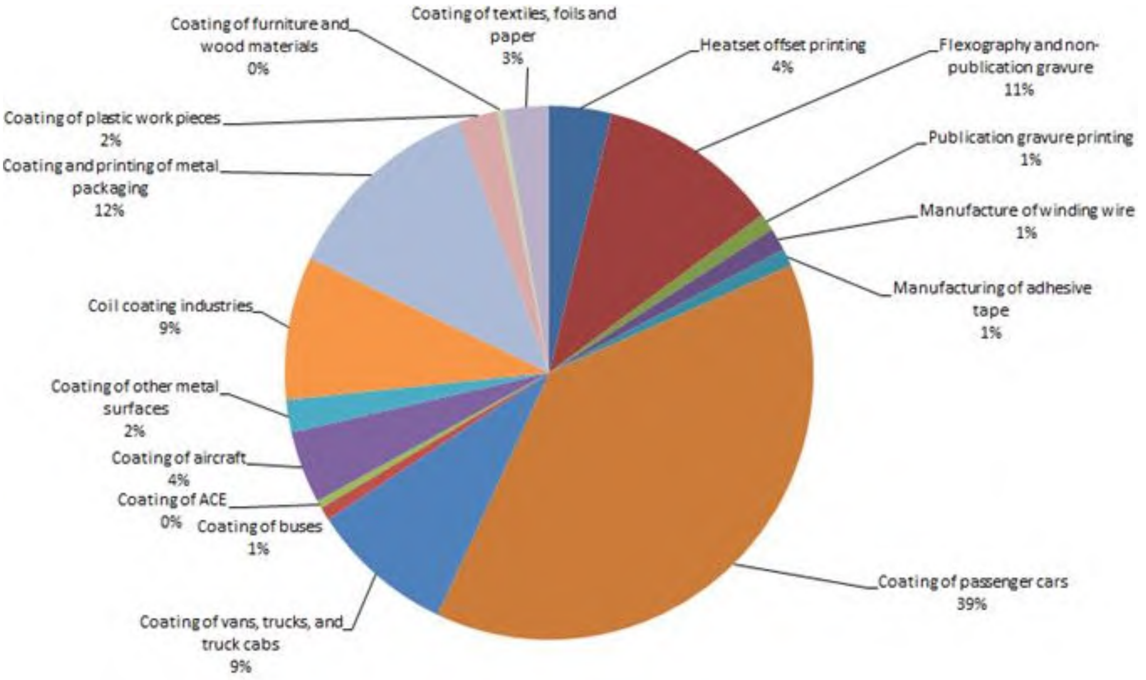
Table 21.28: Removal efficiency of solvent recovery with activated carbon

Activated carbon recovery	**Removal efficiency**	**75.0 %**	**80.0 %**	**85.0 %**	**90.0 %**	**92.5 %**	**95.0 %**	**97.5 %**	**99.0 %**	**99.5 %**	**99.9 %**
Group 1 solvents	0.5-1.0 g solvent/m^3	🟩	🟩	🟩	🟩	🟩					
Inlet concentration	1.0-2.0			🟩	🟩	🟩	🟩				
	2.0-6.0					🟩	🟩	🟩	🟩		
	6.0-12.0							🟩	🟩	🟩	
Activated carbon recovery	**Removal efficiency**	**75.0 %**	**80.0 %**	**85.0 %**	**90.0 %**	**92.5 %**	**95.0 %**	**97.5 %**	**99.0 %**	**99.5 %**	**99.9 %**
Group 2 solvents	0.5-1.0 g solvent/m^3	🟩	🟩	🟩	🟩	🟩	🟩				
Inlet concentration	1.0-2.0			🟩	🟩	🟩	🟩	🟩			
	2.0-6.0						🟩	🟩	🟩		
	6.0-12.0							🟩	🟩	🟩	
Activated carbon recovery	**Removal efficiency**	**75.0 %**	**80.0 %**	**85.0 %**	**90.0 %**	**92.5 %**	**95.0 %**	**97.5 %**	**99.0 %**	**99.5 %**	**99.9 %**
Group 3 solvents	0.5-1.0 g solvent/m^3		🟩	🟩	🟩	🟩	🟩				
Inlet concentration	1.0-2.0				🟩	🟩	🟩	🟩			
	2.0-6.0						🟩	🟩	🟩		
	6.0-12.0							🟩	🟩	🟩	
Activated carbon recovery	**Removal efficiency**	**60.0 %**	**80.0 %**	**85.0 %**	**90.0 %**	**92.5 %**	**95.0 %**	**97.5 %**	**99.0 %**	**99.5 %**	**99.9 %**
Methanol	0.5-1.0 g solvent/m^3	🟩	🟩	🟩	🟩						
Inlet concentration	1.0-2.0		🟩	🟩	🟩	🟩	🟩				
	2.0-6.0				🟩	🟩	🟩	🟩			
	6.0-12.0						🟩	🟩	🟩		
Activated carbon recovery	**Removal efficiency**	**60.0 %**	**80.0 %**	**85.0 %**	**90.0 %**	**92.5 %**	**95.0 %**	**97.5 %**	**99.0 %**	**99.5 %**	**99.9 %**
Methyl acetate	0.5-1.0 g solvent/m^3	🟩	🟩	🟩	🟩						
Inlet concentration	1.0-2.0		🟩	🟩	🟩	🟩	🟩				
	2.0-6.0				🟩	🟩	🟩	🟩			
	6.0-12.0						🟩	🟩	🟩		

21.6.1 Abatement efficiency of applied techniques as reported in the STS data collection (2016)

[155, TWG 2016]

Data for TVOC emissions in waste gases were reported for a total of 868 emission points. Most of the data for TVOC emissions in waste gases were reported for the vehicle coating sector (coating of passenger cars, vans, trucks and truck cabins) which is related to the high number of emission points per installation (see Figure 21.14).



Source: [155, TWG 2016]

Figure 21.14: Share of emission points reporting application of a VOC abatement technique by sector in the total number of emission points

It is noted that 22 % of the total number of emission points do not apply any abatement technique and no information on the applied abatement technique was provided for 10.5 % of the emission points. The number of emission points applying a certain technique as a share of the total number of emission points where an abatement technique is applied is presented in Figure 21.15.

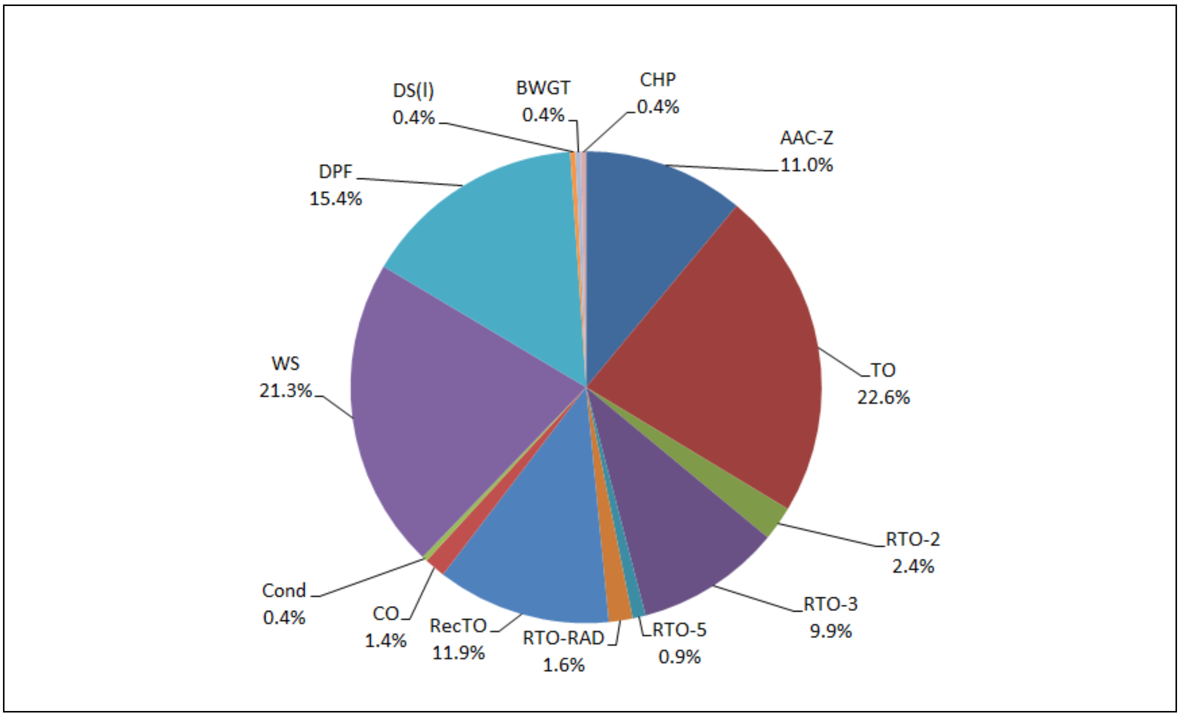


Figure 21.15: Application of abatement technique as a percentage of the total number of emission points

For some sectors, certain abatement techniques are more commonly applied. The distribution of the applied abatement techniques (per sector), expressed as a percentage of the total number of emission points (for the sector) where an abatement technique is applied, is presented in Figure 21.16.

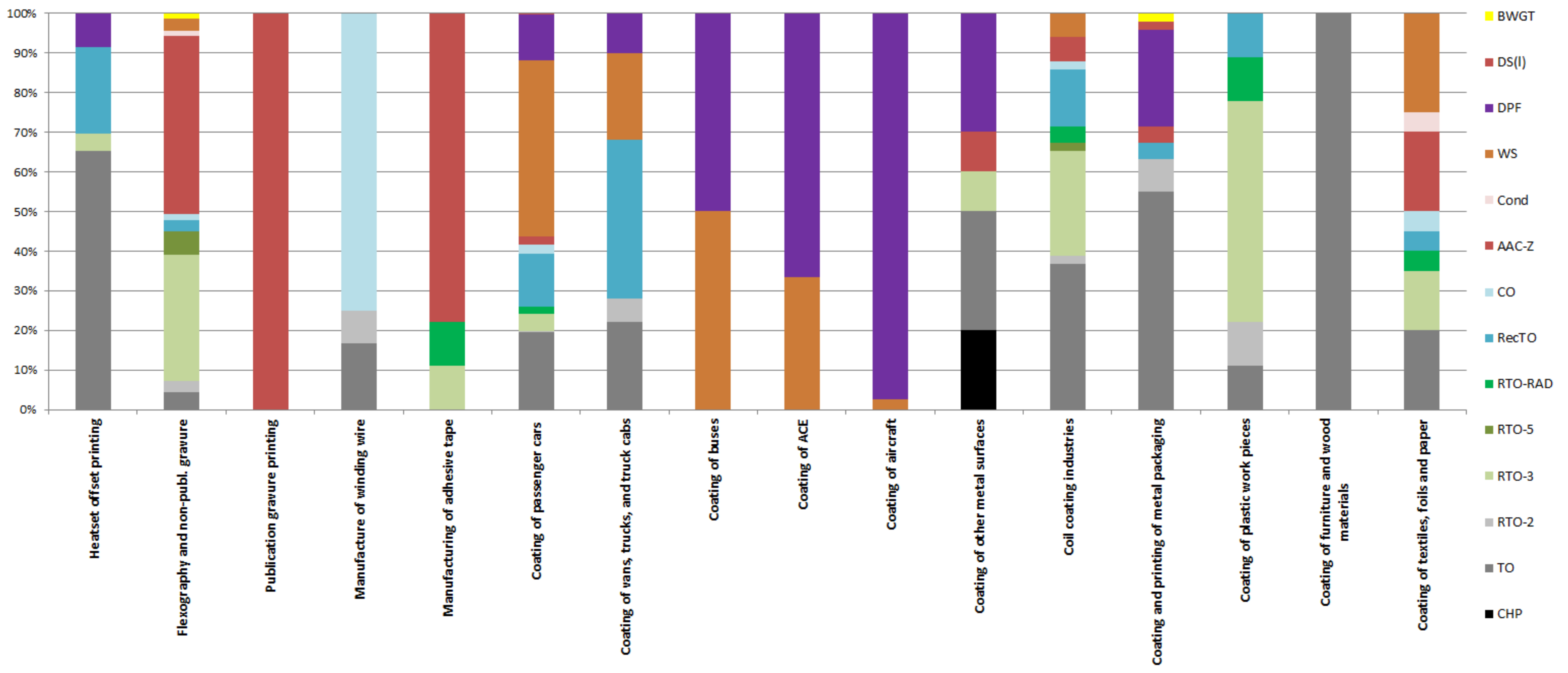


Figure 21.16:Distribution of applied techniques per STS sector expressed as a percentage of the total number of emission points (in the sector) where an abatement technique is applied

The reported values for the abatement efficiency of the applied techniques are summarised in the following table.

Table 21.29: Reported values for the VOC abatement efficiency of the applied off-gas treatment techniques

Technique	Average abatement efficiency	Number of values	Max.-min. range	75th-25th percentile range	Derivation of abatement efficiency
Thermal oxidation (TO)	96.94	50	99.99-93.93	99.94-96.98	16 R 16 S 8 D 9 C 1 NI
Regenerative thermal oxidation – 2-bed (RTO-2)	98.36	9	99.6-94.4	99.5-98.0	6 R 2 S 1 NI
Regenerative thermal oxidation – 3- or 5-bed (RTO-3/RTO-5)	98.27	25	99.8-87.8	99.4-98.5	8 R 3 S 10 D 1 C 3 NI
Regenerative thermal oxidation-valveless rotated air distributor (RTO-RAD)	93.34	16	99.3-90	97.25-90	3 R 4 S 9 D
Recuperative thermal oxidation (RecTO)	98.31	43	99.9-89.4	99.55-97.85	15 R 17 S 10 D 1 C
Catalytic oxidation (CO)	98.33	3	99-97	NA	2 R 1 S
Adsorption to activated carbon or zeolites (AAC-Z)	96.89	35	99.9-80	98.92-98	6 R 6 S 23 D
Wet scrubbing (WS)	79.2	5	96-75	NA	1 S 3 C
Biological off-gas treatment (BWGT)	88.65	2	94.3-83	NA	1 C 1 D
Condensation	95	1	NA	NA	S

NB: In the comments column, the reported method for derivation of the abatement efficiency is stated:
R: Recent simultaneous measurements of raw and clean gas.
S: Simultaneous measurements of raw and clean gas taken when system installed.
D: Design value.
C: Calculated by other method.
Source: [155, TWG 2016]

21.7 Additional information on printing

[1, INTERGRAF and EGF 1999] [78, TWG 2005] unless stated differently, [INTERGRAF comment #108 in [212, TWG 2018]]

21.7.1 Printing industry in the European Union

The printing industry is a large manufacturing industry in the European Union. It is an industry which serves all sectors of the economy including public authorities, financial services, publishers, the retail sector and manufacturing industries. Its customers range from major institutions to the smallest business.

According to Eurostat data, the European printing industry (NACE 18.1) in the EU-28 consists of approximately 120 000 companies, employing about 630 000 people and generating a turnover of EUR 80 billion. These data on the one hand include many activities and installations that are outside the scope of this document and also on the other hand may not cover some of the packaging printing activities (i.e. flexible packaging) [INTERGRAF comment #108 in [212, TWG 2018]].

Table 21.30: Printing industry turnover, number of printing companies and number of employees in European countries

2014	Turnover (million EUR)	Number of companies	Number of employees
Austria	1 852.5	854	10 625
Belgium	3 248.0	4 158	13 088
Bulgaria	348.0	1 026	8 570
Croatia	537.5	1 399	7 515
Cyprus	63.9	250	969
Czech Republic	1 220.6	7 546	15 145
Denmark	1 006.5	771	6 403
Estonia	216.9	357	2 593
Finland	1 206.2	887	8 487
France	8 787.6	21 320	57 095
Germany	18 260.8	11 002	138 748
Greece	493.8	2 217	6 702
Hungary	890.3	3 198	13 302
Ireland	640.7	1 014	4 593
Italy	9 976.9	15 206	62 519
Latvia	204.0	471	3 439
Lithuania	217.2	605	4 162
Luxembourg	111.6	90	699
Malta	159.4	135	1260
Netherlands	3 748.4	3 656	20 744
Poland	2 977.4	8 254	35 300
Portugal	983.4	2 467	14 135
Romania	737.1	1 973	15 378
Slovakia	381.7	1 410	5 797
Slovenia	415.2	1 183	3 647
Spain	5 559.5	13 649	48 670
Sweden	2 331.9	2 896	12 933

United Kingdom	13 014.9	11 608	106 324
Norway	1 128.2	1 036	5 229
Switzerland	3 532.8	1 238	20 076
EU-28	**79 591.9**	**119 602**	**628 842**

Source: [NACE 18.1, Eurostat and Intergraf data 2016, INTERGRAF comment #108 in [212, TWG 2018]]

Table 21.31: Evolution of printing industry turnover, number of companies and number of employees, 2000-2014

	2000	**2004**	**2010**	**2011**	**2012**	**2013**	**2014**	**% change 2014/2004**	**% change 2014/2000**
Turnover (million EUR)	103 866.5	102 123.7	88 004.6	88 076.0	84 936.1	79 439.0	79 592	-22.1%	-23.4%
Number of companies	124 971	131 548	122 980	118 782	116 837	118 473	119 602	-9.1%	-4.3%
Number of employees	958 409	885 411	713 655	684 893	652 210	630 692	627 582	-29.1%	-34.5%

Source: [Eurostat and Intergraf data 2016, INTERGRAF comment #108 in [212, TWG 2018]]

21.7.2 Printing processes

As well as printing on paper, additional markets for printing on other substrates such as plastics, cardboard and metal are also considerable (for printing on metal, see Chapter 10).

While many of the products listed in Figure 21.17 can be produced on the same kind of machine, economics dictate that some of them have to be printed using specialised equipment. The main processes have specific properties and associated costs, and are used as requirements demand. Sometimes, more than one process may be used on the same job, and occasionally a specific printing press may incorporate more than one process.

Printing processes convert original text and pictures into an image on a carrier, and the main process types are named according to how this image is carried. The carrier can be a plate, cylinder or stencil. All image carriers have two separate surfaces – an image (printing) area and a non-image (non-printing) area. The image area accepts the ink, but the non-image area does not accept or retain any ink.

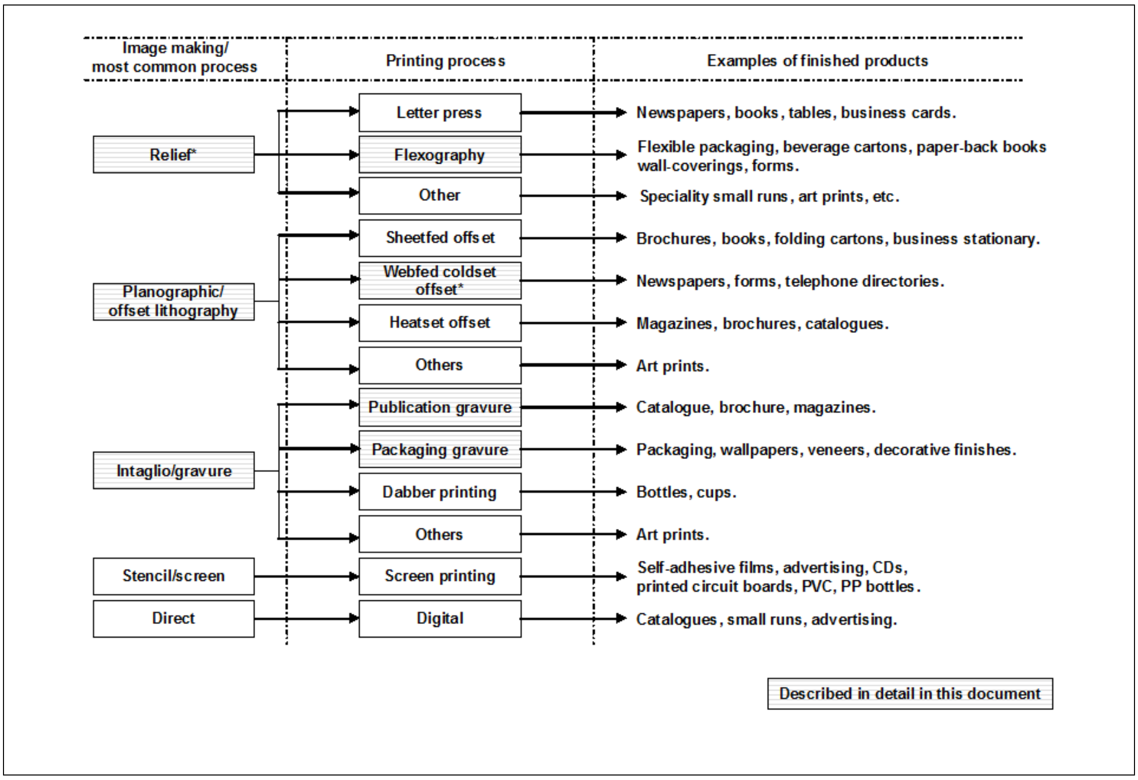


Figure 21.17: Overview of main printing processes

Relief printing

This uses a printing surface that is in relief, i.e. raised above the non-printing surface. ***Letterpress*** and ***flexography*** are examples of this process. Flexographic printing can run in installations large enough to exceed the criteria in IED Annex I (6.7), but often at this size it is found running with packaging gravure, together with laminating and varnishing.

Offset printing

The image and non-image areas are in the same plane on a plate, which can be of metal, plastic or paper (a technique known as ***lithography***, usually abbreviated to '***litho***').

Because offset plates do not last when being constantly abraded by contact with the printing substrate on long print runs, the image is put or 'offset' onto a softer intermediate blanket which transfers the image to the substrate. This type of printing is known as '***offset***' and is the most commonly used process.

The substrate can be fed as a roll or web, known as '***webfed***', or as sheets ('***sheetfed***'). '***Heatset***' and '***coldset***' refer to the technique used to dry the ink. Heatset web offset can run in installations large enough to exceed the criteria in IED Annex I (6.7).

Gravure

This is the best known of the intaglio printing processes, but copperplate and die stamping are others. Here, the printing areas are tiny recesses inscribed on a cylinder below the non-printing areas. These recesses are filled with ink, the surplus ink is removed and the substrate is pressed against the printing cylinder. Publication gravure and packaging gravure can run in installations large enough to exceed the criteria in IED Annex I (6.7).

Stencil

Screen printing is an example of stencil printing, in which the printing and non-printing areas are carried on a screen. The non-printing areas are formed by blocking out parts of the screen, while the ink is forced through the non-blocked parts onto the substrate.

Digital

This produces an image directly onto a substrate from digital information without the creation of an intermediate permanent image.

The business side of the processes

While many businesses also handle the creation of the image and all the processes involved before the actual printing takes place, along with the binding and finishing, a large number of companies exist solely to perform these specific operations. Equally, many thousands of commercial firms such as banks do their own printing in-house.

Additionally, there are high street printing shops (copy shops). Traditionally, they used the same equipment as the smaller ‘conventional’ printer, but now these businesses are based on photocopying and inkjet and/or digital printing.

21.7.3 Printed products

21.7.3.1 Newspapers

Virtually all newspapers are printed by coldset web offset. A typical local newspaper plant might have one or two presses with four units on each press, but larger, specialist printers printing national newspapers may have as many as 10 presses. Coldset machines with a narrower web are also used for the production of advertising flyers, paperback books and telephone directories.

Older letterpress machines may still be found in some countries, but their use has declined rapidly over the last 20 years. Few companies have changed to the flexography process recently. Where the newspaper printers switch to flexography, this is always water-based.

21.7.3.2 Magazines and catalogues

Magazines with a circulation of over 10 000 are generally printed by heatset web offset, although shorter runs will be done by sheetfed offset. Heatset web offset is also used to print travel brochures, mail order catalogues, and advertising material for inserting into newspapers and magazines. It is also used for printing some colour books.

Very long-run magazines and similar publications tend to be printed by gravure, where the extra costs of making a gravure cylinder over those of offset plate making can be sustained. As a result of the high level of investment and the high output, these processes are generally used in large companies.

Gravure has a reputation for being able to print on relatively poor paper surfaces, yet still achieve a good, rich print. Heatset web offset, on the other hand, requires a good coated or uncoated paper to achieve the same quality. Some companies have both gravure and heatset web offset presses to print magazines of different run lengths.

21.7.3.3 Books

Most colour and short-run black and white books tend to be printed by sheetfed offset, whereas long-run single colour books such as paperbacks are printed on a web, usually by coldset web offset but sometimes by letterpress. Mainly, sections of 8, 16 or 32 pages are printed at one time, and then bound to produce the book.

Several hundred firms in each country are capable of printing short-run books by sheetfed offset, for in-house or off-site binding. Long-run work would only be done by a few specialists.

A very small number of specialised continuous belt presses are in existence, which print the entire book in one operation, rather than in several separate sections. These normally print by letterpress using flexible plates. The production of short-run books and booklets is mainly a local operation, but long-run work is open to national and international competition.

21.7.3.4 General printing

There is an enormous variety of printed work known as general or commercial work, which includes advertising literature, company reports and accounts, greetings cards, calendars, brochures, leaflets, posters and the like, which are printed by sheetfed offset.

21.7.3.5 Security printing

The general category of security printing includes a large number of products, from banknotes, passports, stamps, cheques, tickets and coupons to those that rely on the security of the information, such as company reports and accounts, city financial documents and examination papers. This requires a wide range of processes, some of which are specific only to security printing.

21.7.3.6 Labels

There are basically two types of label, i.e. wet labels and self-adhesive roll labels. The former are usually printed by conventional sheetfed offset, then guillotined for subsequent gluing and wrapping around cans and bottles. Self-adhesive labels are printed on a web made up of several layers, including the backing paper, adhesive and front layer, which is printed and cut to the desired shape.

Self-adhesive roll label printing is a highly specialised operation and the equipment is only used for that purpose. The presses may be rotary letterpress, flexo, or offset (water-based or waterless), and may also incorporate screen printing and foil blocking. A specific press may incorporate several processes.

21.7.3.7 Business forms

The printing of business forms is also highly specialised, although the market is rapidly declining due to ever increasing IT capabilities. It can be broken down into two areas: continuous forms and cut sets which are usually A4 size. Business form sets may be printed in sheet form, then collated to form the set, and glued by pasting one edge of a thick block of many sets, for later separation by the user.

21.7.3.8 Paper and cardboard packaging

Paper and cardboard packaging comes in three main forms: paper packaging such as paper bags, and cartons made from either solid or corrugated cardboard. It is a very large market, of around the same order of magnitude as the markets for newspapers, books and security printing.

Cheap paper bags will often be printed by flexography, using water-based inks.

There are a number of markets: food and drink packaging and pharmaceuticals are the largest. With food packaging, printing is often done using UV inks, to ensure complete drying (curing) and no leaching of ink into the food.

Cartons made of solid board are printed by sheetfed offset on large, multicolour machines, to a high quality and accuracy. Corrugated board is generally printed in water-based sheetfed flexography.

For longer runs, printing may be by web offset, flexography or gravure. Gravure is used when high quality is required, for instance for cigarette packets.

21.7.3.9 Products requiring thick ink films

Screen printing produces a characteristically thicker film and is therefore used for many different products such as:

- for high visual impact, such as in point of sale advertising, posters, car decals;
- PVC, polycarbonate or PET bottles;
- CDs, DVDs;
- printing designs onto paper for transfer to T-shirts using heat;
- some specialist wall coverings;
- the thick coatings needed for ‘scratch card’ gaming tickets;
- the magnetic strips on railway tickets and credit cards;
- applying etch-resist in making printed circuit boards (more information can be found in the STM BREF [23, COM 2006]);
- textiles.

The substrates printed in screen printing consist of about 40 % of the printing on self-adhesive films, 20 % of printing on plastics (including rigid plastics), and 20 % of printing on cardboard. Much use of the process is also made in printing on textiles and metals. Run lengths are usually very small, with two thirds of all orders being under 1 000 copies.

21.7.3.10 Wallpaper, decorative paper and paper-based foils for the furniture and lamination industry

A variety of processes are used to print wall coverings, with gravure (similar to packaging gravure) and flexography having largely replaced offset. Many products are also embossed, and it is quite common to see combinations of all three processes used on the same reel of wall covering.

Many printers use the same range of inks to print both vinyl-coated and plain papers by both gravure and flexography.

21.7.3.11 Envelopes

Envelopes can be printed by flexography for the inside, and using water- or solvent-based inks for the outside. Printing, gluing and die cutting can be carried out at the same time from a reel. Alternatively, envelopes can be 'preprinted' by offset, and printed sheets or printed reels are die cut after printing. Supplementary to this, the finished envelope can be printed on the outside by sheetfed offset using conventional or UV drying inks.

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 legislation), 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. Monetary units
III. Unit prefixes, number separators and notations
IV. Units and measures
V. Chemical elements
VI. Chemical formulae commonly used in this document
VII. Acronyms
VIII. Definitions

I. ISO country codes

ISO code	Country
Member States ([1])	
AT	Austria
BE	Belgium
BG	Bulgaria
CZ	Czech Republic
CY	Cyprus
DE	Germany
DK	Denmark
EE	Estonia
EL	Greece
ES	Spain
FI	Finland
FR	France
HR	Croatia
HU	Hungary
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia
Non-member countries	
CH	Switzerland
NO	Norway
UK	United Kingdom

([1]) The protocol order of the Member States is based on the alphabetical order of their geographical names in the original language(s).

II. Monetary units

Code([1])	Country/territory	Currency
Member State currencies		
EUR	Euro area ([2])	euro (pl. euros)
Other currencies		
USD	United States	US dollar

([1]) ISO 4217 codes.

([2]) Includes Austria, Belgium, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Portugal, Slovakia, Slovenia and Spain.

III. Unit prefixes, number separators and notations

Numbers in this document are written using the '.' character as the decimal separator and the space as the separator for thousands.

The symbol ~ (around; about) is the notation used to indicate approximation.

The following table contains the frequently used prefixes:

Symbol	**Prefix**	**10^n**	**Word**	**Decimal Number**
G	giga	10^9	Billion	1 000 000 000
M	mega	10^6	Million	1 000 000
k	kilo	10^3	Thousand	1 000
-------	-------	1	One	1
d	deci	10^{-1}	Tenth	0.1
c	centi	10^{-2}	Hundredth	0.01
m	milli	10^{-3}	Thousandth	0.001
µ	micro	10^{-6}	Millionth	0.000 001

IV. Units and measures

Unit symbol	Unit name	Measure name (measure symbol)	Conversion and comment
A	ampere	Electric current (I)	
kWh	kilowatt-hours	Electric energy	
atm	normal atmosphere	Pressure (P)	1 atm = 101 325 N/m^2
bar	bar	Pressure (P)	1.013 bar = 100 kPa = 1 atm
°C	degree Celsius	Temperature (T) temperature difference (ΔT)	
d	day	Time	
g	gram	Weight	
h	hour	Time	
Hz	hertz	Frequency (f)	
J	joule	Energy	
K	Kelvin	Temperature (T) temperature difference (ΔT)	0 °C = 273.15 K
kcal	kilocalorie	Energy	1 kcal = 4.1868 kJ
kg	kilogram	Weight	
kJ	kilojoule	Energy	
kPa	kilopascal	Pressure	
kWh	kilowatt-hour	Energy	1 kWh = 3 600 kJ
l	litre	Volume	
m	metre	Length	
m^2	square metre	Area	
m^3	cubic metre	Volume	
mg	milligram	Weight	1 mg = 10^{-3} g
mm	millimetre		1 mm = 10^{-3} m
min	minute		
MW$_e$	megawatts electric (energy)	Electric energy	
MW$_{th}$	megawatts thermal (energy)	Thermal energy Heat	
nm	nanometre		1 nm = 10^{-9} m
Nm^3	normal cubic metre	Volume	at 101.325 kPa, 273.15 K
Pa	pascal		1 Pa = 1 N/m^2
ppb	parts per billion	Composition of mixtures	1 ppb = 10^{-9}
ppm	parts per million	Composition of mixtures	1 ppm = 10^{-6}
ppmw	parts per million by weight	Composition of mixtures	
ppmv	parts per million by volume	Composition of mixtures	
rpm RPM	Revolutions per minute	Rotational speed, frequency	
s	second	Time	
t	metric tonne	Weight	1 t = 1 000 kg or 10^6 g

t/d	tonnes per day	Mass flow Materials consumption	
t/yr	tonnes per year	Mass flow Materials consumption	
V	volt	Voltage (V) Electric potential	
vol-% % v/v	percentage by volume	Composition of mixtures	
wt-% % w/w	percentage by weight	Composition of mixtures	
W	watt	Power	1 W = 1 J/s
yr	year	Time	
µm	micrometre	Length	1 µm = 10^{-6} m

V. Chemical elements

Symbol	Name	Symbol	Name
Ac	Actinium	Mn	Manganese
Ag	Silver	Mo	Molybdenum
Al	Aluminium	N	Nitrogen
Am	Americium	Na	Sodium
Ar	Argon	Nb	Niobium
As	Arsenic	Nd	Neodymium
At	Astatine	Ne	Neon
Au	Gold	Ni	Nickel
B	Boron	No	Nobelium
Ba	Barium	Np	Neptunium
Be	Beryllium	O	Oxygen
Bi	Bismuth	Os	Osmium
Bk	Berkelium	P	Phosphorus
Br	Bromine	Pa	Protactinium
C	Carbon	Pb	Lead
Ca	Calcium	Pd	Palladium
Cd	Cadmium	Pm	Promethium
Ce	Cerium	Po	Polonium
Cf	Californium	Pr	Praseodymium
Cl	Chlorine	Pt	Platinum
Cm	Curium	Pu	Plutonium
Co	Cobalt	Ra	Radium
Cr	Chromium	Rb	Rubidium
Cs	Caesium	Re	Rhenium
Cu	Copper	Rf	Rutherfordium
Dy	Dysprosium	Rh	Rhodium
Er	Erbium	Rn	Radon
Es	Einsteinium	Ru	Ruthenium
Eu	Europium	S	Sulphur
F	Fluorine	Sb	Antimony
Fe	Iron	Sc	Scandium
Fm	Fermium	Se	Selenium
Fr	Francium	Si	Silicon
Ga	Gallium	Sm	Samarium
Gd	Gadolinium	Sn	Tin
Ge	Germanium	Sr	Strontium
H	Hydrogen	Ta	Tantalum
He	Helium	Tb	Terbium
Hf	Hafnium	Tc	Technetium
Hg	Mercury	Te	Tellurium
Ho	Holmium	Th	Thorium
I	Iodine	Ti	Titanium
In	Indium	Tl	Thallium
Ir	Iridium	Tm	Thulium
K	Potassium	U	Uranium
Kr	Krypton	V	Vanadium
La	Lanthanum	W	Tungsten
Li	Lithium	Xe	Xenon
Lr	Lawrencium	Y	Yttrium
Lu	Lutetium	Yb	Ytterbium
Md	Mendelevium	Zn	Zinc
Mg	Magnesium	Zr	Zirconium

VI. Chemical formulae commonly used in this document

Chemical formula	Name (explanation)
C_6H_6	Benzene
CO	Carbon monoxide
CO_2	Carbon dioxide
F^-	Fluoride ion
HCl	Hydrochloric acid
HF	Hydrogen fluoride
NH_3	Ammonia
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides, the sum of nitrogen monoxide (NO) and nitrogen dioxide (NO_2), expressed as NO_2
SO_2	Sulphur dioxide

VII. Acronyms

Acronym	Full phrase
AAC-Z	Adsorption to activated carbon or zeolite
ACEA	European Automobile Manufacturers' Association
ADEME	Agence de l'Environnement et de la Maîtrise de l'Energie
AFERA	European Adhesive Tape Association
AOX	Adsorbable organically bound halogens
ASD	European Aeronautics, Space, Defence and Security Industries
BAT	Best Available Techniques
BAT-AEL	Best Available Techniques - associated emission level
BAT-AEPL	Best Available Techniques - associated performance emission level
BOD	Biochemical oxygen demand
BREF	BAT reference document
BTEX	Benzene, toluene, ethylbenzene, xylene
BWGT	Biological off-gas treatment
CAD	Computer-aided design
CBN	Cubic boron nitride
CDC	Cathodic dip coating
CEFIC	Conseil Européen de l'Industrie Chimique (European Chemical Industry Council)
CEN	Comité Européen de Normalisation (European Committee for standardisation)
CHP	Combined heat and power (cogeneration).
CITEPA	Centre Interprofessionnel Technique d'Etudes de la Pollution Atmosphérique
CMR	Carcinogenic, mutagenic, reprotoxic
CO	Catalytic oxidation
COD	Chemical oxygen demand
CEPE	European Council of the Paint, Printing Ink and Artists' Colours Industry
DEFRA	Department for Environment, Food and Rural Affairs (UK)
DEHP	Bis(2-ethylhexyl) phthalate
DIN	Deutsches Institut für Normung (German national organisation for standardisation)
DMF	N,N-dimethylformamide
DPF	Dry particle filter
DS(l)	Dry scrubbing with limestone
EB	Electron beam
ECCA	European Coil Coating Association
EDTA	Ethylene diamine tetra acetic acid
EEB	European Environmental Bureau
EF	Emission factors
EEA	European Environment Agency
ELV	Emission limit value
EMAS	Eco-Management and Audit Scheme (Council Regulation (EC) No 1221/2009)
EMS	Environmental management system.
EN	European Norming (EN standards)
EOE	Easy-open ends
EPA	Environmental Protection Agency (US)
EPDM	Ethylene-propylene-diene monomer
EPF	European Panel Federation
E-PRTR	European Pollutant Release and Transfer Register
EQS	Environmental quality standard
ERA	European Rotogravure Association
ESIG	European Solvents Industry Group
ESP	Electrostatic precipitator
ESTA	Electrostatic application
ESVOCCG	European Solvents Volatile Organic Compounds Co-Ordination Group
EU	European Union
EU-15	Member States of the European Union before 1 May 2004
EU-25	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 until 30 June 2013
EU-28	Member States of the European Union from 1 July 2013 until 31 January 2020
EURATEX	European Apparel and Textile Confederation
EVA	ethylene vinyl acetate
EWPM	European Wood Preservative Manufacturers Group
FID	Flame ionisation detector/detection

FM	Filter mat
FPE	Flexible Packaging Europe
GDP	Gross domestic product
GRT	Gross registered tonnes
GT	Gross tonnes
HBS	High-boiling solvents
HDF	High-density fibre
HF	High frequency
HP	High pressure
HVLP	High-volume low-pressure
HVAC	Heating, ventilation and air-conditioning
IBC	Intermediate bulk container
IED	Industrial Emission Directive (2010/75/EU)
IEC	International Electrotechnical Commission
IMO	International Maritime Organisation
INTERGRAF	European Federation for Print and Digital Communication
ISO	International Organisation for Standardisation
IPA	Isopropyl alcohol, propan-2-ol (also called isopropanol)
IPPC	Integrated pollution prevention and control
IR	Infrared
LCP	Large combustion plant
LP	Low pressure
LWC	Low weight coated
MDF	Medium-density fibre (boards)
MEK	Methyl ethyl ketone
MF	Microfiltration
MPE	Metal Packaging Europe
MS	(European Union) Member State
NA	Not applicable OR not available (depending on the context)
NACE	Nomenclature des Activités Economiques (statistical classification of economic activities in Europe)
NC	Nitrocellulose
NEOE	Non-easy-open ends
NF	Nanofiltration
NGO	Non-Governmental organisation
NI	No information provided
NIR	Near infrared
NMP	n-Methyl-pyrrolidone
NMVOC	Non-methane volatile organic compound (see VOC)
NOC	Normal Operating Conditions
NP/NPE	Nonylphenol and nonylphenol ethoxylates
NR	Natural rubber
OECD	Organisation for Economic Co-operation and Development
OEL	Occupational exposure limit
OEM	Original equipment manufacturer
OFP	Ozone-forming potential
ORGALIM	Europe's Technology Industries
PA	Polyamide
PAHs	Polycyclic aromatic hydrocarbons
PBTs	Persistent, bioaccumulative and toxic substances
PCP	Pentachlorophenol
PCDD/Fs	Polychlorinated dibenzodioxins/dibenzofurans
PE	Polyethylene (polythene)
PET	Polyethylene terephthalate
PID	Photoionisation detector
PM	Particulate matter
POP	Persistent organic pollutant
PP	Polypropylene
PS	Polystyrene
PTFE	Polytetra fluoro ethylene
PU or PUR	Polyurethane
PVA (or PVAC)	Polyvinyl acetate
PVB	Polyvinyl butyrate

PVC	Polyvinyl chloride
PVdF (or PVF_2)	Polyvinylidene difluoride
PVF	Polyvinyl fluoride
RA	Rate of evaporation
RecTO	Recuperative thermal oxidation
RH	Relative humidity
ROI	Return on investment
RTO	Regenerative thermal oxidiser (dual, three or five beds)
SBR	Butadiene styrene copolymer
SBS	Styrene butadiene styrene (block copolymer)
SEA SMRC	Ships and Maritime Equipment Association
SIS	Styrene isoprene styrene (block copolymer)
SME	Small and medium enterprise(s)
SMB	Solvent mass balance
SMP	Solvent management plan (Part 2 of Annex VII to the IED)
STP	Standard temperature and pressure
TBT	Tributyltin
TEQ	Toxicity equivalents (iTEQ: international toxicity equivalents)
TGIC	Triglycidyl isocyanurate: a mutagenic substance used in powder coatings.
TO	Thermal oxidiser
TOC	Total organic carbon
TPM	Total particulate material
TSS	Total suspended solids
TVOC	Total volatile organic carbon
TWG	Technical Working Group
UF	Ultrafiltration
UF	Urea formaldehyde
UBA	Umweltbundesamt – Federal Environment Agency, i.e. from Germany or Austria
UP	Unsaturated polyester
UV	Ultraviolet
VCA	Vegetable cleaning agent
VHR	Vapour hazard ratio
VOC	Volatile organic compound
WEI	European Institute for Wood Preservation
WHO	World Health Organisation
WPA	Wood Protection Association
WS	Wet scrubber
WW	Winding wire
WWT(P)	Waste water treatment (plant)

VIII. Definitions

1K / 2K	One- / two-component, usually used for paints
Acid	A proton donor: a substance that liberates hydrogen ions in water solution.
Aerobic	A biological process that occurs in the presence of oxygen.
Alkali (base)	A proton acceptor. A substance that liberates hydroxide ions in water solution.
Anaerobic	A biological process which occurs in the absence of oxygen.
ATEX	Atmospheric explosives (according to Directive 94/9/EC of the European Parliament and of the Council of 23 March 1994 on the approximation of the laws of the Member States concerning equipment and protective systems intended for use in potentially explosive atmospheres).
Base coat	Paint which, when applied to a substrate, determines the colour and the effect (e.g. metallic, pearlescent).
Batch discharge	Discharge of a discrete, contained volume of water.
Biocidal product(s)	Any substance or mixture, in the form in which it is supplied to the user, consisting of, containing or generating one or more active substances, with the intention of destroying, deterring, rendering harmless, preventing the action of, or otherwise exerting a controlling effect on any harmful organism by any means other than mere physical or mechanical action (Biocidal product as defined in Article 3(1) of Directive 2012/528/EU).
Biodegradable	Can be broken down physically and/or chemically by microorganisms. For example, many chemicals, food scraps, cotton, wool and paper are biodegradable.
BIW, body in white	A standard term in the vehicle manufacturing industry and refers to the bare metal shell of the vehicle before it has been degreased, dipped and painted.
Blue stain	According to CEN standard EN 1001-2 (August 2005): stain caused by fungi in which the discoloration ranges from pale blue to black. Usually affects the sapwood of certain species.
Blue stain in service	According to CEN standard EN 1001-2 (August 2005): staining of the sapwood of timber in service as a result of the growth of fungi with pigmented hyphae within the wood cells.
Blue stain treatment	Treatment to protect against blue stain (see above).
C	Abbreviation used for creosote (plant)
CAFE	Clean Air For Europe: the programme that underpins the EU's thematic strategy on air pollution.
CAS number	A unique numerical identifier assigned by the Chemical Abstracts Service (CAS) to every chemical substance, organic or inorganic, e.g. 872-50-4 (for NMP). It will be found on SDSs (safety data sheets) to clearly identify substances.
Clear coat	Coating material which, when applied to a substrate, forms a solid transparent film with protective, decorative or specific technical properties.
CMR (substance)	Substances classified as carcinogenic, mutagenic or toxic to reproduction carrying the hazard statements H340, H341, H350, H351, H360 or H361 (categories 1A, 1B or 2); *refer to Regulation (EC) No 1272/2008 on Classification, Labelling and Packaging of substances and mixtures (CLP).*
CMR-VOC	Substances or mixtures which, because of their content of volatile organic compounds classified as carcinogens, mutagens, or toxic to reproduction under Regulation (EC) No 1272/2008, are assigned or need to carry the hazard statements H340, H350, H350i, H360D, H360F or halogenated VOCs which are assigned or need to carry the hazard statements H341 or H351. *(Refer also to IED Art. 58 and IED, Annex VII, Part 4).*
Combiline	Combination of hot-dip galvanising and coil coating in the same process line.
Composite sample	Two or more samples or spot samples (either discretely or continuously) mixed/blended together in appropriate known proportions from which the average result of a desired characteristic may be obtained.

Containment, contained area	(Secondary) containment refers to additional protection against storage tank releases over and above the inherent protection provided by the tank container itself. There are two major types of secondary containment for leakages, namely those that are part of the tank construction, such as double-tank bottoms (only for above-ground tanks), double-skinned and double-walled tanks and impervious barriers which are placed upon the soil surface below the tanks [44, COM 2006].
Continuous measurement	Measurement using an automated measuring system permanently installed on site for continuous monitoring of emissions, according to EN 14181.
Cross-media effects	Relevant negative environmental effects due to implementing a technique, allowing a comparison amongst techniques in order to assess the impact on the environment as a whole. See also Commission Implementing Decision 2012/119/EU Section 2.3.7.2.5.
CSBR	Carboxylated styrene butadiene styrene block copolymer
Direct discharge	Discharge to a receiving water body without further downstream waste water treatment.
Drip tray	Tray or pan-like devise for collection of spills and drippage.
DWI	Draw and wall ironed: a type of can in the metal packaging industry.
Effluent	Physical fluid (air or water together with contaminants) forming an emission.
EGTEI	See Annex 21.3.1. EGTEI home page: http://www.citepa.org/forums/egtei/egtei_index.htm
ELV	Emission limit value: the mass, expressed in terms of certain specific parameters, concentration and/or level of an emission, which may not be exceeded during one or more periods of time.
EMEP	European Monitoring and Evaluation Programme (https://www.emep.int/).
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.
'End-of-pipe' technique	A technique that reduces final emissions or consumption by some additional process but does not change the fundamental operation of the core process. Synonyms: 'secondary technique', 'abatement technique'. Antonyms: 'process-integrated technique', 'primary technique' (a technique that in some way changes the way in which the core process operates, thereby reducing emissions or consumption).
Environmental footprint	A measure of the burden or impact that a product, operation or business places on the environment. This will be: • the consumption of energy, raw materials and water; • emissions to air, water, groundwater, and soil; and as waste; • noise and vibrations, odour emissions; • damage to material property and the impairment or interference with amenities and other legitimate uses of the environment.
Flat tint	A printed area containing halftone dots that are all the same size, as opposed to a halftone or a vignette. Flat tints are usually just called 'tints'.
Flocculation	Waste water treatment involving gentle stirring whereby small particles in flocs are collected into larger particles so their weight causes them to settle to the bottom of the treatment tank.
Fugitive emission	In this document, the IED definition is used: any emissions not in waste gases of volatile organic compounds into air, soil and water as well as solvents contained in any products, unless otherwise stated in Part 2 of Annex VII; they include uncaptured emissions released to the outside environment via windows, doors, vents and similar openings (conversely, see also waste gas).
Grade B or C creosote	Types of creosote for which specifications are given in EN 13991.
Hexavalent chromium	Hexavalent chromium, expressed as Cr(VI), includes all chromium compounds where the chromium is in the oxidation state +6 (dissolved or bound to particles).
HOI	Hydrocarbon oil index, the sum of compounds extractable with a hydrocarbon solvent (including long-chain or branched aliphatic, alicyclic, aromatic or alkyl-substituted aromatic hydrocarbons).
Indirect discharge	Discharge which is not a direct discharge.

Installation	A stationary technical unit where one or more activities listed in Annex I to Directive 2010/75/EU are carried out, and any other directly associated activities which have a technical connection with an activity listed in Annex I and which could have an effect on emissions and pollution
K1 **K2** **K3**	An indication of flammability used in the Netherlands and Belgium, according to flashpoint: • K1: < 21 °C; • K2: 21-55 °C; • K3: > 55 °C.
LEL	Lower explosive limit – the lowest concentration (percentage) of a gas or vapour in air capable of producing a flash of fire in the presence of an ignition source. Concentrations lower than LEL are 'too lean' to burn. Also called lower flammable limit (LFL).
LoD **(limit of detection)**	The output signal or concentration value above which it can be affirmed with a stated level of confidence that a sample is different from a blank sample containing no determinant of interest.
LoQ **(limit of quantification)**	A stated multiple of the limit of detection at a concentration of the determinant that can reasonably be determined with an acceptable level of accuracy and precision. The limit of quantification can be calculated using an appropriate standard or sample, and may be obtained from the lowest calibration point on the calibration curve, excluding the blank.
MKM	An Environmental Costing Model (MilieuKostenModel), see Annex 21.3.2.
Monitoring	Process intended to assess or to determine the actual value and the variations of an emission or another parameter, based on procedures of systematic, periodic or spot surveillance, inspection, sampling and measurement or other assessment methods intended to provide information about emitted quantities and/or trends for emitted pollutants.
Naphthalene	Organic compound with formula C10H8. It is the simplest polycyclic aromatic hydrocarbon.
Nickel	Nickel, expressed as Ni, includes all inorganic and organic nickel compounds, dissolved or bound to particles.
NP (1 - 6)	Penetration class as defined in EN 351 (Classification of preservative penetration and retention). EN 351 establishes classification for preservative-treated wood in terms of preservative penetration and gives guidance on a classification of retention. These can be used as a basis for specifying preservative treatments for particular products.
Oblongs	From can-making: refers to the shape of a general line container where the top and bottom ends are rectangular in shape with rounded corners.
ODP	Ozone depletion potential: a relative index indicating the extent to which a compound may cause ozone depletion.
Off-gas	The gas extracted from a process, equipment or area which is either directed to treatment or discharged directly to air through a stack.
Operator	Any natural or legal person who operates or controls the installation or, where this is provided for in national legislation, to whom decisive economic power over the technical functioning of the installation has been delegated.
Organic solvent	Organic solvent as defined in Article 3(46) of Directive 2010/75/EU.
Organic compound	Organic compound as defined in Article 3(44) of Directive 2010/75/EU.
OTNOC	Other than normal operating conditions. Article 14 (f) of the IED refers to other than normal operating conditions as start-up and shutdown operations, leaks, malfunctions, momentary stoppages and definitive cessation of operations.
Ozone depletion	Destruction of the stratospheric ozone layer, which can be caused by the photolytic breakdown of certain compounds containing chlorine and/or bromine (e.g. chlorofluorocarbons), which catalytically decompose ozone molecules.
Plant	All parts of an installation that carry out an activity listed in point 6.7 or 6.10 of Annex I to Directive 2010/75/EU and any other directly associated activities which have an effect on consumption and/or emissions. Plants may be new plants or existing plants.

Pollutant	Individual substance or group of substances which can harm or affect the environment.
Pre-product	A workpiece that is not the final product, but is treated and coated separately. In this document, for example, flat sheets that may be coated and/or printed prior to shaping and adding end pieces to form a can.
Primer coat	Paint formulated for use as a layer on a prepared surface, to provide good adhesion, protection of any layers below and filling of surface irregularities.
Primary measure/technique	A technique that in some way changes the way in which the core process operates, thereby reducing raw emissions or consumption (see end-of-pipe technique).
RAINS	Regional Air Pollution Information and Simulation for Europe. See Annex 21.3.2. Where RAINS is referred to in this document, it is RAINS version CP_CLE_Aug04(Nov04). For a review of data used in the RAINS-VOC model: http://www.iiasa.ac.at/web-apps/tap/RainsWeb/
REACH	Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC.
Reference conditions	From standard text – See Chapter 18.
Right first time	Production management quality control technique to enable product quality to be correct within a minimum number of completed items.
Sap stain	According to CEN standard EN 1001-2 (August 2005): discolouration of wood resulting from the growth of micro-fungi which derive their nourishment from cell contents but do not cause significant decomposition of the wood. Its development is principally confined to the sapwood of green timber (freshly felled timber).
Sap stain treatment	Protective treatment of a temporary nature given to green timber against sap-staining fungi.
Secondary measure/technique	See end-of-pipe technique.
Sector	Any of the surface treatment activities that are part of activities listed in point 6.7 or 6.10 of Annex I to Directive 2010/75/EU.
Sensitive receptor	Area which needs special protection, such as: - residential areas; - areas where human activities are carried out (e.g. neighbouring workplaces, schools, day-care centres, recreational areas, hospitals or nursing homes).
Solid mass input	The total mass of solids used as defined in Part 5, 3(a)(i) of Annex VII to Directive 2010/75/EU.
Solvent input	The total quantity of organic solvents used as defined in Part 7, 3(b) of Annex VII to Directive 2010/75/EU.
Solvent-based (SB)	Type of paint, ink or other coating material using solvent(s) as the carrier. For preservation of wood and wood products, it refers to the type of treatment chemicals.
Solvent based-mix (SB-mix)	Solvent-based coating where one of the coating layers is water-based (WB).
Solvent mass balance (SMB)	A mass balance exercise conducted at least once every year according to Part 7 of Annex VII to Directive 2010/75/EU.
SOMO 35	Statistical term: sum of ozone mean values over 35 ppb.
Specific emission	Emission related to a reference basis, such as production capacity, or actual production (e.g. mass per tonne or per unit produced).

SVHC (substances of very high concern)	Substances that have been proposed to be subject to authorisation (e.g. to be included in Annex XIV) under the REACH Regulation. According to Article 57, these may be substances that are: CMR (category 1A or 1B), PBT (persistent, bioaccumulating, and toxic), vPvB (very persistent and very bioaccumulating), or of equivalent level of concern, ELoC (endocrine disrupting). *(Refer to Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH).)*
Surface run-off water	Water from precipitation that flows over land or impervious surfaces, such as paved streets and storage areas, rooftops etc. and does not soak into the ground.
Treatment chemicals	Chemicals used in wood and wood products preservation such as biocides, chemicals used for waterproofing (e.g. oils, emulsions) and flame retardants; this also includes the carrier of active substances (e.g. water, solvent).
Total emissions	The sum of fugitive emissions and emissions in waste gases as defined in Article 57(4) of Directive 2010/75/EU.
Treatment area	For the preservation of wood and wood product with chemicals, the treatment area consists of the treatment vessels, working vessels, associated pipework, treatment vessel loading area consisting of the full rail line (and/or access ways for vehicles, cane loading /handling area) and post-treatment drying area.
Treatment vessel	A dipping tank, a deluging tank or an autoclave used for preservative treatment.
TWG	Technical working group, consisting of technical experts representing Member States, industries, non-governmental organisations (NGOs) and the Commission, in charge of drawing up or reviewing BREF documents.
UC (1 - 5)	Use class as defined in EN 335. EN 335 defines five use classes which represent different service situations to which wood and wood-based products can be exposed.
Varnish	Varnishes are preparations consisting of resinous matter dissolved in an oil or in solvent or other volatile liquid. When applied to the surface of wood, metal, etc., it dries and leaves a hard, more or less glossy, usually transparent coating.
Water-based (WB)	Type of paint, ink or other coating material in which water replaces all or part of the solvent content. For preservation of wood and wood products, it refers to the type of treatment chemicals
Waste gas	In this document, the IED definition is used: the final gaseous discharge containing volatile organic compounds or other pollutants from a stack or abatement equipment into air.
WFD	Water Framework Directive: Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy.
White spirit	CAS No: 8052-41-3. Also known as mineral spirits, high flash naphtha, petroleum distillate fractions, Stoddard solvent, petroleum distillates. Used as a paint thinner, a degreaser and a cleaning agent. It is a mixture of saturated aliphatic and alicyclic C7-C12 hydrocarbons with a content of 15-20 % (by weight) of aromatic C7-C12 hydrocarbons and a boiling range of 130-230 °C. The C9-C11 hydrocarbons (aliphatics, alicyclics and aromatics) are most abundant, constituting > 80 % (by weight) of the total. Flashpoint (fp) and boiling point (initial, bp) according to grade: • low flash grade: fp 21-30 °C, bp 130-144 °C; • regular flash grade: fp 31-54 °C, bp 145-174 °C; • high flash grade: fp => 55 °C, bp 175-200 °C. [136, WHO_IPCS 1996]
Working vessel	Intermediate storage vessel for preservative solution in pressure processes. Preservative feeds from the bulk tank or containers to the working vessel, and from there into the treatment vessel.
Zinc	Zinc, expressed as Zn, includes all inorganic and organic zinc compounds, dissolved or bound to particles.

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