



# JRC SCIENCE FOR POLICY REPORT

## Best Available Techniques (BAT) Reference Document for the Textiles Industry

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

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## Abstract

The Best Available Techniques (BAT) Reference Document (BREF) for the Textiles Industry 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 for the Textiles Industry covers the pretreatment operations such as washing, bleaching, mercerisation or dyeing of textile fibres or textiles where the treatment capacity exceeds 10 tonnes per day, as specified in Point 6.2 of Annex I to Directive 2010/75/EU. This BREF also concerns independently operated treatment of waste water that is not covered by Directive 91/271/EEC as specified in point 6.11 of Annex I to Directive 2010/75/EU, provided that the main pollutant load originates from the activities covered in this BREF.

The BREF also covers the following:

- Coating, dry cleaning, fabric production, finishing, lamination, printing, singeing, wool carbonising, wool fulling, spinning of fibres (other than man-made fibres), washing or rinsing associated with dyeing, printing or finishing; if directly associated with the activities covered by this BREF,
- The combined treatment of waste water from different origins, provided that the waste water treatment is not covered by Directive 91/271/EEC and that the main pollutant load originates from the activities covered by this BREF.
- Combustion processes directly associated with the activities covered by this BREF provided that:
  1. the gaseous products of combustion are put into direct contact with the textile fibres or textiles (such as direct heating, drying, heat-setting), or
  2. the radiant and/or conductive heat is transferred through a solid wall (indirect heating), without using an intermediary heat transfer fluid).

Important issues for the implementation of Directive 2010/75/EU in the textiles (TXT) sector are emissions to water and air, use and handling of chemicals as well as energy consumption. Chapter 1 provides general information on the TXT sector and Chapter 2 on the industrial processes and techniques used within this sector. Chapter 3 provides information on emission and consumption levels in the TXT sector. Chapter 4 provides information on techniques to prevent or reduce the environmental impact of operating installations. Chapter 5 presents the BAT conclusions as defined in Article 3(12) of the Directive, both general and sector-specific. Chapter 6 provides information on emerging techniques. Chapter 7 is concerned with the concluding remarks and recommendations for future work. A number of annexes detailing the list of installations who participated in the data collection and other information on specific technical issues are presented in Chapter 8.

## **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: Fair and Sustainable Economy under the supervision of Serge Roudier (Head of the EIPPCB), Alejandro Villanueva (Deputy Head of the Circular Economy and Sustainable Industry Unit) and Mikel Alvarez Lanbadaso (Acting Head of the Circular Economy and Sustainable Industry Unit).

The authors of this BREF were Joze Roth, Benoit Zerger, Damien De Geeter, Jorge Gómez Benavides 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, Bulgaria, Czechia, Denmark, Finland, France, Germany, Hungary, Ireland, Italy, Malta, the Netherlands, Poland, Portugal, Slovakia, Spain, Sweden and the United Kingdom (until 31/01/2020);
- among industry: CEFIC (European Chemical Industry Council), EURATEX (European Apparel and Textile Association), FEAD (European Federation of Waste Management and Environmental Services), IWTO (International Wool Textile Organisation), HWE (Hazardous Waste Europe), ESA (European Sealing Association);
- among environmental non-governmental organisations: EEB (European Environmental Bureau).

Eric Aries, George Chronopoulos and Martin Weiss contributed significantly to the internal discussions and task force sessions realised for the development of this document while working at the EIPPCB during the comments assessment period.

The whole EIPPCB team provided contributions and peer reviewing.

This report was edited by Anna Atkinson and formatted by Carlos Javier Muñoz Crespo, Carmen Ramirez and Daniela Antonova.

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

<b>Reference Document on Best Available Techniques (BREF)</b>	<b>Code</b>
Ceramic Manufacturing Industry	CER
Common Waste Gas Management and Treatment Systems 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 and Pigs	IRPP
Iron and Steel Production	IS
Large Combustion Plants	LCP
Large Volume Inorganic Chemicals – Ammonia, Acids and Fertilisers Industries	LVIC-AAF
Large Volume Inorganic Chemicals – Solids and Others Industry	LVIC-S
Large Volume Organic Chemical Industry	LVOC
Management of Tailings and Waste-rock in Mining Activities	MTWR
Manufacture of Glass	GLS
Manufacture of Organic Fine Chemicals	OFC
Non-ferrous Metals Industries	NFM
Production of Cement, Lime and Magnesium Oxide	CLM
Production of Chlor-alkali	CAK
Production of Polymers	POL
Production of Pulp, Paper and Board	PP
Production of Speciality Inorganic Chemicals	SIC
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 Wood and Wood Products Preservation with Chemicals	STS
Tanning of Hides and Skins	TAN
<i>Textiles Industry</i>	<i>TXT</i>
Waste Incineration	WI
Waste Treatment	WT
<b>Reference Document (REF)</b>	
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 publicly available and can be downloaded from <http://eippcb.jrc.ec.europa.eu>.

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## PREFACE

### 1. Status of this document

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

This BAT reference document for the Textiles Industry 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.

The original best available techniques (BAT) reference document (BREF) for the Textiles Industry was adopted by the European Commission in 2003. This document is the result of a review of that BREF. The review commenced in August 2017.

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 2022/2508/EU on the BAT conclusions contained in Chapter 5 was adopted on 09/12/2022 and published in the Official Journal of the European Union (OJ L 325) on 20/12/2022.

### 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 and Chapter 2 provide general information on the textiles sector and on the industrial processes used within this sector.

Chapter 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, water consumption, use of energy and the generation of waste.

Chapter 4 describes in more detail the techniques to prevent or, where this is not practicable, to reduce the environmental impact of installations in this sector that were considered in determining the BAT. This information includes, where relevant, the environmental performance levels (e.g. emission and consumption levels) which can be achieved by using the techniques, the associated monitoring and the costs and the cross-media issues associated with the techniques.

Chapter 5 presents the BAT conclusions as defined in Article 3(12) of the Directive, both general and process-specific.

Chapter 6 presents information on ‘emerging techniques’ as defined in Article 3(14) of the Directive.

Concluding remarks and recommendations for future work are presented in Chapter 7.

#### **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 textiles sector;
- examination of the techniques most relevant to address these key issues;
- identification of the best environmental performance levels, on the basis of the data available 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 Chapter 4. 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 plant 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 plants.

#### **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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## SCOPE

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

- 6.2. Pre-treatment (operations such as washing, bleaching, mercerisation) or dyeing of textile fibres or textiles where the treatment capacity exceeds 10 tonnes per day.
- 6.11. Independently operated treatment of waste water not covered by Directive 91/271/EEC provided that the main pollutant load originates from activities covered by these BAT conclusions.

These BAT reference document (BREF) also cover the following:

- The following activities when they are directly associated with activities specified in point 6.2 of Annex I to Directive 2010/75/EU:
  - coating;
  - dry cleaning;
  - fabric production;
  - finishing;
  - lamination;
  - printing;
  - singeing;
  - wool carbonising;
  - wool fulling;
  - spinning of fibres (other than man-made fibres);
  - washing or rinsing associated with dyeing, printing or finishing.
- The combined treatment of waste water from different origins, provided that the main pollutant load originates from activities covered by these BAT conclusions and that the waste water treatment is not covered by Directive 91/271/EEC.
- On-site combustion plants that are directly associated with the activities covered by these BAT conclusions, provided that the gaseous products of combustion are put into direct contact with the textile fibres or textiles (such as direct heating, drying, heat-setting) or when radiant and/or conductive heat is transferred through a solid wall (indirect heating) without using an intermediary heat transfer fluid.

This BREF does not cover the following:

- Coating and lamination with an organic solvent consumption capacity of more than 150 kg per hour or more than 200 tonnes per year. These are covered by the BAT conclusions on surface treatment using organic solvents including preservation of wood and wood products with chemicals (STS).
- Production of man-made fibres and yarns. This may be covered by the BAT conclusions for the production of polymers.
- Unhairing of hides and skins. This may be covered by the BAT conclusions for the tanning of hides and skins (TAN).

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

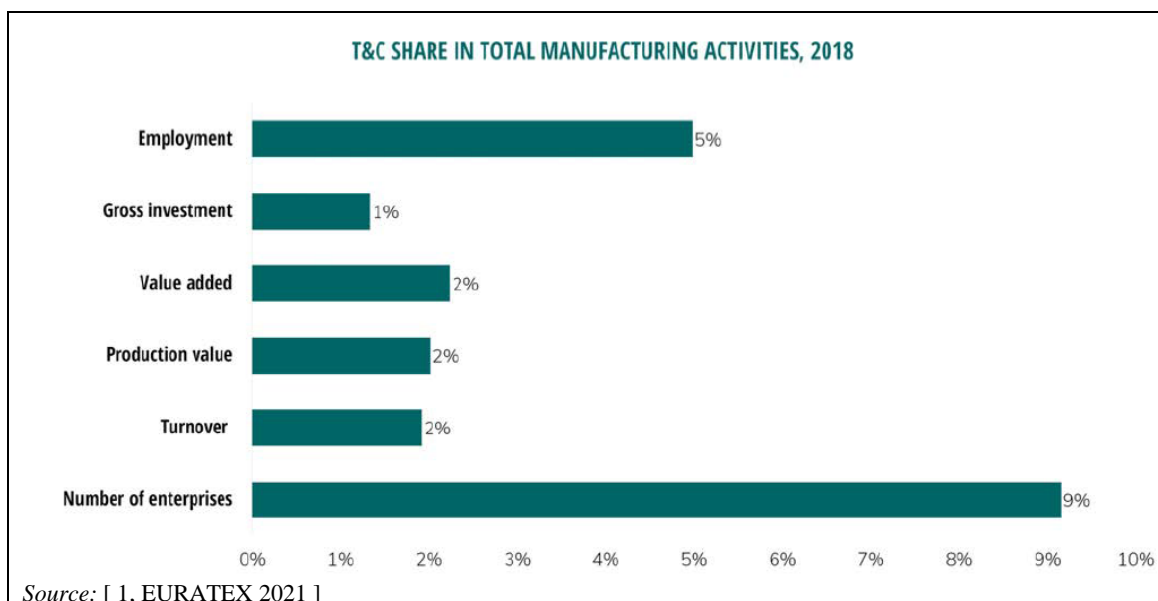
- Surface Treatment Using Organic Solvents including Preservation of Wood and Wood Products with Chemicals (STS);
- Waste Incineration (WI);
- Waste Treatment (WT);

- Emissions from Storage (EFS);
- Energy Efficiency (ENE);
- Industrial Cooling Systems (ICS);
- Monitoring of Emissions to Air and Water from IED Installations (ROM);
- Economics and Cross-Media Effects (ECM).

## 1 GENERAL INFORMATION

The textile industry is one of the longest and most complex industrial production/supply chains in the manufacturing industry. It is a fragmented and heterogeneous sector dominated by a majority of small and medium-sized enterprises, with demand largely driven by three main end-uses: clothing, home furnishing and industrial use.

According to Euratex [1, EURATEX 2021], the textile and clothing (T&C) industry is relatively important in the European economy, representing 5 % of its workforce and almost 10 % of the enterprises (see Figure 1.1 below).



**Figure 1.1: Textile & clothing in total EU manufacturing activities**

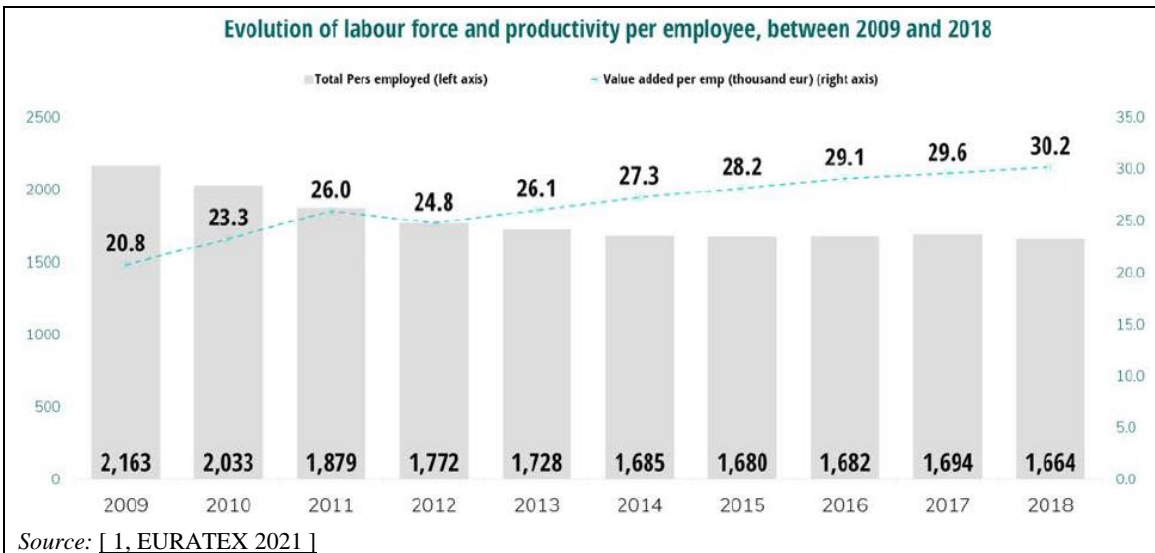
Micro and SME (small and medium-sized) enterprises represented 99.8 % of the total number of companies in the T&C industry (see Table 1.1); of these 33 % were textiles and 67 % clothing companies.

**Table 1.1: Companies in the T&C industry (2018)**

Size of company (number of employees)	Share (%)
Micro (0-9)	88.8
Small and medium-sized (10-249)	11.0
Large (>250)	0.2

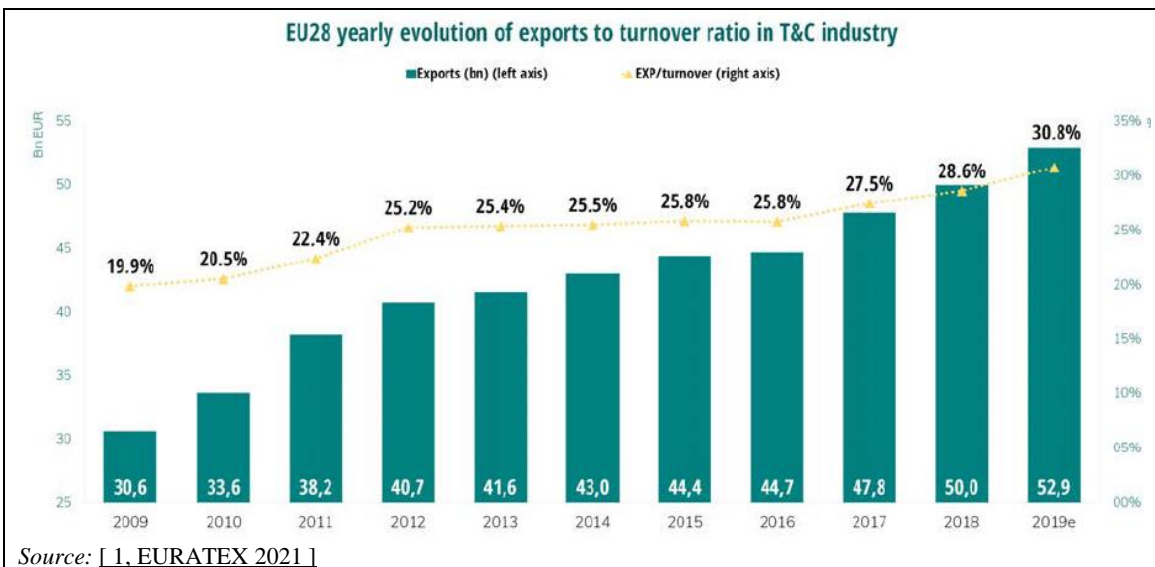
Source: [1, EURATEX 2021]

The EU T&C industry has achieved considerable gains in productivity per employee over the years (see Figure 1.2).



**Figure 1.2: Employment and productivity per employee**

Furthermore, the EU T&C industry became more competitive on the global market over the period 2009-2019 (see Figure 1.3). The total turnover of the industry was EUR 162 billion (in 2019), of which textiles had a 51 % share, man-made fibres 4 % and clothing a 45 % share.



**Figure 1.3: Turnover and exports of the T&C industry (2009-2019)**

Outerwear and accessories was the main subsector contributing to the total textile production; however, industrial and technical textiles are growing in importance (see Figure 1.4).

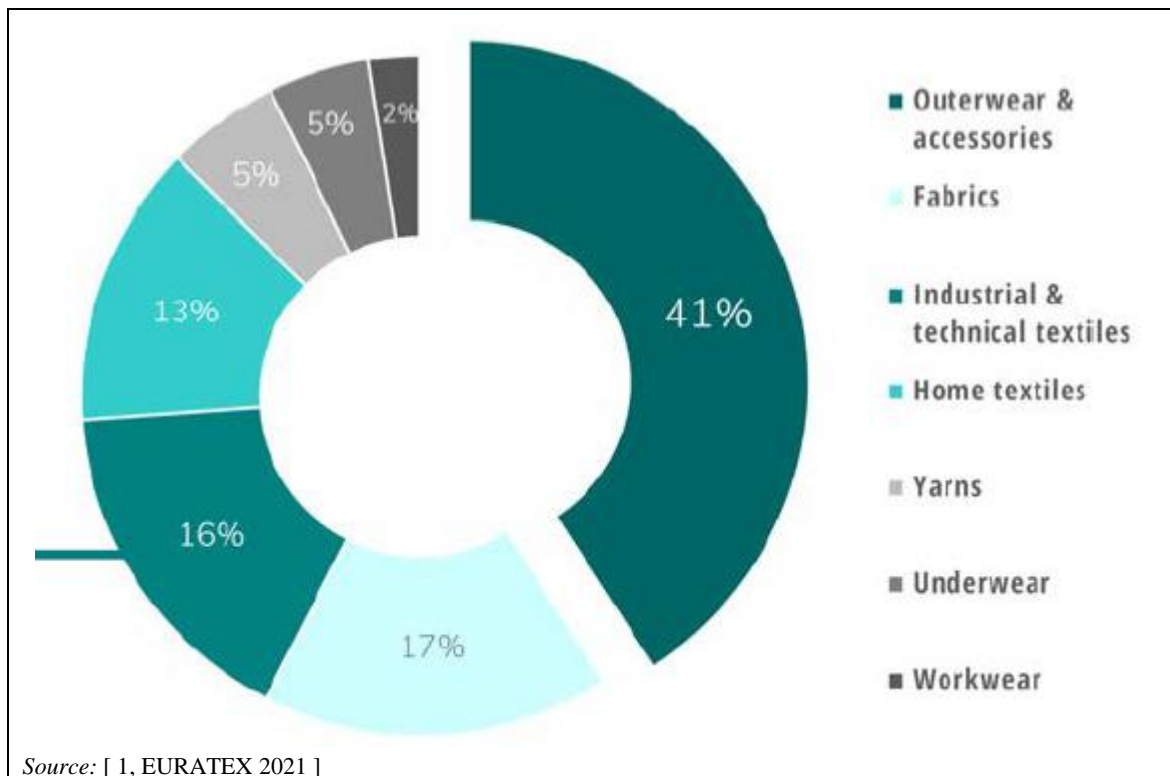


Figure 1.4: Production share by subsector (2018)

The following figures present the increasing share of Technical and industrial textiles in the total production (see Figure 1.5), the shares of different substrate types in Technical and industrial textiles production (see Figure 1.6), and the production of Technical and industrial textiles per Member State (see Figure 1.7).

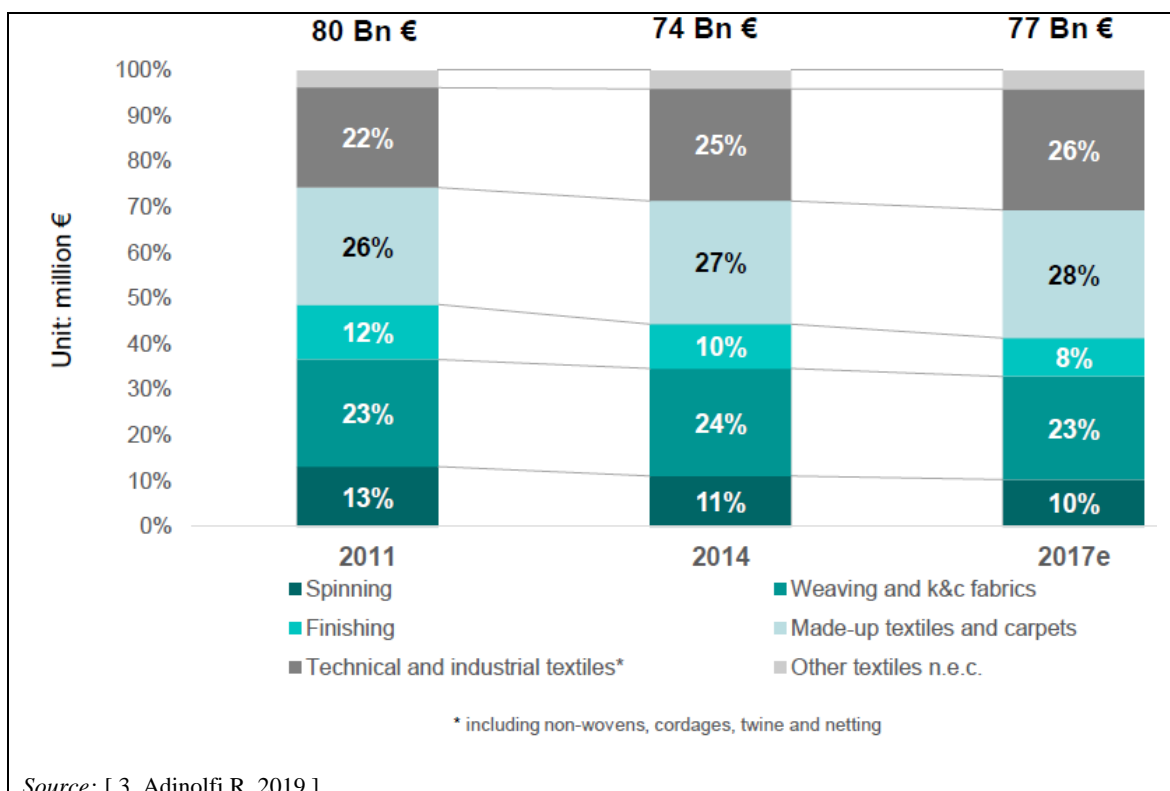
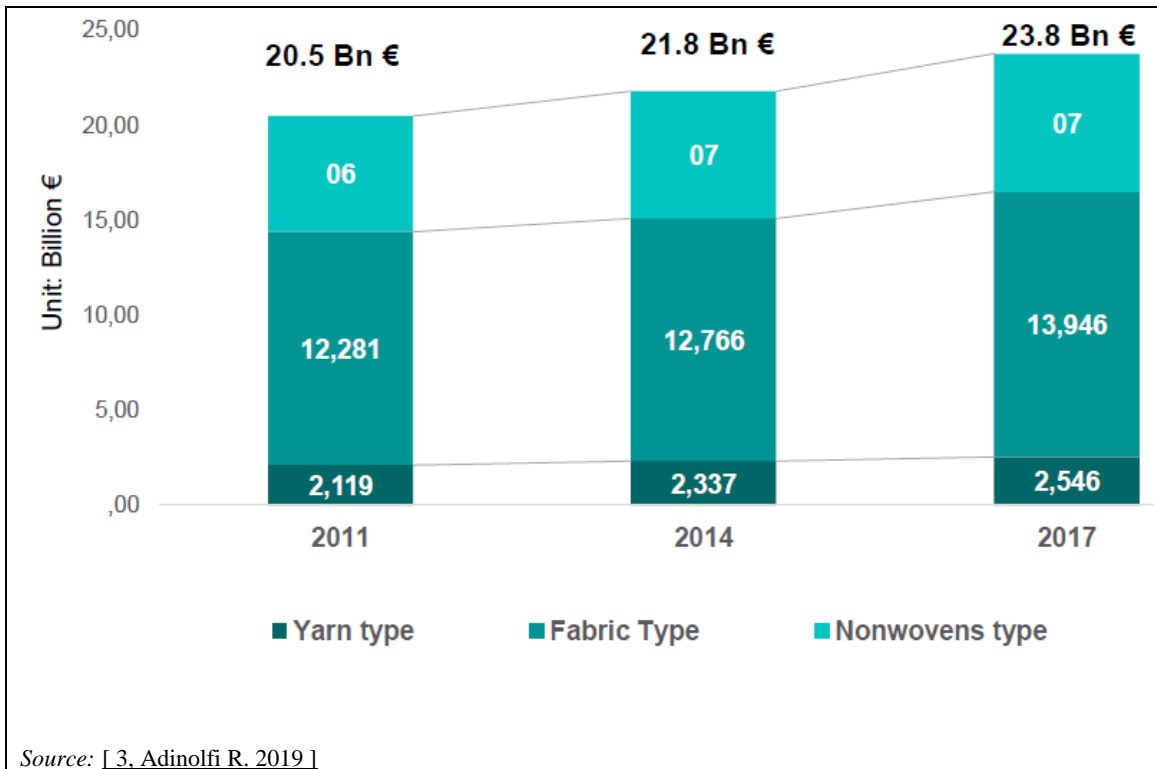
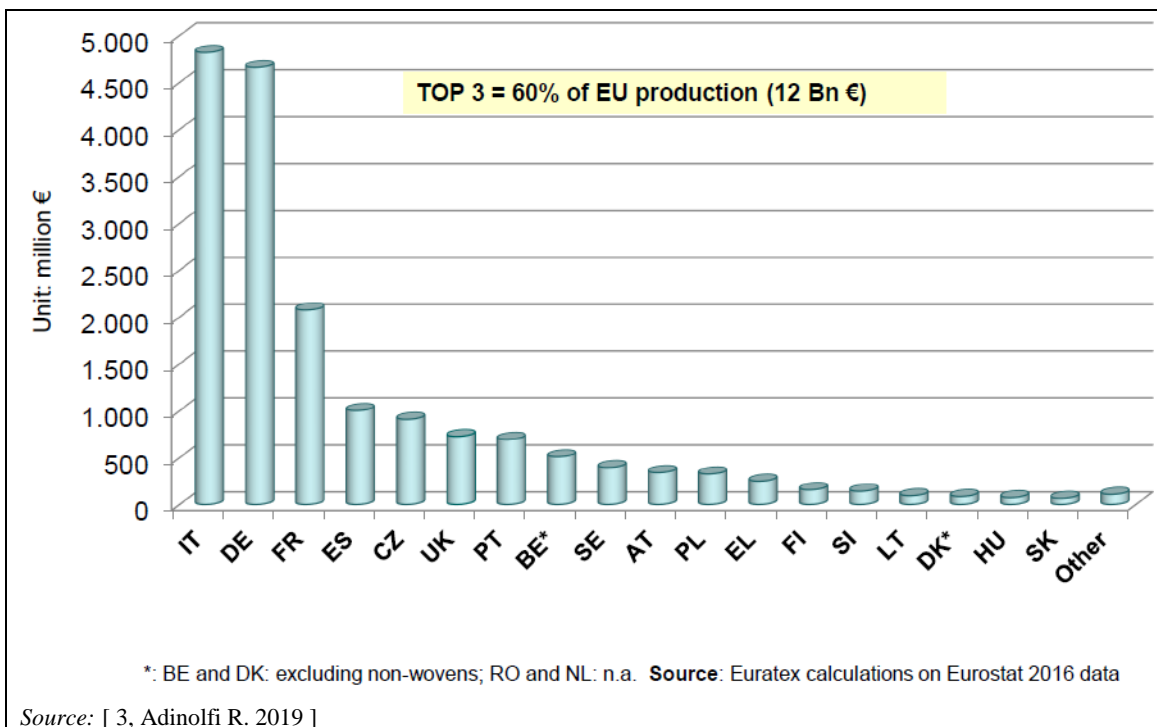


Figure 1.5: Increasing share of Technical and industrial textiles in total production



Source: [ 3, Adinolfi R. 2019 ]

Figure 1.6: Share of different substrate types in Technical and industrial textiles production



\*: BE and DK: excluding non-wovens; RO and NL: n.a. Source: Euratex calculations on Eurostat 2016 data

Source: [ 3, Adinolfi R. 2019 ]

Figure 1.7: Technical and industrial textiles production per Member State

In recent years investments in the T&C industry have been steadily growing (see Figure 1.8), with companies in Italy investing almost double the amounts invested in other EU countries (see Figure 1.9).

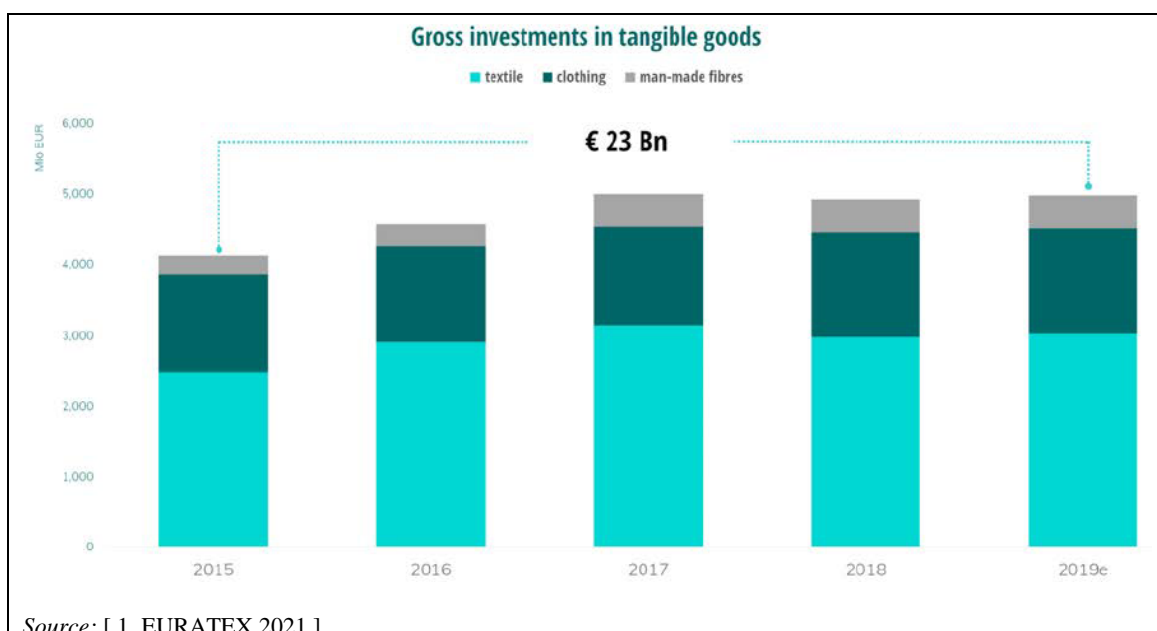


Figure 1.8: Gross investments in the textile, clothing and man-made fibres sectors

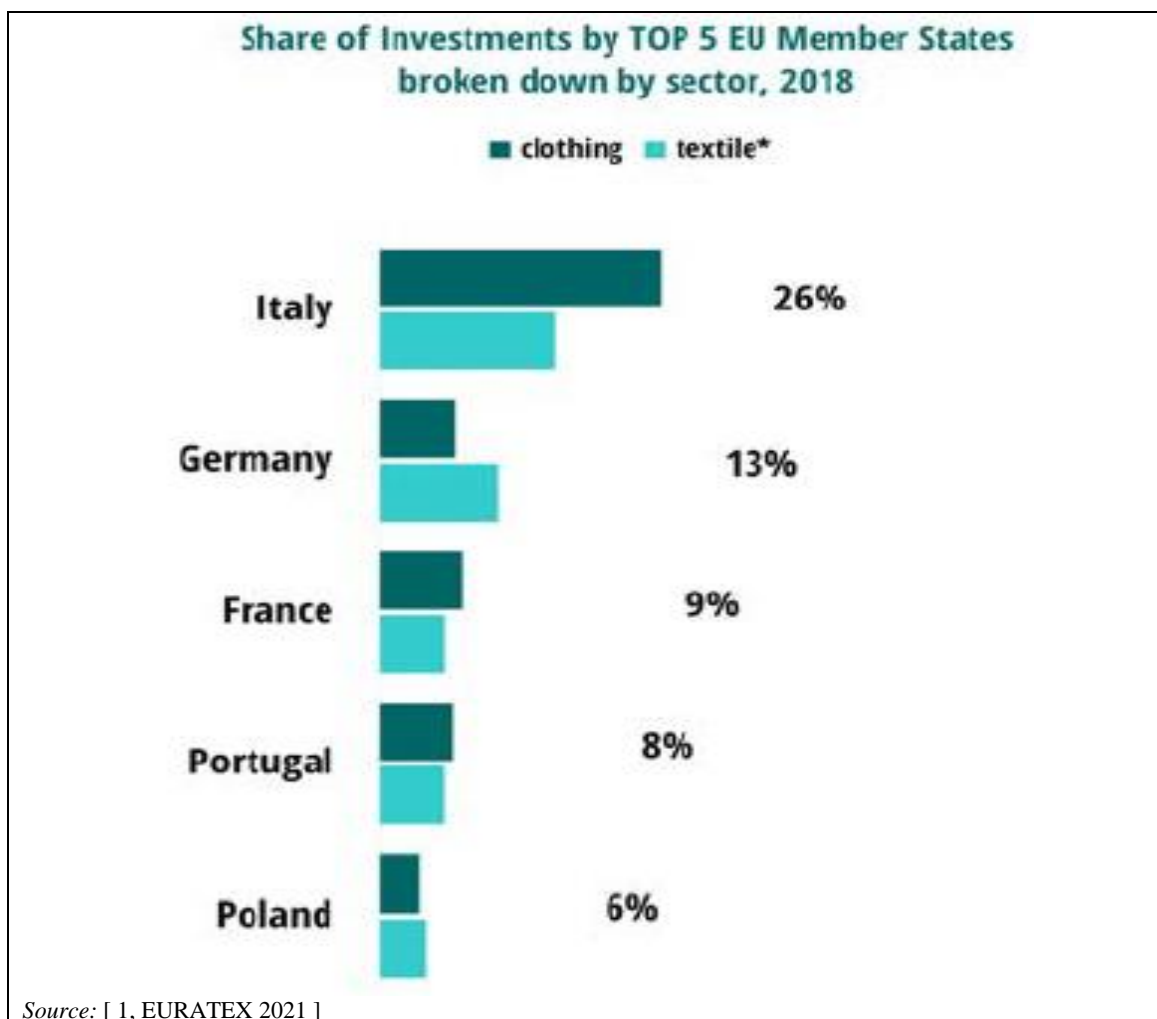


Figure 1.9: Share of investments by top 5 EU Member States

The textile and clothing production chain is composed of a wide range of subsectors covering the entire production cycle from the production of raw materials (man-made fibres) to semi-



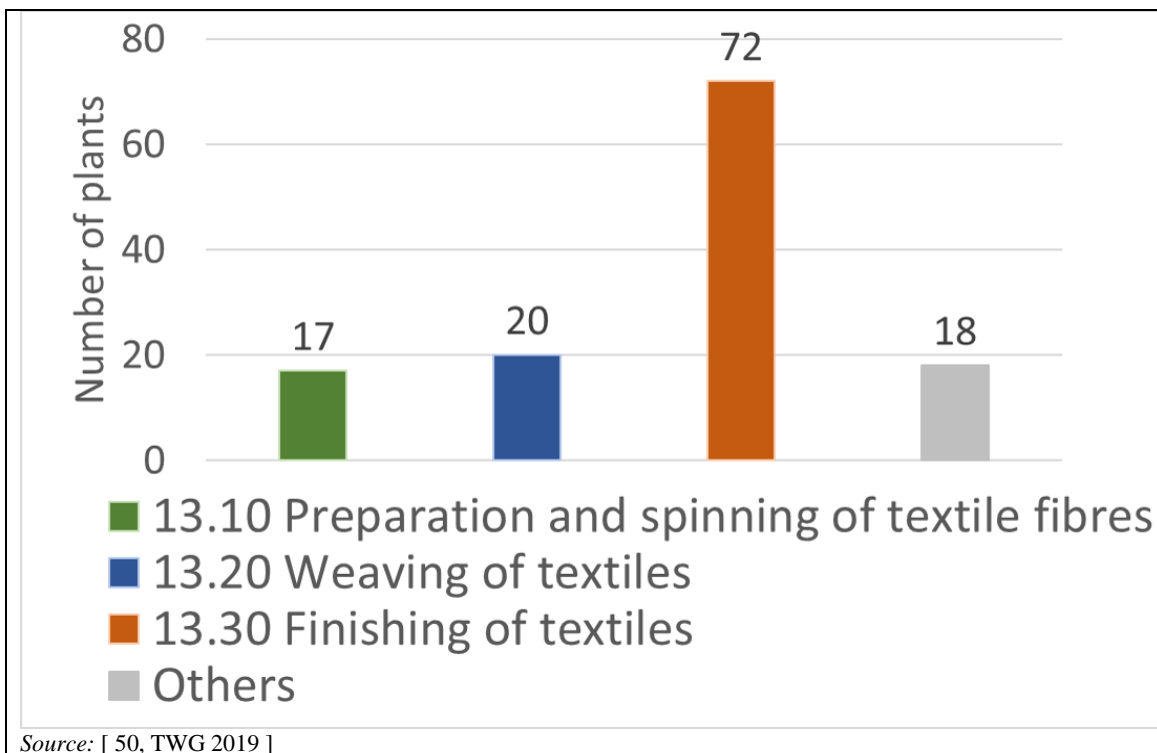
processed materials (yarns, woven and knitted fabrics with their finishing process) and final/consumer products (carpets, home textiles, clothing and industrial textiles).

The complexity of the sector is also reflected in the diversity of activities covered by the Statistical Classification of Economic Activities [ 2, EU 2008 ] (see Table 1.2).

**Table 1.2: NACE (Rev. 2) activities of the Manufacturing of textiles**

<p>C MANUFACTURING</p> <p>13 Manufacture of textiles</p> <p>13.1 Preparation and spinning of textile fibres</p> <p>13.2 Weaving of textiles</p> <p>13.3 Finishing of textiles</p> <p>13.9 Manufacture of other textiles</p> <p>13.91 Manufacture of knitted and crocheted fabrics</p> <p>13.92 Manufacture of made-up textile articles, except apparel</p> <p>13.93 Manufacture of carpets and rugs</p> <p>13.94 Manufacture of cordage, rope, twine and netting</p> <p>13.95 Manufacture of non-wovens and articles made from non-wovens, except apparel</p> <p>13.96 Manufacture of other technical and industrial textiles</p> <p>13.99 Manufacture of other textiles n.e.c.</p>
<p>Source: [ 2, EU 2008 ]</p>

As for the scope of this document, the majority of the plants participating in the data collection (72 out of 106) reported that their main NACE activity is 13.30 Finishing of textiles (see Figure 1.10).



**Figure 1.10: NACE activities reported by plants in the data collection**

## 1.1 Main environmental issues

The main environmental issues arising from the activities in the textile industry which are covered in this document regard primarily emissions to water and air and energy consumption.

Among these, water is the most important concern. The textile industry uses water as the principal medium for removing impurities, applying dyes and finishing agents, and for the generation of steam.

Losses to the product are negligible; therefore, apart from a minor amount of water which is evaporated during drying, the bulk is discharged as aqueous effluent. The main concern is therefore about the amount of water discharged and the chemical load it carries.

An overview of these environmental loads is given in Table 1.3. The data reported more than 20 years before the date of drafting this document from a research study in Germany and Austria have been extrapolated to the European level.

**Table 1.3: Main charging loads from the textile industry in Europe**

Substances	Environmental load (t/yr)
Salts	200 000-250 000
Natural fibre impurities (including biocides) and associated material (e.g. lignin, sericine, wax)	50 000-100 000
Sizing agents (mainly starch, starch derivatives, but also polyacrylates, polyvinylalcohol, carboxymethylcellulose and galactomannans)	80 000-100 000
Preparation agents (mainly mineral oils, but also ester oils)	25 000-30 000
Surfactants (dispersing agents, emulsifiers, detergents and wetting agents)	20 000-25 000
Carboxylic acids (mainly acetic acid)	15 000-20 000
Thickeners	10 000-15 000
Urea	5 000-10 000
Complexing agents	< 5 000
Organic solvents	NI
Special auxiliaries with more or less ecotoxicological properties	< 5 000
NI – no information	
Source: [ 4, EURATEX 2000 ]	

From the reported figures it appears that a large percentage of the total emission load from textile industry activities is attributable to substances that are already on the raw material before it enters the finishing process sequence. Typically these are:

- sizing agents;
- preparation agents;
- natural fibre impurities and associated material.

Sizing agents are used to assist the weaving process. They are removed from the woven fabric before the finishing process, thus producing high organic loads in the water.

Preparation agents and spinning oils are applied to fibres in various steps of the process, from the manufacture of the fibre itself (for synthetic fibres only) to the formation of the yarn. These organic substances are removed during pretreatment at the finishing mill either through wet processing (washing) or through dry processing (heat-setting). In the former they contribute to the increase of the organic load of the final water effluent and in the latter they become airborne.

All natural fibres contain a percentage of impurities and associated material. Associated materials are an essential part of natural fibres (e.g. grease for wool, pectin and hemicellulose for cotton, lignin for flax and sericine for silk). Impurities are metals, minerals and pesticides. All these substances have to be removed from the fibre before it can undergo finishing processes. They therefore also have the potential for considerable environmental impact.

The input of chemicals and auxiliaries added at the finishing mills can be up to 1 kg per kg of processed textiles, which appears to be high. The range of these substances is very extensive, for example TEGEWA lists more than 7 000 auxiliaries. However, as shown in Figure 1.11, in a typical finishing mill, 80 % of the annual consumption is covered by only 20 % of the product types used.

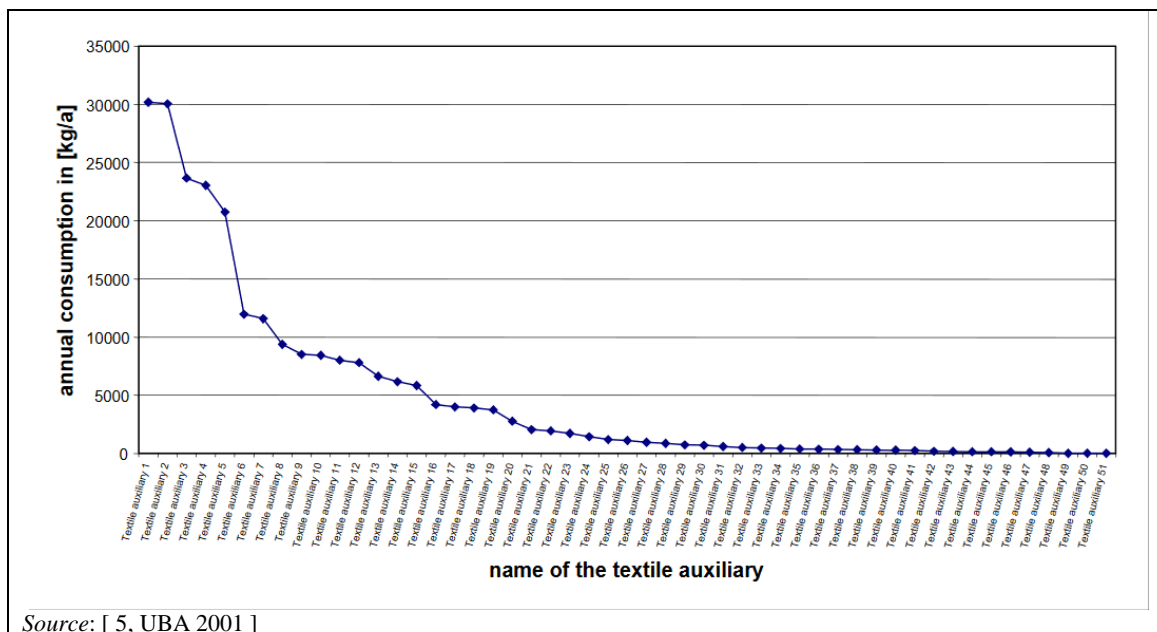


Figure 1.11: Auxiliaries pattern usage in a typical finishing mill

On the basis of the data reported in Table 1.3, among the products applied during the process, the highest environmental loads arise from salts, detergents and organic acids (in that order).

Dyestuffs are not mentioned in the table; nevertheless they are responsible for the colour of the effluent and other environmental concerns (e.g. difficult-to-eliminate organic loads, AOX, metals), particularly for certain classes of dyestuffs.

Table 1.4 shows consumption ranges for chemical products applied in textile dyeing and finishing based on the extensive worldwide benchmarking of one of the voluntary certification schemes.

Table 1.4: Typical ranges for consumption of chemical products in textile dyeing and finishing

Category <sup>1,2</sup>	Chemical product	Typical range (g/kgpv) <sup>3,4</sup>	Median (g/kgpv)	Average (g/kgpv)
Knitted fabric synthetic (117 data sets)	Auxiliaries	20-230	104.9	106.7
	Dyestuffs	10-70	23.5	27.4
	Basic chemicals	20-350	82.0	101.9
Woven fabric synthetic (126 data sets)	Auxiliaries	40-260	106.9	121.3
	Dyestuffs	10-60	24.4	26.3
	Basic chemicals	50-400	167.7	188.3

Knitted fabric cellulosic (20 data sets)	Auxiliaries	40-180	108.6	100.4
	Dyestuffs	10-40	27.0	25.0
	Basic chemicals	200-800	445.2	578.2
Woven fabric cellulosic (15 data sets)	Auxiliaries	50-350	134.0	163.3
	Dyestuffs	20-60	36.0	36.3
	Basic chemicals	300-700 <sup>5</sup>	454.0	468.5

<sup>1</sup> The categories are defined according to a defined share of the total product portfolio: knitted or woven > 55 %; synthetic or cellulosic > 70 %.

<sup>2</sup> Data sets for animal fibers are not available in sufficient numbers to give an accurate picture.

<sup>3</sup> Normalising factor for determination of specific consumptions: production volume (PV) of the related data reference period.

<sup>4</sup> Variations depend on many factors such as applied processes, product type, substrate variations and substrate mixes, application of BAT in manufacturing and more.

<sup>5</sup> High demand of salt for salting out of reactive or direct dyes (mainly cotton).

Source: [ 6, bluesign 2020 ]

A number of chemicals that may be used in the textile process are worth specifically mentioning for their potential negative effects on the environment:

- Alkylphenol ethoxylates (detergents, wetting agents, levelling agents, etc.): their metabolites (octyl and nonylphenols) are highly toxic to aquatic life and are reported to disturb the reproduction of aquatic species by disrupting the endocrine system (octyl and nonylphenol are on the list of ‘Priority Substances’ targeted for priority action under the Water Framework Directive (2000/60/EC), in particular nonylphenol is identified as a ‘Priority Hazardous Substance’). In addition, nonylphenol (NP) and nonylphenol ethoxylates (NPE) are subject to restriction (Annex XVII entries 46 and 46a) under the REACH Regulation [ 7, EU 2006 ] and included in the Candidate List of substances of very high concern for authorisation, due to their endocrine disruption properties for the environment.
- Polybrominated diphenyl ethers and chlorinated paraffins (flame retardants) some brominated diphenylethers and some short-chain chloroalkanes are ‘Priority Hazardous Substances’ as per the Water Framework Directive and/or prohibited by the POP Regulation (EC/850/2004). Some halogenated flame retardants are also subject to restriction or to authorisation as per the REACH Regulation (EC/1907/2006).
- Per and polyfluoroalkyl substances (PFAS) used for water-, oil- or soil-repellence: the use of perfluorooctanic acid (PFOA) is restricted by the REACH Regulation and perfluorooctane sulphonic acid and its derivatives (PFOS) are ‘Priority Hazardous Substances’ and prohibited by the POP Regulation.
- Mothproofing agents based on permethrin and cyfluthrin (carpet sector) and other biocides: these are highly toxic to aquatic life.
- Sequestering agents such as EDTA and DTPA and NTA: these are capable of forming very stable complexes with metals (EDTA and DTPA are also poorly bioeliminable).
- Chlorine and chlorine-releasing compounds such as sodium hypochlorite (bleaching agent) and sodium dichloroisocyanurate (wool anti-felting agent): these are capable of reacting with organic compounds to form adsorbable organic halogens (AOX).
- Metal-containing compounds such as potassium dichromate, which is subject to authorisation as per the REACH Regulation (EC/1907/2006).
- Substances with carcinogenic potential, such as a number of aromatic amines, formed by cleavage of some azo dyes (see Section 2.7.8.1), or vinylcyclohexene and 1,3-butadiene, which can be present in polymer dispersions due to an incomplete reaction during polymerisation.
- Carriers such as trichlorobenzene, o-phenylphenol, etc.

With regard to emissions to air, volatile organic compounds are released from particular activities such as:

- printing processes, in cases when organic solvents are used (e.g. they are contained in pigment printing pastes);
- cleaning with organic solvents;
- thermal treatment (e.g. thermofixation, heat-setting, drying, curing) when the textile materials contain substances that evaporate or degrade thermally (for example, oils, plasticisers, finishing agents and residues from upstream processes); emissions of formaldehyde and uncombusted methane can be particularly significant in poorly maintained, directly heated stenters;
- vulcanisation of the backing layers (carpet sector).

Moreover, emissions of CO<sub>2</sub>, SO<sub>x</sub>, NO<sub>x</sub> and particulates associated with the on-site burning of fossil fuels to produce thermal energy are also to be taken into account.

Energy is consumed primarily in raising the temperature of the baths (e.g. pretreatment, dyeing) and in drying and curing operations. With this aim, steam is produced on site. Electrical energy is required for driving the machinery.

Based on the information mentioned above, the Technical Working Group (TWG) responsible for reviewing this document decided upon a list of environmental issues to be investigated during the review. These ‘Key Environmental Issues’ (KEIs) are listed in Table 1.5 for emissions to water and in Table 1.6 for emissions to air.

**Table 1.5: KEIs for emissions to water considered for the review of the BREF**

(Groups of) Substance(s)	Remarks
Total suspended solids (TSS)	KEI for direct discharges only
Chemical oxygen demand (COD)	KEI for direct discharges only
Total organic carbon (TOC)	KEI for direct discharges only
Total nitrogen (Total N)	KEI for direct discharges only
Total phosphorus (Total P)	
Hydrocarbon oil index (HOI)	
Sulphide (S <sup>2-</sup> )	KEI for the installations using sulphur dyes
AOX (adsorbable organically bound halogens)	
Alkylphenols and alkylphenol ethoxylates	
Brominated flame retardants	
Pesticides	KEI for wool scouring
Toxicity	
Per- and polyfluorinated compounds (PFC)	
Antimony (Sb) and its compounds, expressed as Sb	
Chromium (Cr) and its compounds, expressed as Cr	
Copper (Cu) and its compounds, expressed as Cu	
Nickel (Ni) and its compounds, expressed as Ni	
Zinc (Zn) and its compounds, expressed as Zn	
<i>Source: [ 8, EIPPCB 2018 ]</i>	

**Table 1.6: KEIs for emissions to air considered for the review of the BREF**

(Groups of) Substance(s)	Remarks
Dust	
Nitrogen oxides (NO <sub>x</sub> )	
Sulphur oxides (SO <sub>x</sub> )	KEI for combustion plants
Ammonia (NH <sub>3</sub> )	
TVOC (Total volatile organic compounds)	
Formaldehyde	

Tetrachloroethylene (PER)	KEI for solvent-based wool scouring and dry cleaning
N-Methyl-2-pyrrolidone	KEIs for certain types of processes or fibres
N-Ethyl-2-pyrrolidone	
Dimethylformamide	
Dimethylacetamide	
Toluene	
Acrylonitrile	
Acrylamide	
1,3-Butadiene	
Styrene	
<i>Source:</i> [ 8, EIPPCB 2018 ]	

The TWG decided to also investigate the water consumption and the amount of waste water discharged, the energy consumption and the amount of waste generated.



## 2 APPLIED PROCESSES AND TECHNIQUES

The textile chain begins with the production or harvest of raw fibre. The basic steps in this chain are schematically represented in Figure 2.1 below and will be described in this chapter.

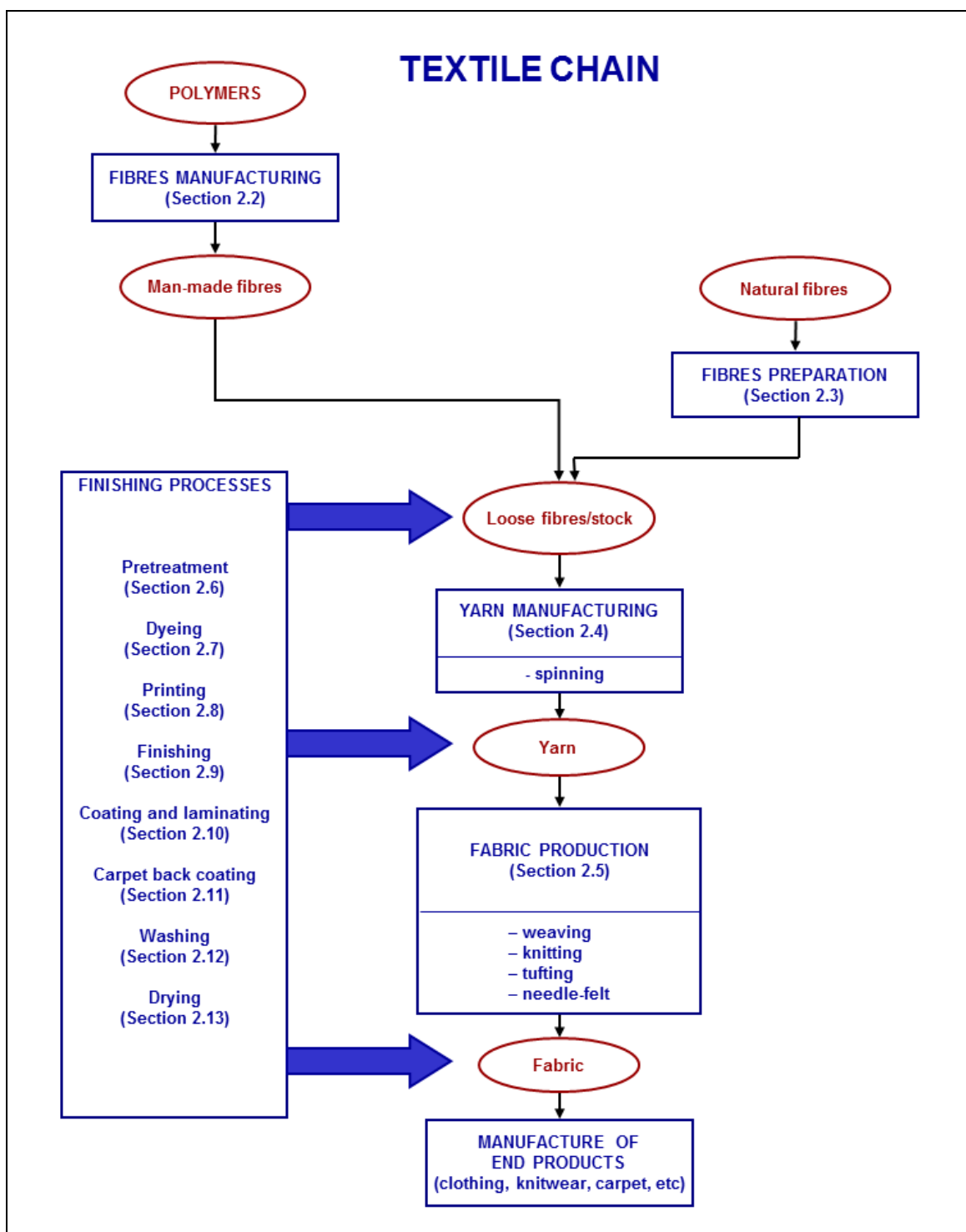


Figure 2.1: General diagram of processes in the textile industry

The main part of this chapter will describe those treatments that are broadly referred to as ‘finishing processes’ (i.e. pretreatment, dyeing, printing, finishing and coating, including washing and drying). As the diagram shows, they can take place at different stages of the production process: the substrates for finishing can be fabrics, yarns or loose fibres.



‘Textile finishing’ cannot be defined as a standard sequence of treatments, but rather is a combination of unit processes that can be applied within the production of a textile product, depending on the requirements of the final user. For this reason, finishing treatments will be described (from Section 2.6 to Section 2.10.2) as unit processes without considering the possible sequences in which they can be applied.

In Section 2.13 a distinction is made between the carpet finishing sector and the rest of the finishing industry. Some typical categories of industries have been identified within each sector. The wool scouring industry has also been identified as a stand-alone sector. These categories have typical features which are briefly described.

As well as fibres, the raw materials of the textile industry include a wide range of chemicals and auxiliaries. These chemicals and auxiliaries are often not process-specific and can be found in different steps within the process cycle. For this reason, it has been considered more practical to report the description of these issues in separate annexes (see Sections 8.1 and 8.2).

## 2.1 Raw materials

### 2.1.1 Fibres

Two general categories of fibres are used in the textile industry: natural and man-made. Man-made fibres encompass both purely synthetic materials of petrochemical origin and regenerative cellulosic materials manufactured from wood fibres. A general classification of fibres is shown in Table 2.1 below.

**Table 2.1: General classification of fibres**

Natural origin fibres	Animal origin	Raw wool Silk fibre Hair	
	Vegetable origin	Raw cotton fibre Flax Jute	
Chemical fibres (man-made)	Natural polymer Fibres / Man-made cellulosic fibres (MMCF)	Viscose, Cupro, Lyocell Acetate Triacetate	
	Synthetic polymer fibres	Organic polymer	Polyester (PES) Polyamide (PA) Acrylic (PAC) Polypropylene (PP) Elastane (EL)

Fibres included in this document are described in more detail below, highlighting in particular the typical impurities present in them. Some of these impurities will enter the textile process and will influence the associated emissions.

#### 2.1.1.1 Polyester fibres (PES)

Polyester fibres (PES) are made of linear macromolecules containing at least 85 % of an ester in the chain. To date, three polyester polymers are commercially available:

- poly(ethylene terephthalate) (PET), which is based on ethylene glycol;
- poly(butylene terephthalate) (PBT), which is based on butyl glycol; and
- poly(trimethylene terephthalate) (PTT), which is based on trimethylene glycol.

However, only one of these three polymers, poly(ethylene terephthalate), also known as PET, has so far been widely applied in the textile industry. Therefore in the following sections, unless otherwise specified, the term PES is used to indicate standard polyester fibres based on PET.

PET fibres have a very high degree of crystallinity, which allows for excellent heat resistance and other mechanical properties. On the other hand, this compact structure inhibits the diffusion of the colourants into the fibre during dyeing. As a result, PET fibres cannot be dyed below 100 °C, unless dyeing accelerants (so-called carriers) are used. Carriers are harmful for the environment and in many cases are toxic for humans. Their use is now in decline, but it has been common practice for many years (see also Section 2.7.8.1 and Section 8.1.6.7).

Carrier-free dyeable PES fibres are now available on the market. They include ‘*modified PES fibres*’ and PTT fibres (see list above). ‘Modified PES fibres’ are based on PET. Thanks to physical and chemical alterations made to the structure of the fibre during the manufacturing process, they show lower crystallinity, which makes them easier to dye without the need for

carriers. Because of their high cost, however, these fibres are applied only in specific segments of the market.

As far as PTT is concerned, this aromatic polyester (polytrimethylene terephthalate) is made by the polycondensation of 1,3-propanediol and terephthalic acid. The high cost of synthesis of 1,3-propanediol has for many years prohibited the commercialisation of this fibre. Shell pursued a new lower-cost synthesis route for the production of this monomer, which has led to renewed interest in PTT polymers [131, VITO 2001]. More information about these fibres is reported in Section 4.5.4.1.

On polyester fibres in general, it is also worth mentioning that during the polycondensation reaction, cyclic oligomers with very low water solubility can be formed (1-3 % of the weight of the fibre [4, EURATEX 2000]). These oligomers tend to migrate to the surface of the fibre during dyeing, thus negatively affecting level dyeing and rub-fastness properties. Additionally, polyester fibres typically contain impurities like antimony trioxide ( $\text{Sb}_2\text{O}_3$ ) and lubricant oils, residues from the fibre and yarn production and processing. A leaching content of 75 mg Sb/kg of polyester fibres has been reported [DE comment to D1 # 196 in [324, TWG 2020]]. See Sections 2.2 and 4.1.5.2.3 for more information.

### 2.1.1.2 Polyamide fibres (PA)

The starting polymer comes from the polycondensation reaction between a diamine and a dicarboxylic acid. According to the number of carbon atoms of the end-product, one can speak of PA 6,6 or PA 6.

PA 6,6 is made by thermal polycondensation of equimolecular amounts of adipic acid and 1,6-hexamethylenediamine. The equilibrium condensate contains small amounts of monomers and cyclic dimers (2 %), which remain on fibre as residues (impurities).

PA 6 is made by polymerisation of the cyclic monomer epsilon-caprolactam. The residual caprolactam content in the polymer can be reduced to 0.2 % by extraction with hot water. During the melting process for the production of the fibre (melt spinning), the caprolactam content rises again and is partially emitted during the following thermal treatments. The residual caprolactam can be present on fibres as an impurity.

### 2.1.1.3 Acrylic fibres (PAC)

The polymer is obtained by radical polymerisation of acrylonitrile in aqueous emulsion or in solvent. The obtained polymer, made of 100 % acrylonitrile (also called PAN), gives fibres with insufficient dye-binding capability, due to the high glass transition temperature (above 100 °C). For this reason, this polymer is no longer used in the textile industry. Acrylic fibres (PAC), commonly found on the market today, are anionic copolymers containing 85-89 % acrylonitrile, 4-10 % of a non-ionic comonomer (vinyl chloride, vinylacetate, methyl acrylate) and 0.5-1 % of ionic comonomers containing sulphonic or sulphate groups.

Dry and wet spinning techniques can be used for the production of the fibre. When dry spinning is used, the polymer is dissolved in dimethylformamide (DMF). If the fibre is manufactured through wet spinning, besides DMF, dimethylacetamide, dimethylsulphoxide, ethyl carbonate and aqueous solutions of inorganic salts or acids are also used. Residues of these solvents (0.2-2 % of the weight of the fibre) are found in the waste water from pretreatment.

#### **2.1.1.4 Polypropylene fibres (PP)**

The isotactic polymer is used for fibre production. Due to the tertiary carbon atom, PP is very sensitive to high temperatures and oxidation. Alkylated phenols or p-xylols, together with sulphides or thio-derivatives (dilauryl or distearyl thiopropionate) are used as stabilisers. Substances with benzotriazol groups, Ni complexes, anthraquinone derivatives and sterically hindered diamines are used as UV-absorbents. These low-molecular-weight substances remain in the PP fibres and are considered possible emission-relevant substances.

#### **2.1.1.5 Elastane (EL)**

Elastane fibres are made out of an elastomer containing at least 85 % polyurethane (PU). For the production of the fibre (dry spinning), the polymer is dissolved in dimethylacetamide (DMAC). Residues of this solvent remain in the fibre (< 1 % of the weight of the fibre) and are found in the waste water from pretreatment.

To reduce the high adhesive characteristics and to guarantee sufficient gliding properties during processing, preparation agents are applied to the fibre (approximately 6-7 % add-on). These auxiliaries contain 95 % silicone oils and 5 % surfactants. The high percentage of silicone oils will cause environmental concerns during pretreatment of the textile material, when these substances have to be removed.

#### **2.1.1.6 Viscose (CV)**

The starting material is the cellulose that is extracted from coniferous timber and supplied to the fibre manufacture in sheets about 1 cm thick. The wood contains around 40-50 % cellulose which can be used to make viscose. The cellulose is first allowed to swell in a NaOH solution. The white flakes obtained are then treated with carbon disulphide until the sodium cellulose xantogenate is formed. The xantogenate is soluble in diluted sodium hydroxide and the formed solution (pulp) is already called viscose. The pulp then needs to be spun. Spinning consists of coagulating the xantogenate solution at the outlet of the spinneret in an acid bath containing sulphuric acid, sodium sulphate and zinc sulphate.

#### **2.1.1.7 Cupro (CU)**

Cellulose (wood pulp) can also be dissolved in an aqueous solution of ammonia and copper sulphate. Cupro fibres are produced by wet spinning.

#### **2.1.1.8 Lyocell**

Lyocell is a promising new industrial rayon fibre produced by an advanced solvent spinning process (using N-methylmorpholine N-oxide (NMMO) as solvent) from dissolved wood cellulose or pulp.

#### **2.1.1.9 Acetate fibres**

The cellulose polymer contains three alcohol groups per monomer unit. When between 2 and 2.5 of the 3 groups are esterified with acetic acid, the polymer is called diacetate. When all three alcohol groups are esterified, then the polymer is called triacetate. The acetate fibres contain less than 92 % cellulose acetate, but at least 74 % of the hydroxilic groups are acetylated.

### 2.1.1.10 Wool

Wool is animal hair from the body of sheep. This hair is normally sheared once, or sometimes twice, a year and its quality and quantity vary widely, depending on the breed of sheep and its environment. Wool is a member of a group of proteins known as keratin, also found in horns, nails, etc.

In addition to wool fibre, raw wool contains the impurities listed in the table below.

**Table 2.2: Impurities in the raw wool**

Natural impurities:	- Wool grease	2-25 % of greasy wool weight
	- Suint (dried perspiration)	2-12 % of greasy wool weight
	- Dirt	5-45 % of greasy wool weight
Residues of insecticides, acaricides or insect growth regulators used as veterinary medicines to protect sheep from ectoparasites, such as lice, mites, blowfly, etc.		

The percentage of the above-mentioned components may vary widely depending on the origin of the wool. For example, fine wool from merino sheep, used mainly in apparel, typically contains 13 % wool grease, whereas coarser wool of the types used for carpets contains an average of about 5 % grease.

The clean fibre content of raw wool usually lies within the 60 % to 80 % range, but may vary from 40 % to 90 %.

*Wool grease* is insoluble in water, but soluble in non-polar solvents such as dichloromethane or hexane. Refined wool grease is a valuable by-product.

*Suint* is water-soluble material arising from the secretion of the sweat glands in the skin. Suint is soluble in polar solvents such as water and alcohol.

*Dirt* can include a variety of materials such as mineral dirt, sands, clay, dust and organic materials.

*Ectoparasitocides* have important implications for the discharge of raw wool scouring effluent and disposal of the sludge generated by the treatment of the effluent. The chemicals that can potentially be present in raw wool include those given in the table below.

**Table 2.3: Pesticides found in raw wool**

Organochlorine insecticides (OCs)	- $\gamma$ -Hexachlorocyclohexane (lindane) - Dieldrin - DDT
Organophosphorous insecticides (OPs)	- Diazinon - Propetamphos - Chlorfenvinphos - Chlorpyriphos - Dichlorfenthion
Synthetic pyrethroid insecticides (SPs)	- Cypermethrin - Deltamethrin - Fenvalerate - Flumethrin - Cyhalothrin

Insect growth regulators (IGRs)	<ul style="list-style-type: none"> <li>- Cyromazine</li> <li>- Dicyclanil</li> <li>- Diflubenzuron</li> <li>- Triflumuron</li> </ul>
NB: The use of many of these substances has been prohibited in the EU.	

The organochlorines are hazardous due to their persistence and bioaccumulability. They are thus likely to have long-range effects (in terms of both distance from the source and time after release).  $\gamma$ -Hexachlorocyclohexane (also called lindane) is the most toxic (and also the most active as a pesticide) of the hexachlorocyclohexane isomers ( $\alpha$ - and  $\beta$ -HCHs). The technical crude product contains  $\alpha$ - and  $\beta$ -HCH, the  $\beta$ -isomer being the most persistent. Lindane and DDT compounds are well-studied substances with demonstrated endocrine-disrupting capacity.

The synthetic pyrethroid insecticides show high aquatic toxicity (the predicted no-effect concentration for cypermethrin is estimated at 0.0001  $\mu\text{g/l}$ , while the corresponding value for the OPs diazinon and propetamphos is 0.01  $\mu\text{g/l}$  according to the UK environmental quality standards expressed as annual averages). Organophosphates have lower aquatic toxicity than synthetic pyrethroids and are less persistent than organochlorines. Nevertheless, they have high human toxicity (problems may therefore arise, for example for dyers with steam-volatile OPs).

All major grower countries have banned the use of organochlorine pesticides for sheep treatment. In Europe, biocides are regulated by the Biocidal Products Regulation (BPR) [ 348, EU 2012 ] and some substances listed above are banned in the European Union (lindane, DDT and dieldrin are banned by the Regulation on persistent organic pollutants (POPs) [ 295, EU 2004 ]).

There is however evidence that wool from some former Soviet Union states and South America contain lindane at detectable concentrations. This would suggest that either their grazing is heavily contaminated or that this compound continues to be used occasionally for sheep treatment against ectoparasites.

Wool from the majority of grower nations contains residual sheep treatment medicines, which are used legally to control infestations of lice, ticks and mites. These materials may be organophosphates, typically diazinon, propetamphos and trans-chlorfenvinphos, synthetic pyrethroids, typically cypermethrin and insect growth regulators such as cyromazine. The incidence of these materials on wool is variable and depends on the permitted legal use pattern in each country.

Manufacturers can use databases containing quantitative information on the OC, OP and SP content of wool maintained by the national organisations (e.g. ENco maintains one such database on British sourced wool types, for British Wool) [ 353, Madden M. 2020 ]. Manufacturers use these data to avoid processing wool from suspect sources. The system is of immediate benefit to manufacturers who purchase and process wool from known sources. Manufacturers who do not own either loose fibre or yarn (i.e. working on commission) may not be aware of the origin of the fibre they are processing and so find it more difficult to control their raw material inputs using this approach.

More information regarding ectoparasiticides is reported in Section 2.3.1 where the wool scouring process is discussed.

### 2.1.1.11 Silk

Silk accounts for only 0.2 % of the total fibre production. Nevertheless, this fibre is very important for specific ‘niche’ articles such as ladies’ shirts, jackets and scarves.

Silk is derived from the silk worm, which spins a cocoon around itself. It is a protein fibre like wool and it is the only natural filament fibre to be used with success in the textile industry (the length of the thread is in the range of 700 m to 1 500 m).

The silk fibre is composed of fibroin filaments wrapped with sericine (silk gum), which has to be removed during the pretreatment.

### 2.1.1.12 Cotton and flax

Cotton fibre consists mainly of cellulose and some other components, as shown in Table 2.4 below.

**Table 2.4: Chemical composition of cotton fibre**

Substance	Content
Cellulose	88-96 %
Pectin substances	0.7-1.2 %
Wax	0.4-1.0 %
Proteins	1.1-1.9 %
Ash	0.7-1.6 %
Other organic components	0.5-1.0 %

*Source: [ 10, Ullmann's 2011 ]*

Cotton production may use chemicals such as pesticides, herbicides and defoliant and these may remain as a residue on raw cotton fibres that reach the textile mill.

Other sources ([ 9, TWG 2001 ]) report that bales of cotton were found to be contaminated with pentachlorophenol from its use not only as a defoliant, but also as a fungicide applied on the bales of cotton during transport.

Flax is a bast fibre that can be grown in Europe. It has advantageous environmental impacts (e.g. water consumption, nutrient and plant protection aspects) compared to cotton, but challenging fibre processing [ 11, Beton et al. 2014 ]. Many economic factors have contributed to this fibre losing much of its previous importance. Nevertheless, flax remains a noble fibre with a wide range of applications.

## 2.1.2 Chemicals and auxiliaries

A huge number of organic dyestuffs/pigments and auxiliaries are applied in the textile industry. In this document they will be divided into the following categories:

- Dyestuffs and pigments.
- Basic chemicals (also known as ‘Commodities’), which include all inorganic chemicals and organic reducing and oxidising agents as well as the aliphatic organic acids.
- Auxiliaries, which comprise all textile auxiliaries containing mainly organic compounds except organic reducing and oxidising agents and organic aliphatic acids. They are also known as ‘Specialities’ - blends and proprietary formulations whose composition is not fully disclosed.

To give an idea of the variety of products available on the market (in particular, auxiliaries), it is worth noting that in the International Textile Auxiliaries Buyers’ Guide more than 5 500 commercial products are reported, based on 400 to 600 active components [ 12, TEGEWA 2018 ]. They are classified according to the TEGEWA nomenclature, according

to their functional use in the production process, although the chemical nature of these products is too varied to allocate them unequivocally to one category [ 13, TEGEWA 2018 ].

Chemicals and auxiliaries may be subject to specific regulatory measures under the EU's REACH Regulation [ 7, EU 2006 ] that each actor in the supply chain must comply with.

These specific regulatory measures are:

- restrictions on the manufacture, placing on the market and use of certain dangerous substances, mixtures, and articles (Annex XVII);
- the need for authorisation from the European Commission for each specific use of the substances included in Annex XIV;
- the obligation to notify ECHA and/or to inform actors in the supply chain of substances included in the candidate list of substances of very high concern (SVHC), for authorisation.

These measures are dynamic, as Annexes XVII and XIV, as well as the list of candidates, are regularly updated (see <https://echa.europa.eu/substances-restricted-under-reach>).

At the time of writing this document (2021), there are 11 entries in Annex XVII to REACH that relate to and/or restrict chemicals in textiles (see Table 2.5). Two of these entries are general and make references to substances included in Appendices 8 and 9 (azo dyes) and Appendix 12 (CMRs in textiles) of REACH. Additionally, there are many entries on the Restriction List (Annex XVII) which cover articles. Such entries are, for instance, entries 50 - 52, 61 and 63. These may address types of textiles and leather articles, even if these are not explicitly mentioned.

Annex XIV includes the list of substances subject to authorisation. Substances on this list cannot be used unless an authorisation for use is granted or an exemption exists. The REACH Regulation is a dynamic system with many changes and the examples in Table 2.5 serve only as a starting point (may be quickly outdated). The up-to-date regulatory status of the hazardous substances can be checked via the Public Activities Coordination Tool (PACT, <https://echa.europa.eu/pact>). Additional information on how a specific substance is regulated by different pieces of EU chemicals legislation is available via the EU Chemicals Legislation Finder (EUCLEF, <https://echa.europa.eu/information-on-chemicals/euclef>).

**Table 2.5: Restrictions that apply specifically to the textile sector from Annex XVII to REACH**

ENTRY IN ANNEX XVII	SUBSTANCE RESTRICTED FOR USE IN TEXTILE SECTOR
4	Tris (2,3 dibromopropyl) phosphate
7	Tris(aziridinyl)phosphin oxide
8	Polybromobiphenyls; Polybrominatedbiphenyls (PBB)
18	Mercury compounds
20	Organostannic compounds
23	Cadmium
43	Azocolourants and Azodyes
46	(a) Nonylphenol C <sub>6</sub> H <sub>4</sub> (OH)C <sub>9</sub> H <sub>19</sub> (b) Nonylphenol ethoxylates (C <sub>2</sub> H <sub>4</sub> O) <sub>n</sub> C <sub>15</sub> H <sub>24</sub> O
46bis	Nonylphenol ethoxylates (NPE) (C <sub>2</sub> H <sub>4</sub> O) <sub>n</sub> C <sub>15</sub> H <sub>24</sub> O
50	Polycyclic-aromatic hydrocarbons (PAHs): (a) Benzo[a]pyrene (BaP) (b) Benzo[e]pyrene (BeP) (c) Benzo[a]anthracene (BaA) (d) Chrysen (CHR) (e)



	Benzo[b]fluoranthene (BbFA) (f) Benzo[j]fluoranthene (BjFA) (g) Benzo[k]fluoranthene (BkFA) (h) Dibenzo[a,h]anthracene (DBAhA)
51	Phthalates: Dibutyl phthalate (DBP), Benzyl butyl phthalate (BBP), Bis (2-ethylhexyl) phthalate (DEHP)
52	Phthalates: 1,2-Benzenedicarboxylic acid, di-C8-10-branched alkyl esters, C9-rich, 1,2-Benzenedicarboxylic acid, di-C9-11-branched alkyl esters, C10-rich, Di-“isononyl” phthalate (DINP), Di-“isodecyl” phthalate (DIDP), Di-n-octyl phthalate (DNOP)
61	Dimethylfumarate (DMF)
63	Lead and its compounds
68	Perfluorooctanoic acid (PFOA) (CAS No 335-67-1, EC No 206-397-9) and its salts. Any related substance (including its salts and polymers) having a linear or branched perfluoroheptyl group with the formula C 7 F 15 - directly attached to another carbon atom, as one of the structural elements. Any related substance (including its salts and polymers) having a linear or branched perfluorooctyl group with the formula C 8 F 17 - as one of the structural elements. The following substances are excluded from this designation: — C 8 F 17 -X, where X = F, Cl, Br. — C 8 F 17 -C(=O)OH, C 8 F 17 -C(=O)O-X' or C 8 F 17 -CF 2 - X' (where X' = any group, including salts).
72	CMR substances in textile articles and clothing.

For practical reasons, the information about dyestuffs and textile auxiliaries is reported in this document in separate annexes (see Sections 8.1 and 8.2).

### 2.1.3 Materials handling and storage

Basic fibrous raw materials arrive on site in press-packed bales and are stored in covered warehousing, which may also be used to store and dispatch finished goods to customers.

Basic chemical intermediates, acids, alkalis and bulk auxiliary chemicals are normally held within a bound or contained storage area. Large bulk containers may be situated in the open. High-value and moisture- or environmentally sensitive materials are normally transferred directly to the preparation area ('colour kitchen') from where they are dispensed.

Some synthetic organic colourants are regarded as a potential health hazard. Therefore colour kitchens are normally equipped with air extraction and filter systems to suppress dust levels in the workplace during dispensing.

The chemicals (dyestuffs, pigments, basic chemicals and auxiliaries) are metered out either in powder form or as solutions. This operation can be done manually or with computer-aided metering devices.

The required measured amount of products is in general dispersed, diluted or mixed before being fed to the finishing machinery. Various systems are found in the industry, ranging from completely manual procedures to fully automatic ones. In the case of manual systems, the prepared chemicals are added directly into the machine or in a storage container near the equipment, from which they are then pumped into the machine. In some companies, the chemicals are mixed in a central mixing station, from which they are supplied to the various machines through a network of pipes. The quantities and the addition of chemicals and auxiliaries are normally determined automatically according to predetermined programmes (further details about dosing and dispensing systems are given in Section 4.1.6.7).

## 2.2 Fibre manufacturing: chemical (man-made) fibres

The manufacturing of man-made fibres is not covered by this document. However, some preparation agents used in manufacturing may have an impact on the emissions from subsequent fibre processing (pretreatment). This is why some information about manufacturing of man-made fibres is given in this section.

Man-made fibres are typically extruded into continuous filaments. The continuous filaments can then be:

- used directly (in general, following further shaping or texturing);
- cut into staple length and then spun in a process resembling the one used for wool or cotton (see Section 2.4).

Three main methods are used to produce the continuous filaments (primary spinning):

- melt spinning;
- dry spinning;
- wet spinning.

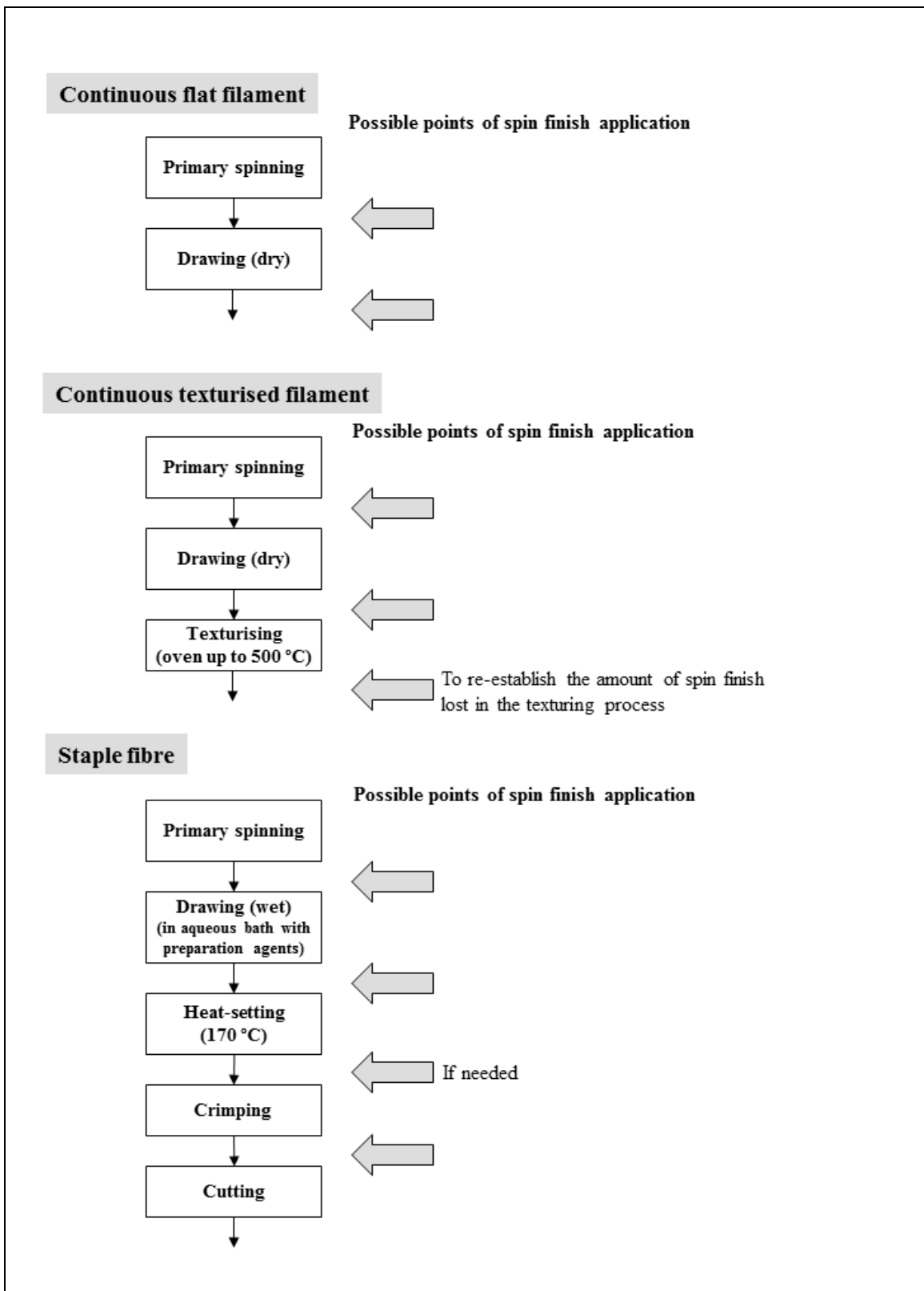
*Melt spinning:* The polymer is melted in a melt-extruder. The liquid is forced through the spinner opening under pressure and cooled by a jet of air to form the filament. A spinning preparation (spin finish) is generally applied at the bottom of the spinning duct. The melting process is suitable for thermoplastic fibres such as polyester, polyamide, polyolefins (e.g. polypropylene) and glass fibre.

*Dry spinning:* The polymer is dissolved in a solvent. The dissolved polymer is extruded through a spinneret into a chamber of heated air or gas where the solvent evaporates and the filament forms. This filament is further after-treated with a spin finish. The dry spinning process is principally used for acetate, triacetate and polyacrylonitrile.

*Wet spinning:* The polymer is dissolved in solution. The solution is forced under pressure through an opening into a liquid bath in which the polymer is insoluble. As the solvent is dissipated, the fibre forms. The solvent can be dissipated through extraction or by means of a chemical reaction between the polymer solution and a reagent in the spinning bath (reactive spinning). The residual solvent can be extracted by simple washing. After the thread is formed and the solvent is washed out, a spin finish can be applied. Wet spinning produces viscose and acrylic fibres.

Following primary spinning, the applied treatments vary, depending on the final product and the processed fibre. Two simplified process sequences can be identified for this stage:

- process for the manufacturing of continuous filament in flat or texturised form;
- process for the manufacturing of staple fibres.



**Figure 2.2: Simplified process sequences for manufacturing of continuous filaments (flat and texturised) and staple fibres**

As shown in Figure 2.2 above, preparation agents can be applied at various stages during the manufacture of the chemical fibres. Application of preparation agents in primary spinning (fibre manufacturing) is usually followed by further additions during secondary spinning, when the yarn is manufactured, including operations such as coning, twisting, warping, etc.

The preparation agents need to be removed to ensure uniform penetration of dyes and finishing agents and to avoid reaction or precipitation with them. Due to their high organic content and their often low bioeliminability, these substances are responsible for waste water pollution and emissions to air in the subsequent fibre pretreatment. Particularly relevant in this respect is the production of continuous filaments destined for the production of knitted fabric and the manufacturing of elastomeric fibres, because in this case the amount of preparation agents applied is higher.

The amount of preparation agents applied varies according to the fibre (e.g. PES, PA) and make-up (flat or texturised filament, staple fibre). Information about the chemistry of the preparation agents and the amount applied on the fibre is given in Section 8.1.2.

## 2.3 Fibre preparation: natural fibres

### 2.3.1 Wool

Wool is usually opened and de-dusted before it is fed to the scouring bowls. This is a mechanical process designed to shake out dirt from the wool and to open the fleeces in order to improve the efficiency of the scouring bowls in removing contaminants. The process also roughly blends the wool and produces a layer of fibres suitable for presentation to the scouring bowls. The opening and de-dusting processes vary considerably in severity depending on the characteristics of the particular wool being processed. The process produces a solid waste comprising dirt, sand, fibre fragments and vegetable matter.

The object of subsequent raw wool scouring processes is to remove contaminants from the wool fibre and to make it suitable for further processing.

Almost all scouring plants are based upon aqueous washing. Solvent scouring is much less widely practised.

#### 2.3.1.1 Cleaning and washing with water

A conventional wool scouring set is shown in Figure 2.3. The process is carried out by passing the wool through a series of four to eight wash bowls, each followed by a mangle or squeeze press which removes excess scouring liquor from the wool and returns it to the bowl. Clean water is added to the last bowl and passes via a counter-flow system from bowl to bowl with final discharge from the first bowl in a controlled manner to drain.

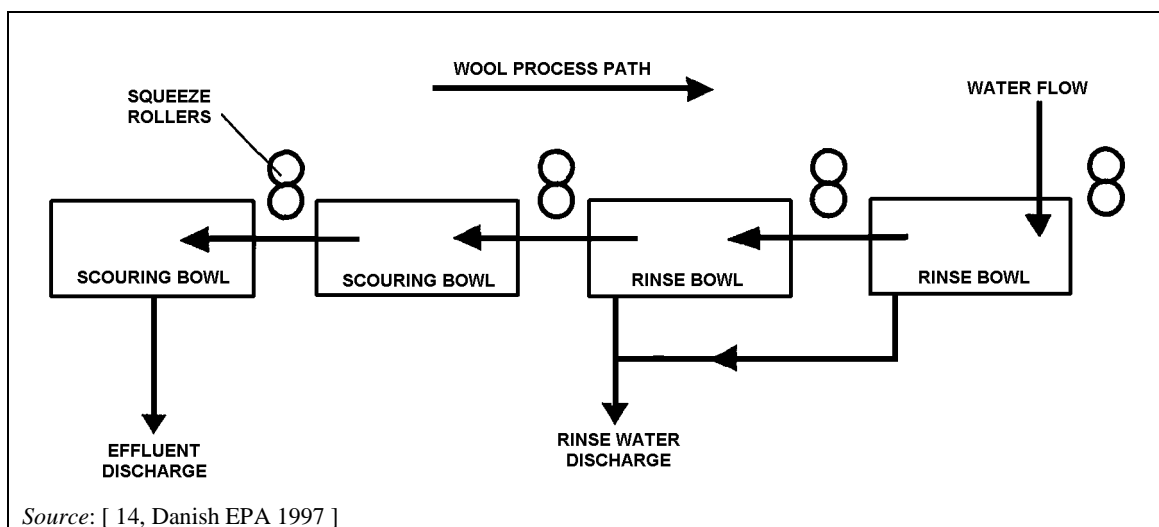


Figure 2.3: Conventional wool scouring arrangement

In the scouring bowls, suint is removed from the wool by dissolution, grease by emulsification and dirt by suspension.

For merino wools, the first bowl may be charged with water only and, in that case, its purpose is the removal of water-soluble suint before the wool enters the scouring process proper (this bowl is usually called 'de-suint').

In order to achieve grease emulsification, the scouring bowls are charged with detergent and often with sodium carbonate, or another alkali, which acts as a detergent builder. Concentrations

of detergent and builder are usually highest in the first scouring bowl and they decrease in subsequent bowls.

Detergents used by scourers are mainly synthetic non-ionic surfactants, namely alcohol ethoxylates. Some scourers also report the use of 'solvent-assisted detergents' for the removal of marking fluids from fleeces.

Finally, the wool is rinsed by passing it through bowls containing water only.

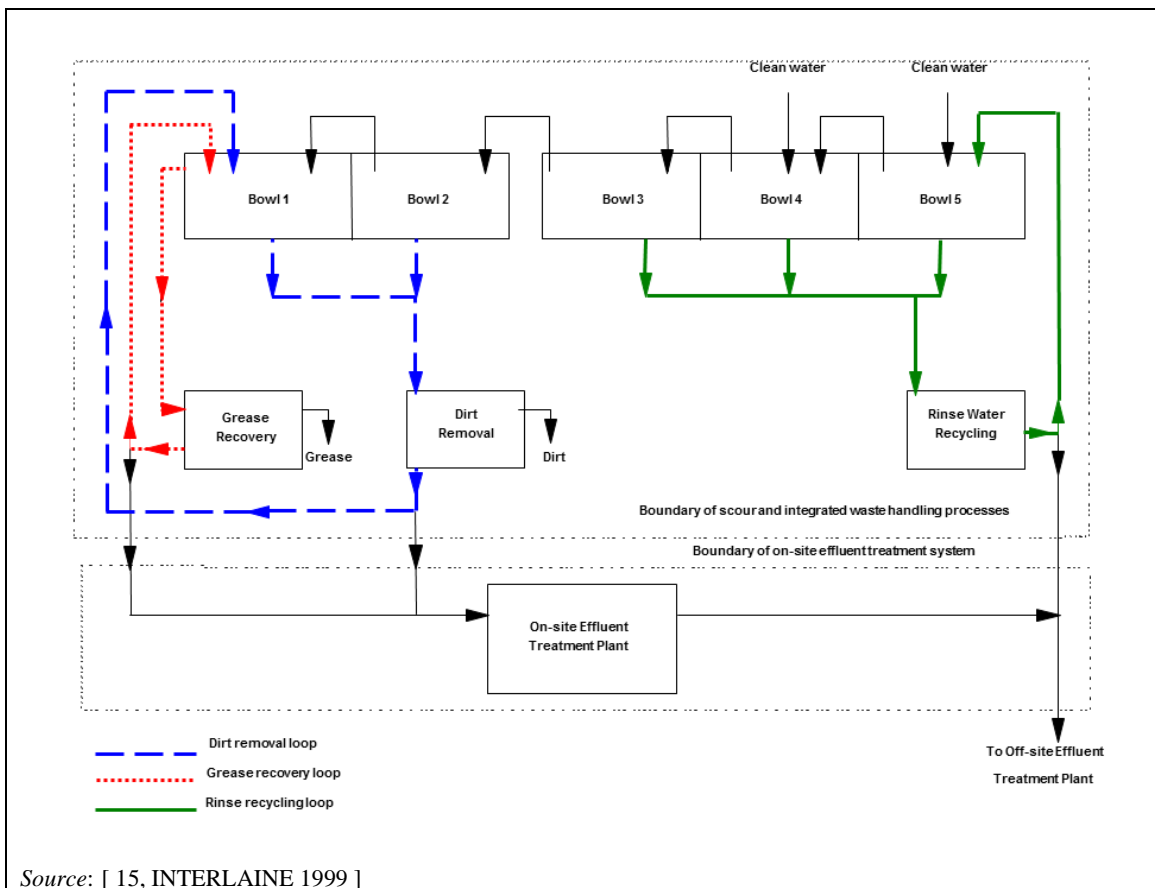
In coarse wool scouring plants, the final bowl of the scouring train is sometimes used for chemical treatments. In this case, it is isolated from the countercurrent liquor flow system and may also be isolated from the drain if the chemical treatment uses ecotoxic chemicals. The most commonly used treatment is bleaching, in which hydrogen peroxide and formic or acetic acid are added to the bowl. Other treatments sometimes applied include mothproofing, using a synthetic pyrethroid insecticide and acetic or formic acid, and sterilisation (of goat hairs) using formaldehyde.

Wool grease has a melting point around 40 °C. Since removal of solid grease from wool by detergents is slow and difficult, 40 °C is the lowest temperature at which aqueous scouring liquors are effective for removing grease. In addition, non-ionic detergents lose efficiency rather rapidly below 60 °C, which means that scour and rinse bowls are typically operated at 55-70 °C.

After leaving the final squeeze roller, the wool will contain 40 % to 60 % moisture. It is therefore dried by convection in a hot-air dryer. The dryer is usually heated either by closed steam pipes or by direct gas firing. The heat supply to the dryer may be controlled by a signal from a device which senses the humidity of the dryer atmosphere or the moisture content of the wool at the output end, thus saving energy and avoiding overdrying the wool.

The mechanical design of wool scours and the arrangements for circulating the scour and rinse liquors vary widely. Since these matters have a direct influence on energy and water usage, as well as the partial removal of contaminants from the effluent, it is important to illustrate them in more detail.

New-generation scouring plants like the one illustrated in Figure 2.4 have an integrated system for grease and dirt recovery.



**Figure 2.4: Schematic diagram showing a scouring line, integrated waste handling process and on-site effluent treatment plant**

The dirt tends to settle at the bottom of the bowl and modern scouring bowls usually have hopper-shaped bottoms from which the sludge is removed by gravity through a valve. Opening of the valve may be under the control of a timer or may respond to a signal from a turbidity meter which senses the thickness of the dirt suspension in the hopper bottom. The discharge from the scouring bowl hopper bottoms is led to a heavy-solids settling tank where it is gravity-settled and the settled liquor partly recycled to scouring bowl 1 and partly discharged. Flocculant may be added to the heavy-solids settling tank to assist the separation of dirt, or a decanter centrifuge or hydrocyclone may be used in preference to gravity settling for dirt removal.

For grease recovery, modern scouring bowls have a side tank in which the grease-rich liquors removed from the wool by the squeeze press are collected. From here, part of the flow may be pumped to the previous bowl or, in the case of bowl 1, to a primary grease centrifuge. The centrifuge separates the liquor into three phases. The top phase, referred to as the cream, is rich in grease and passes to secondary and possibly tertiary centrifuges for further dewatering, finally producing anhydrous grease; the bottom phase is rich in dirt and goes to the heavy-solids settling tank; the middle phase is low in both grease and dirt compared with the input and this is split, part being recycled to scouring bowl 1 and part being discharged.

In a commonly used variation of the above recycling arrangements, the dirt and grease removal and recycling loops may be combined. In this case, scouring liquor may be removed from the bottoms of the bowls only, or from top and bottom, and passed first through the dirt removal equipment, then through the primary grease centrifuge.

Some scourers recycle rinsing water (see Figure 2.4). The flowdown from the first rinse bowl can be treated to make it suitable for addition to the feed to the final rinse bowl. Normally, this

is accomplished by removing dirt in a hydrocyclone and processing the water through a membrane filtration plant to remove other impurities.

It is normally necessary to purge dirty liquors which collect at the bottoms of the rinse bowls, but this is not always the case.

Purging of rinse bowls will depend upon the efficiency of the bowls. Some modern scouring sets control the rinse bowls' discharge using solids detectors, but generally rinse bowls merely have a timed discharge of bottom liquor which operates automatically whatever the state of the liquor [9, TWG 2001].

The dirt removal and grease recovery loops described above serve several purposes. They save water, by recycling effluent to the scouring bowls, and they act as a process-integrated partial effluent treatment. The recovered wool grease can be sold. Finally, since the discharges from the loops are the only points at which heavily contaminated scouring liquors are discharged, valves and meters at these points can be used to control the rate of water usage in the scouring section.

For more information about the performance of the dirt removal and grease recovery loops, see Sections 3.7.1, and Section 4.2.1.1.

### **2.3.1.2 Environmental issues associated with wool scouring (with water)**

This section discusses the environmental issues associated with the overall scouring process including the treatment of the process effluent.

The main environmental issues associated with the wool scouring process arise from emissions to water, but solid waste and the emissions to air also need to be taken into account.

#### **2.3.1.2.1 Potential for pollution of water**

The removal of contaminants present on the raw fibre leads to the discharge of an effluent in which the main polluting contributors are:

- highly concentrated organic material in suspension and in solution, along with dirt in suspension;
- micro-pollutants resulting from the veterinary medicines applied to protect sheep from external parasites.

There are also detergents in the discharged water, which contribute to the increase of the chemical oxygen demand of the effluent. The detergent is recycled via the grease recovery/dirt removal loop. As a result, low efficiency in this recovery system is associated with higher amounts of detergent in the effluent. Compared to the chemical oxygen demand attributable to wax, dirt, etc., the detergents can be considered minor contributors to water pollution (for more detail on environmental issues regarding detergents, see Section 8.1.1).

As for the organic matter coming from wax and dirt, according to [349, Stewart R.G. 1988] the COD of effluent and of greasy wool can be calculated using the following equation:

$$\text{COD (mg/kg)} = (8\,267 \times \text{suint (\%)}) + (30\,980 \times \text{oxidised grease (\%)}) + (29\,326 \times \text{top grease (\%)}) + (6\,454 \times \text{dirt (\%)}) + 1\,536$$



Since the coefficients for top grease and oxidised grease<sup>1</sup> in this equation are similar and since approximately equal quantities of top grease and oxidised grease are present in many wools, it is possible to combine the two grease terms in the above equation as follows:

$$\text{COD (mg/kg)} = (8\,267 \times \text{suint (\%)}) + (30\,153 \times \text{total grease (\%)}) + (6\,454 \times \text{dirt (\%)}) + 1\,536$$

It is then possible to calculate the COD content of 'typical' merino and cross-bred wools:

Merino wool: suint = 8 %; grease = 13 %; dirt = 15 %

$$\text{COD} = (8\,267 \times 8) + (30\,153 \times 13) + (6\,454 \times 15) + 1\,536 = 556 \text{ g/kg greasy wool}$$

Cross-bred wool: suint = 8 %; grease = 5 %; dirt = 15 %

$$\text{COD} = (8\,267 \times 8) + (30\,153 \times 5) + (6\,454 \times 15) + 1\,536 = 315 \text{ g/kg greasy wool}$$

These high levels of oxygen-depleting substances are removed from the effluent before it can be safely discharged to the environment.

Organohalogenes, organophosphorus compounds and biocides are among the polluting substances listed for emission control in the IED [16, EU 2010].

Worldwide, the most common ectoparasiticides used for treating sheep are diazinon (OP), propetamphos (OP), cypermethrin (SP) and cyromazine (fly-specific IGR), for control of blowfly. Insect growth regulators such as dicyclanil, diflubenzuron and triflumuron are registered only in Australia and New Zealand. Organochlorine pesticides (in particular, hexachlorocyclohexane) are still found on wool coming from the former Soviet Union, the Middle East and some South American countries [15, INTERLAINE 1999] (see also Section 2.1.1.10).

Concerning the fate of ectoparasiticides when they enter the scouring process, a distinction has to be made between lipophilic and hydrophilic compounds such as cyromazine. The lipophilic compounds – OCs, OPs and SPs – associate strongly with the wool grease and are removed with it during scouring (although a fraction – up to 4 % – is retained by the fibre and will be released in the subsequent wet finishing processes). This behaviour also applies to diflubenzuron (IGR). Studies have shown that triflumuron (IGR) associates partially with the dirt and partially with the grease. As a result, compared to other lipophilic compounds, a higher proportion of this pesticide is likely to be retained on site (on the wool fibre and on the recovered wool grease and dirt) and not be discharged in the aqueous effluent [17, Savage G. 1998]. In contrast, IGRs such as cyromazine and dicyclanil are appreciably water-soluble (11 g/l at 20 °C, for cyromazine), which means that they are not removed in wool grease recovery systems.

In the waste water treatment systems, an additional fraction of the pesticide residues is removed. Physico-chemical separation techniques remove the biocide residue at approximately the same rate as the grease and the dirt with which they are associated. On the other hand, evaporation systems remove OCs and SPs in significant quantities, but up to 30 % of the OPs may appear in the condensate because they are steam-volatile. The water-soluble compounds, such as the IGR cyromazine are probably not removed from the effluent stream except by evaporating treatments [15, INTERLAINE 1999].

Despite these treatments, the removal of pesticides is often incomplete and there is potential for pesticides to enter the aquatic environment when the effluent is discharged. The environmental concentrations of ectoparasiticides in the receiving water depend greatly on local circumstances,

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<sup>1</sup> Top grease is unoxidised grease which is readily separated from scour liquors by centrifuging; oxidised grease is less hydrophobic and is less readily separated.

in particular the amount of scouring activity concentrated in a given catchment and the dilution available between scouring discharges and the river which receives the treated effluent.

### 2.3.1.2.2 Potential for pollution of land

Two main 'wastes', grease and sludge, are produced as a consequence of the scouring activities (and related effluent treatment).

Depending on its oxidation extent, it may be possible to recover from 20 % to 40 % of the grease initially present on the raw wool. This is to be regarded as a by-product rather than a waste, since it can be sold to lanolin refiners for the production of high-value products in the cosmetics industry. However, high levels of pesticide residues in the grease can also be a problem for the lanolin refiners, especially for the production of lanolin-based pharmaceuticals and cosmetics, since more expensive and sophisticated techniques have to be used to reduce the pesticides to acceptable levels. Acid-cracked grease has no market value and has to be landfilled.

The sludge produced as a result of physico-chemical treatment of waste water also contains grease, dirt and the portion of pesticides which are strongly associated with either grease or dirt. Concentrates and sludges from evaporation or membrane filtration may also contain suint, which is mainly potassium chloride and potassium salts of fatty acids. Suint is a by-product which can be used in agriculture.

Sludge and concentrate disposal may follow several routes:

- incineration (with heat recovery);
- pyrolysis/gasification;
- brick manufacturing;
- composting or co-composting with other organic material;
- landfill.

The first three sludge disposal routes destroy the organic material in the sludge, including grease and pesticides. The ash from incineration may contain potassium salts, derived from suint, and heavy metals characteristic of the soil on which the sheep producing the wool have grazed. The ash is normally disposed of to landfill. The characteristics of the char from pyrolysis/gasification are unknown and this char is also typically disposed of to landfill. The use of wool scouring sludges in brick manufacture results in no residues for immediate disposal. These three sludge disposal methods probably have the least potential to pollute land.

Wool scouring sludges cannot be composted alone, but require the addition of carbon-rich organic material. Green waste from agriculture or horticulture has been used. Composting is not yet regarded as a fully developed, fail-safe technique and only partly degrades the pesticides present in the sludge. However, since the pesticides present in the sludge are there because of their lipophilicity or their strong propensity to be absorbed by solids, they are likely to be immobile in soil, and spreading of compost derived from wool scouring sludges on agricultural land is unlikely to pose an environmental risk of any significance.

Landfill is the simplest and often cheapest method of disposal of sludges. In the longer term, however, landfill is not believed to be either economically or environmentally sustainable. The fate of wool scouring sludges in landfill is not known, but there is a small potential for the ectoparasiticides present to arise in leachate. Anaerobic degradation of the organic material in the sludge will give rise to methane emissions [ 15, INTERLAINE 1999 ].

### 2.3.1.2.3 Potential for pollution of air

Air pollution is not a major issue for wool scouring processes. Nevertheless, two issues can be mentioned:

Hot acid cracking, which involves heating the scouring effluent with sulphuric acid, when used near residential areas, has been the subject of odour complaints.

Incineration is used in conjunction with evaporation of the effluent because the surplus heat from the incinerator can be used in the evaporation process. Incineration of wool scouring sludges has potential for air pollution. Since sludges contain relatively high levels of chloride (from suint) as well as organically bound chlorine from ectoparasiticides etc., there is potential for the production of polychlorodibenzodioxins and furans, when they are incinerated (catalytic and high-temperature incinerators are now available to prevent these emissions). The sludges also contain relatively high levels of sulphur and nitrogen and the combustion process therefore produces SO<sub>x</sub> and NO<sub>x</sub>. Dust and odours should also be taken into account.

### 2.3.2 Cotton and flax

Raw cotton is a much cleaner raw fibre than wool and initial operations are mainly dry. The fibres are supplied to the spinning mill in compressed bales. The fibres are sorted by grade, cleaned to remove particles of dirt and blended with fibres from different bales to improve the consistency of the fibre mix. Sorting and cleaning is performed in machines known as openers.

With flax, the isolation of the fibre from the flax stem is done in different steps. After crop plucking, the flax is retted (dew retting, water retting, enzymatic, microbotic, steam or chemical retting). Retting is a wet process that can result in waste water with high contents of COD and BOD: pectinic and hemicellulosic substances are degraded in this step. Rovings are produced by further mechanical treatment before spinning.

### 2.3.3 Silk

For silk production, the silk worm is killed with steam and the filament is unwound directly from the cocoon. The filament is submitted to pretreatment processes to remove the silk gum and other organic impurities (see Section 2.6.3).

## 2.4 Yarn manufacturing

Almost all textile apparel products are made from spun yarns of 100 % natural fibres, 100 % man-made staple fibres or blends. Only a few apparel products, for instance smooth sportswear, are made exclusively of filament yarns (although increasing use is being made of fabrics that contain multifilament yarns, generally textured, and one or more staple fibre yarns).

Secondary spinning is the process by which staple fibres are transformed into yarn suitable for the textile industry. There are two main spinning processes:

- the wool spinning process;
- the cotton spinning process.

### 2.4.1 The wool spinning process

The wool spinning process is mainly used to produce wool and wool-blend yarns. A distinction is made between the worsted and the woollen process. In worsted spinning, higher-quality longer fibres are processed and the result is a fine yarn which is used to produce worsted fabric. In woollen spinning, shorter fibres are processed.

In the worsted process, the fibres are paralleled in a combing machine and are then drawn and spun. In the woollen system, the fibres are only carded and then spun. The resulting yarn is then twisted (if required) and finally prepared for the subsequent treatments (dyeing, weaving, tufting, etc.) through an operation called winding.

In both the woollen and worsted systems, the various fibres (e.g. wool fibres from different sources, different types of synthetic fibres) are combined during the blending operation. In order to allow efficient mechanical processing in the subsequent operations, spinning lubricants are applied to the fibres at this stage (or later, before or after carding, depending on the system applied).

### 2.4.2 The cotton spinning process

The cotton spinning process is generally used for cotton and man-made fibres. As has already been described in Section 2.3.2, cotton fibres are first submitted to opening and cleaning operations. The following steps, which are the same for cotton and man-made fibres, are:

- carding;
- combing;
- drawing;
- roving;
- spinning;
- twisting (if required);
- winding.

### 2.4.3 Environmental issues

The preparation agents (conditioning agents and spinning lubricants) applied to the fibre during the spinning process have significant environmental implications for the subsequent finishing steps of the textile chain. Since these auxiliaries, together with spin finishes added in primary

spinning (in the case of man-made staple fibres), need in general to be completely removed before dyeing, they are found either in the exhaust air from the high-temperature processes or in the water from wet treatments. In the first case they give rise to air pollution, whereas in the second they contribute to the organic load of the final effluent.

Spinning lubricants may be responsible for the emission not only of hard-to-biodegrade organic substances such as mineral oils, but also of hazardous compounds such as polyaromatic hydrocarbons, APEO and biocides.

The resulting pollution depends on the type and amount of lubricant applied to the fibre. In the wool spinning process, for example, a distinction is to be made between fabric derived from carded yarn (woollen process) and fabric manufactured using combed yarn (worsted process). There is a substantial difference, in fact, not only from a mechanical point of view, but also in the quantity of lubricants applied. This is approximately 5 % in the woollen process and is always less than 2 % in the worsted process (this consideration only holds for textiles, because in the woollen process for carpet yarn, the amount of lubricants ranges from 1 % to 1.5 %).

As regards synthetic fibres (staple fibres), the amount of preparation agents applied at the yarn manufacturing stage is especially relevant in the case of elastomeric fibres where the final content of preparation agents (mainly silicone oils) can be in the order of 7 % of the weight of the fibre.

Additional information about the composition of spinning oils is given in Section 8.1.2. It is however difficult to analyse in detail the environmental aspects associated with the use of these substances because of the large variety of commercial products. Spinning mills usually buy lubricants from dealers who buy chemical products from large petrochemical producers, and mix them according to the specific needs of each spinning mill. This makes the identification of the chemical substances present on the yarn when this enters the finishing mill even more difficult.

## 2.5 Fabric production

Raw materials for cloth production are spun yarns and filament yarns. These raw materials can then be converted into:

- woven textiles;
- knitted textiles;
- floor coverings and non-woven fabrics.

The last item covers a number of different end-products which are typical of the carpet industry.

### 2.5.1 Woven textiles

#### 2.5.1.1 Warping

Before weaving, warp yarns are wound onto beams in a process called warping. During this operation, there is no consumption of auxiliary agents that could have a negative influence on the emissions from the subsequent finishing processes.

In some cases (wool mills) the warp yarn is not sized, but treated with liquid paraffin.

#### 2.5.1.2 Sizing

In order to lubricate and protect the warp yarn during weaving, sizing agents (in the form of water solutions or water dispersions) are applied after warping. The main sizing agents can be grouped into two classes:

- Sizing agents based on native polysaccharides:
  - starch;
  - starch derivatives such as carboxymethyl starch or hydroxyethyl starch ether;
  - cellulose derivatives, especially carboximethyl cellulose (CMC);
  - galactomannans;
  - protein derivatives.
- Fully synthetic polymers:
  - polyvinyl alcohols (PVA);
  - polyacrylates;
  - polyvinylacetate;
  - polyester.

The ratio of synthetic sizing agents to native sizing agents is variable (e.g. about 1:3 in Germany [5, UBA 2001], 1:4-1:5 in Spain [9, TWG 2001]).

It is important to bear in mind that:

- the type of sizing agent applied varies according to the fibres to be processed, the weaving technique adopted and the demands of any system used for recycling the sizing agents;
- sizing agent formulations are usually mixtures of the substances mentioned above.

With cotton, additional auxiliaries are present in the sizing mixtures. These are mainly the following [ 10, Ullmann's 2011 ]:

- *Viscosity regulators*: complex formation between borax and the hydroxyl groups of starch increases the viscosity of the paste, while urea reduces it. Important viscosity regulators include starch-degrading agents such as peroxodisulphates, peroxosulphates that act by oxidative cleavage of the macromolecules.
- *Sizing fats*: they are used to improve the weaving behaviour of the warp. Suitable materials include sulphated fats and oils and mixtures of fatty acid esters with non-ionic and anionic emulsifiers.
- *Antistatic agents* (mainly based on polyglycol ethers).
- *Wetting agents*: fatty alcohols poly(glycol ethers) with a low degree of ethoxylation.
- *De-foaming agents*: their addition is often necessary when the sizing agents tend to produce foam (e.g. with PVA) or if wetting agents are added. Suitable products are based on paraffin oils, phosphoric esters, fatty acid esters or silicone oils.
- *Preservatives*: for sizing liquors that are stored for long periods and contain degradable components such as starch and starch derivatives, fungicides and/or bacteriocides are added. Typical preservatives include formaldehyde, phenol derivatives, heterocyclic compounds of the isothiazoline type.

Sizing agents used for synthetic fibres (e.g. polyacrylates, polyesters) do not contain these auxiliaries, except for the preservatives, which prevent attacks by bacteria that are present when aqueous systems are used.

Sizing agents are introduced by the weaving firm, but have to be removed by the finisher (during the operation called desizing). This desizing process results in high waste water loads. In the case of woven fabric, sizing agents can represent 30-70 % of the total COD load in waste water. The lower percentage is for finishing of woven fabric consisting mainly of flat filament yarns and the higher for staple fibres, especially for cotton and in the case of native sizing agents. Therefore it is important to know the COD of these substances and their characteristics in terms of biodegradability and bioeliminability. Note that additives present in the formulations (e.g. the preservatives) also influence the aquatic toxicity and biodegradability of the resulting emissions (toxicity and biodegradability cannot be discriminated by using only COD measurements).

Section 8.1.3 gives more details about:

- characteristics of the chemical substances commonly used as sizing agents and specific COD and BOD<sub>5</sub> values;
- typical amounts applied on the various fibres.

### 2.5.1.3 Weaving

Weaving is the process by which yarns are assembled together on a loom and a woven fabric is obtained. The process only requires electricity. Lubricants and oils are used to lubricate the loom, but in particular cases they may contaminate the fabric.

## 2.5.2 Knitted textiles

### 2.5.2.1 Waxing

The yarn specially made for the knitting industry is lubricated or waxed (generally with paraffin wax) to allow knitting at higher speed and protect the yarn from mechanical stresses. Waxing may be done while re-winding the yarn onto bobbins, in which case the process is normally called ‘preparation for knitting’.

### 2.5.2.2 Knitting

Like weaving, knitting is a mechanical process and involves knotting yarn together with a series of needles. Mineral oils are widely used to lubricate the needles and other parts of the knitting machinery. The quantity of oils used depends on the technology of the machine and on the speed of the needles. The value ranges between 4 % and 8 % of the weight of the fabric (when mineral oils are used the amount may rise to 10 %).

The oil and the wax that remain on the final fabric will be washed out during the finishing treatments. Their contribution to the total pollutant load coming from finishing mills may be significant.

Additional information about knitting oils is reported in Section 8.1.2.5.

The main knitting production methods are: *straight knitting* (flat or circular), its advancements: *fully fashioned knitting* and *integral knitting*, and the most recent: *complete garment*. [ 11, Beton et al. 2014 ], [ 18, Peterson et al. 2007 ]

#### *Straight knitting*

Knitting, whether by hand or on a machine, is usually done by using warp and weft knitting techniques. Straight knitting most commonly relies on the weft technique, which consists of using one continuous yarn which is fed to and looped in rows by one or more needles at a time. Two common types of straight weft knitting machines used are:

- Flat knitting machine – also known as a ‘cut and sew’ technique that creates rectangular panels of fabric.
- Circular knitting machine – which is used to create cylindrical panels of knitted fabric (e.g. used for making socks and sweaters).

Both types of machines are also able to create different textures and patterns, such as ribbing.

#### *Fully fashioned knitting*

Fully fashioned knitting is an advancement of the straight knitting technique. The advantage of this knitting machine is that it can produce a custom-shaped sheet of fabric by adding/removing the stitches, so that there is little or no need for cutting panels, and therefore little or no fabric is discarded in the process [ 18, Peterson et al. 2007 ].

#### *Integral knitting*

Integral knitting is a further advancement of the fully fashioned knitting technique. An integral knitting machine is able to add additional trimmings as an integrated part of the fabric panel (e.g. pockets, collars, V-necks). Along with the advantage of reducing fabric losses from cutting, this technique also reduces sewing requirements [ 18, Peterson et al. 2007 ].

#### *Complete garment*

State-of-the-art integral knitting machines are now available which are able to knit complete garments, and therefore eliminate cutting and sewing steps altogether. This type of technology



is becoming increasingly attractive as it eliminates the costs of expensive post-knitting steps, decreases raw material consumption, and also produces higher-quality garments.

A recent study of the influence of novel knitting production methods on the environmental impacts of the total textile production chain in the EU showed that fully fashioned and integral knitting use more energy than flat knitting, but they also significantly reduce material losses. These trade-off leads to a net benefit in many of the environmental indicators (e.g. ozone and water depletion, natural land transformation), making these production methods most popular [ 11, Beton et al. 2014 ].

Fully fashioned, integral or complete garment knitting machines require a significant amount of initial capital investment. However, these costs can be offset by long-term savings in labour and resource costs. Also, there is a growing trend in computerised machines which not only produce at higher efficiencies, but also at much higher outputs and greater speeds, and allow for greater flexibility in design.

### 2.5.3 Textile floor coverings

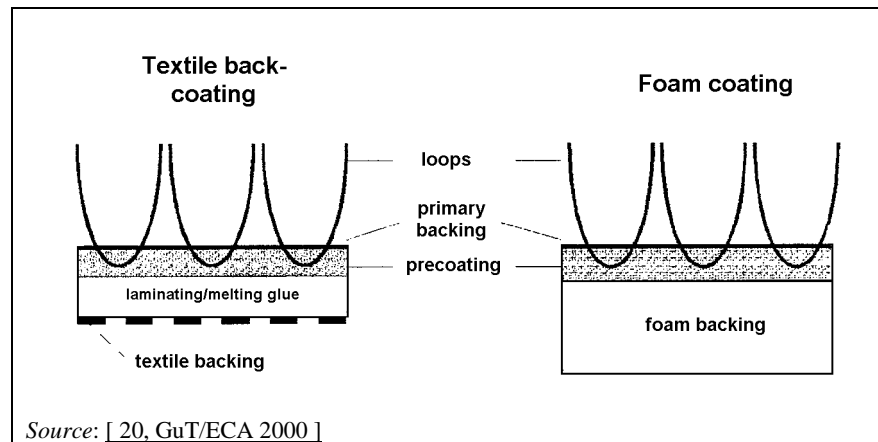
Textile floor covering is a collective noun for articles having a usable surface of textile material. This particular class of products can be schematically described as composite substrates made up of the following layers:

- A *pile yarn (or more generically a face fibre)*, which can be made from filament or staple fibre yarns (mainly polypropylene, polyamide, polyester, wool, acrylic fibres).
- A *carrier layer (or primary backing)*, which is mainly made of polypropylene strips of fabric (75 % of cases), PP or PES webs (16 % and 8 % of cases, respectively) and less commonly of jute fabric (1 % of cases) [ 19, Jacobs et al. 1998 ].
- A *pre-coating layer*, which is typical of tufted carpet and whose function is to anchor the pile onto the carrier layer. This pre-coating layer is made from synthetic rubber or an artificial dispersion based on carboxylated styrene-butadiene rubber latex.
- A *back-coating layer*, which is an additional layer applied to the bottom side of the carpet. It is possible to distinguish between foam coating, textile back-coating and heavy coating methods. The purposes of this final layer are various. Mainly, it is intended to strengthen the attachment of the pile, improve the dimensional stability of the carpet and provide the carpet with properties such as anti-slip, heat insulation, stepping elasticity, or even flame retardancy (carpet coating techniques are described in more detail in Section 2.10.2).

This is, however, a very general definition. In fact, the characteristics of the end-product and the applied manufacturing techniques can vary significantly. The principal methods of manufacturing carpet/floor coverings are tufting, weaving and needling (other methods are knotting, bonding, knitting, etc.). The best way to describe these techniques is probably to describe the different types of carpets.

### 2.5.3.1 Tufting

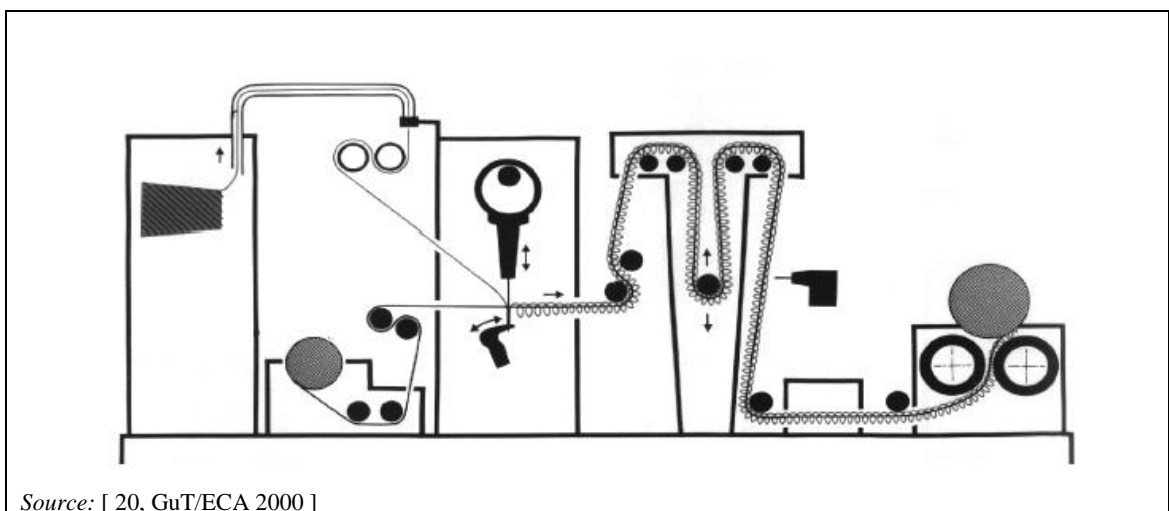
As Figure 2.5 below shows, tufted carpets are made up of several different components.



**Figure 2.5:** Cross-section of a tufted carpet

In the tufting process, pile yarns (face) are inserted by needles into a woven or non-woven carrier material (primary backing), made of polypropylene, polyester or jute, across the entire width of the substrate (up to 5 m). During subsequent manufacturing processes, the base of the pile yarn is anchored in the back of the carpet by means of an applied coating (see Section 2.10.2).

Figure 2.6 is a simplified representation of a tufting plant.



**Figure 2.6:** Simplified representation of a tufting plant

Through variations of the tufting technique, different three-dimensional pile structures can be produced as well as patterned carpets (e.g. level loop pile, multi-level loop pile, cut and loop, velvet and velour, saxony).

Figure 2.7 shows two examples of carpet styles.

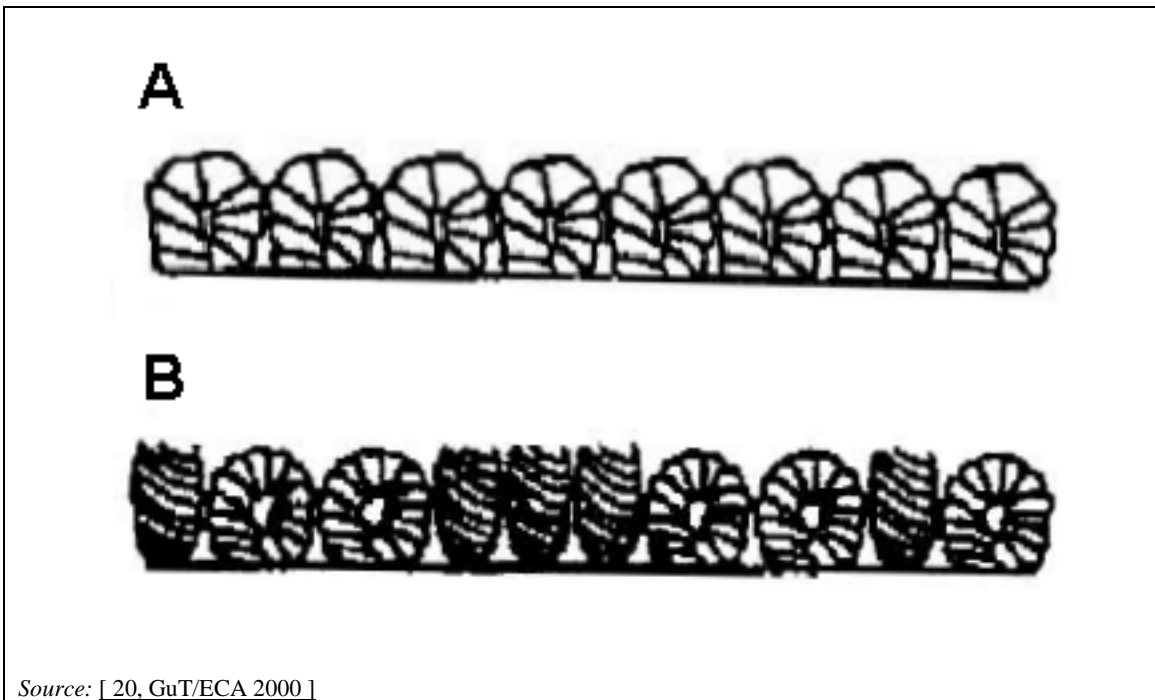


Figure 2.7: A: Level loop pile; B: Cut and loop pile

### 2.5.3.2 Needle-felting

Figure 2.8 shows the manufacturing process for needle-felt carpets. The fibres lie criss-cross to each other and are compressed with needles. This compression is fixed with binding agents [ 19, Jacobs et al. 1998 ]. Needle-felt carpets can consist of one or several layers, with or without a carrier layer. They may be equipped with various types of backings (textile backing, foam, heavy coating). For lasting binding of the fibres, the needled substrate is subsequently subjected to further thermal or chemical treatment (chemical reinforcement).

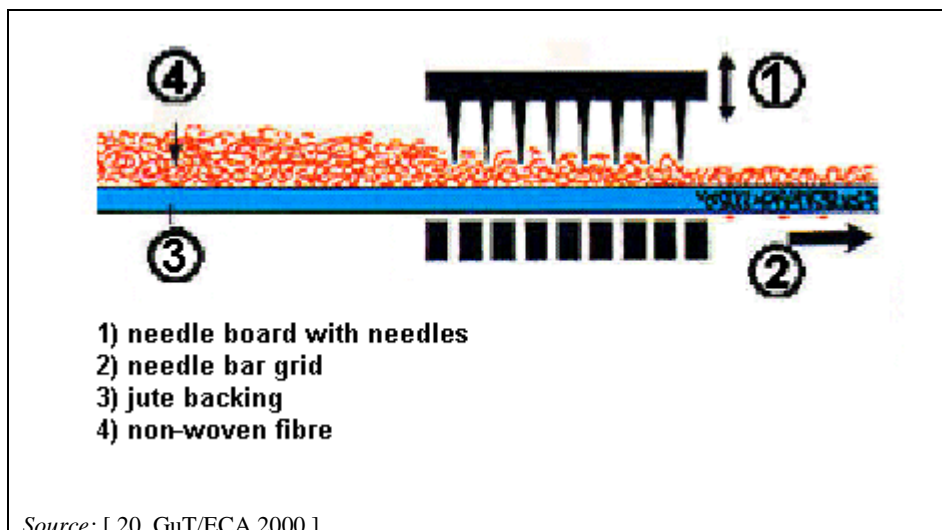
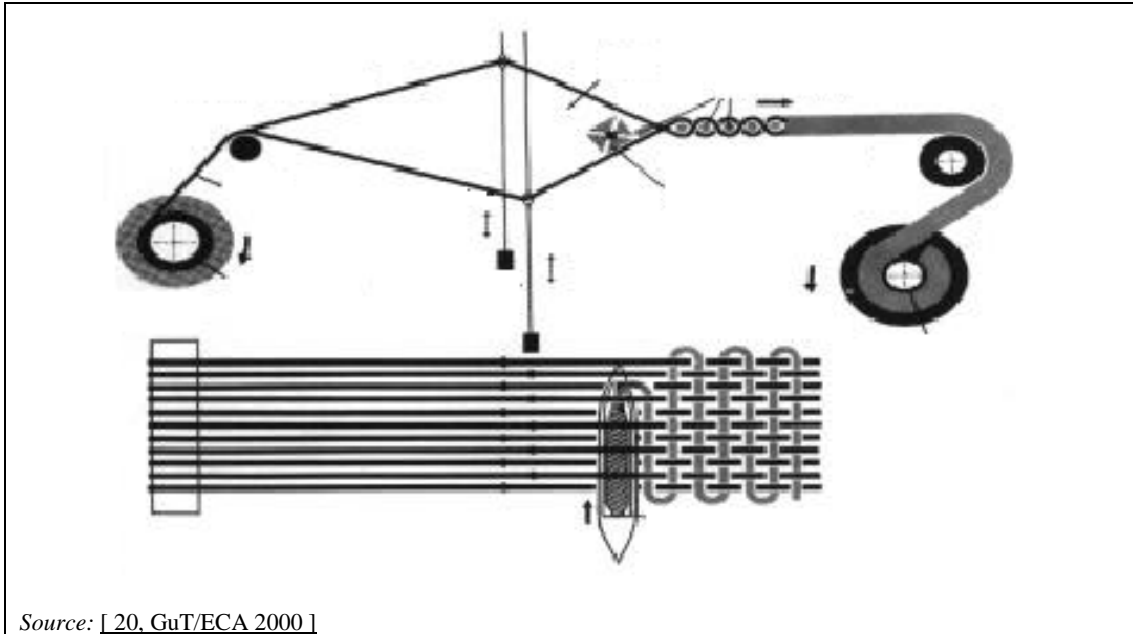


Figure 2.8: Manufacture of needle-felt carpet

Almost all fibres may be used for the production of needle-felts; however, man-made fibres are mostly used (PP, PA, PES, PAC, wool, jute/sisal, viscose).

### 2.5.3.3 Carpet weaving

The manufacturing process for woven carpets is similar to the manufacturing of any other woven good (see Section 2.5.1.3). Since coarse types of yarns are used for woven carpets, the warp is normally not sized. A scheme of the production process for woven carpets is reported in Figure 2.9.



**Figure 2.9:** Representation of the production process for woven carpets

As a rule, woven carpets are provided with a stabilising back-coating. Only in rare cases is an additional heavy coating (e.g. PVC or bitumen) applied.

### 2.5.4 Non-woven textiles

Textiles manufactured without an intermediate yarn-processing step are called non-wovens. The application of these textiles is broad, ranging from backings for coatings, filters, geo-textiles and other technical textiles to dishcloths, etc.

In the fabrication of non-woven textiles, the only significant environmental impact is normally associated with the off-gases emitted during the thermal and chemical bonding steps. The volatile compounds mainly originate from fibre-inherent monomers (especially caprolactam), monomers in the bonding polymers, etc.

## 2.6 Pretreatment

Pretreatment processes should ensure:

- the removal of foreign materials from the fibres in order to improve their uniformity, hydrophilic characteristics and affinity for dyestuffs and finishing treatments;
- the improvement of the ability to absorb dyes uniformly (which is the case in mercerising);
- the relaxation of tensions in synthetic fibres (without this relaxation of tension, unevenness and dimension instabilities can occur).

The position of pretreatment within the production scheme is closely related to the position of dyeing in the sequence. The point is that pretreatment comes immediately before dyeing (and printing).

Pretreatment processes and techniques depend on the following:

- The kind of fibre to be treated: for raw goods made of natural fibres such as cotton, wool, flax and silk, the technical task is more difficult than for those made of synthetic and artificial fibres. Natural fibres in fact are accompanied by a higher amount of substances that can interfere with later processing. Man-made fibres, in turn, usually contain preparation agents.
- The form of the fibre (flock, yarn, woven or knitted fabrics).
- The amount of material to be treated (for example, continuous methods are more efficient, but are only economically viable for large production capacities).

Pretreatment operations are often carried out in the same type of equipment used for dyeing (in batch processing, in particular, the material is most often pretreated in the same machine in which it is subsequently dyed). For ease of reading of this part of the document, machines that are not specific to a given treatment are described in a separate annex (see Section 8.3).

### 2.6.1 Pretreatment of cotton and cellulose fibres

#### 2.6.1.1 Principal processes

Cotton pretreatment includes various wet operations, namely:

- singeing;
- desizing;
- scouring;
- mercerising (and caustification);
- bleaching.

Some of these treatments are obligatory steps only for certain make-ups (e.g. desizing is carried out only on woven fabric).

Moreover, some of these treatments are often combined together in one single step in order to respond to the need to reduce production time and space as much as possible. Nevertheless, for practical reasons they are described in this section as separate treatments, leaving the description of possible process sequences for specific make-ups to the following sections.

### 2.6.1.1.1 Singeing

Singeing can be carried out both on yarns and woven fabrics, but it is more common on fabrics, especially on cotton, cotton/PES and cotton/PA substrates.

Protruding fibre ends at the fabric surface disturb the surface appearance and produce an effect known as 'frosting' when dyed. It is therefore necessary to remove the surface fibres by passing the fabric through a gas flame. The fabric is passed over a row of gas flames and then immediately into a quench bath to extinguish the sparks and cool the fabric. The quench bath often contains a desizing solution, in which case the final step in singeing becomes a combined singeing and desizing operation.

Before singeing, the fabric is combed under aspiration to eliminate remaining dust and fibres.

Singeing has no effect on the effluents because only cooling water is necessary. During singeing, relatively strong odours and emissions of dust and organic compounds are observed [9, TWG 2001]. Odorous substances can be destroyed using catalytic oxidation techniques (see Section 4.1.8.6).

### 2.6.1.1.2 Desizing

Desizing is used for removing (from woven fabric) sizing compounds previously applied to warp (see Section 2.5.1.2) and is usually the first wet finishing operation performed on woven fabric.

Desizing techniques are different depending on the kind of sizing agent to be removed. Currently applied techniques can be categorised as follows:

- techniques for the removal of starch-based sizing agents (water-insoluble sizes);
- techniques for the removal of water-soluble sizes;
- techniques for the removal of water-soluble and insoluble sizes.

#### Techniques for the removal of starch-based sizes

Starch-based sizes are difficult to remove and require either the catalytic action of an enzyme (catalytic degradation) or another chemical treatment in order to be converted into a washable form. This chemical degradation is mainly achieved by either enzymatic or oxidative desizing.

*Enzymatic desizing* is the most widely used method for the removal of starch, amylases being particularly suitable. The advantage in the use of enzymes is that starches are decomposed without damaging cellulose fibre.

In order to reduce the number of steps in the pretreatment process, it is common practice to combine desizing with cold bleaching in a single step. In this case, the process is also called '*oxidative desizing*'. The fabric is impregnated in a bath containing hydrogen peroxide and caustic soda, together with hydrogen peroxide stabilisers and complexing agents. Persulphate is also usually added to the solution.

Due to the action of NaOH, this treatment, besides a desizing/bleaching effect, also serves as a pre-scouring treatment. Furthermore, oxidative desizing is particularly useful when the textile contains enzyme poisons (fungicides) or when sizes are present that are difficult to degrade. However, because starch scarcely differs from cellulose in the cross-linking of the cellulose rings, chemical oxidation, if not well controlled, can damage the fibre.

Desizing is usually carried out in a pad-batch process, but discontinuous (e.g. jigger) and continuous (pad-steam) processes can also be applied. In the case of enzymatic desizing, pad-

steam is applied only for big lots and with enzymes that are stable under steaming conditions. After the reaction time, the fabric is thoroughly washed in hot water (95 °C).

### **Techniques for the removal of water-soluble sizes**

The removal of water-soluble sizes such as PVA, CMC and polyacrylates theoretically only requires washing with hot water and sodium carbonate. However, the washing efficiency can be increased by:

- adding suitable auxiliaries (wetting agents) to the desizing liquor (with some restrictions in the case of size recovery);
- allowing adequate time for immersion in the desizing liquor (this ensures maximum liquor pick-up and adequate time for the size to swell);
- washing thoroughly with hot water in order to remove the solubilised size.

In this case, the process is carried out in normal washing machines. Continuous washers are often used, but sometimes the treatment time may be too short to allow complete desizing. Pad-batch and pad-steam or discontinuous processes for prolonging the residence time are therefore also in use.

### **Techniques for the removal of water-soluble and insoluble sizes**

The 'oxidative desizing' technique mentioned above is applicable not only for water-insoluble sizing agents, but also for water-soluble ones. This technique is particularly useful for textile finishers dealing with many different types of fabrics and therefore sizing agents (see also Section 4.4.1).

#### **2.6.1.1.3 Mercerising**

Mercerising is carried out in order to improve the tensile strength, dimensional stability and lustre of cotton. Moreover, an improvement in dye uptake is obtained (a reduction of 30-50 % of dyestuff consumption can be achieved thanks to the increased level of exhaustion).

Mercerising can be carried out on yarn in hanks, woven and knitted fabric through one of the following different treatments:

- mercerising with tension;
- caustification (without tension);
- ammonia mercerising.

#### *Mercerising with tension*

Caustic soda mercerising is the most commonly applied mercerising technique (it is not applied to flax). Cotton is treated under tension in a solution of concentrated caustic soda (270-300 g NaOH/l, which equates to 170-350 g NaOH/kg of textile) for approximately 40-50 seconds.

During mercerising, the temperature is adjusted at low values (5-18 °C) when the lustre is the priority and at slightly higher levels when the improvement of the other characteristics is preferred. Because the reaction between caustic soda and cellulose is exothermic, cooling systems are applied to keep the temperature of the bath down.

Beside the conventional cold treatment, a hot mercerising process is also applied (for hanks and fabric). The material is soaked in a solution of caustic soda close to boiling point. After hot stretching, the fabric is cooled down to ambient temperature and washed under tension.

In order to ensure a homogeneous penetration of the liquor, especially when operating at ambient temperature, wetting agents are employed. Sulphonates mixed with non-ionic surfactants and phosphoric esters are the most commonly used.

#### *Caustification*

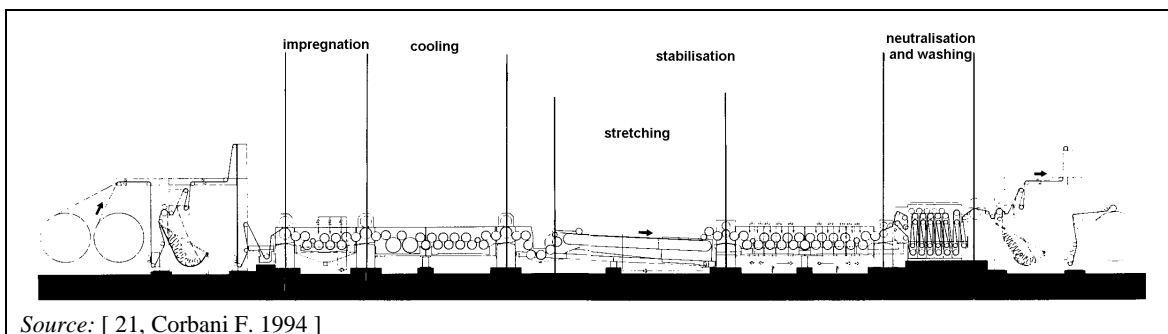
In the caustification process, the material is treated at 20-30 °C with caustic soda at lower concentrations (145-190 g/l) without applying tension. The material is allowed to shrink, thus improving the dye absorption.

#### *Ammonia mercerising*

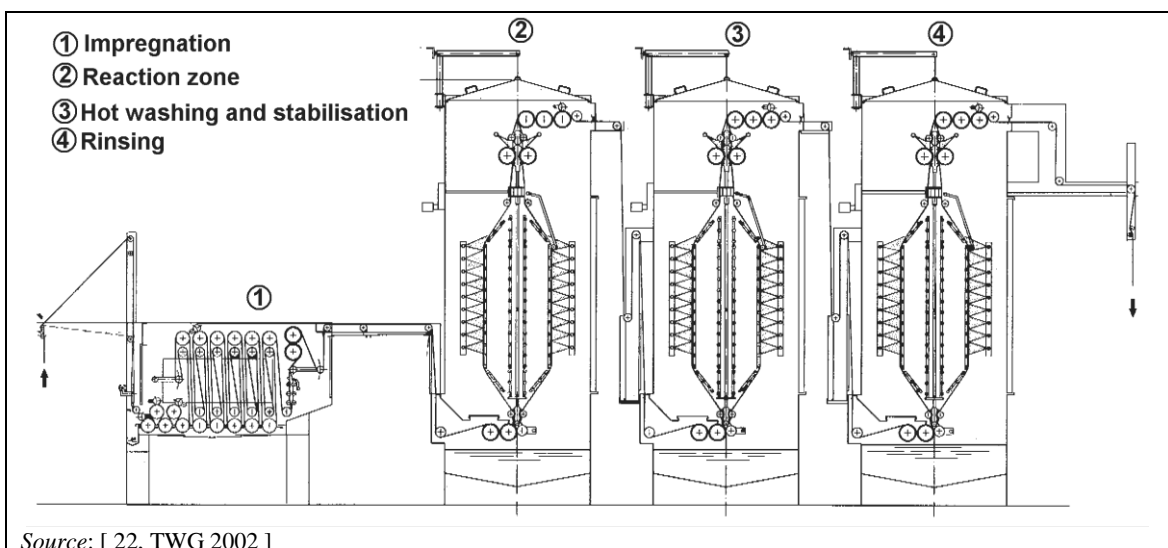
Cotton yarn and fabric can be treated with anhydrous liquid ammonia as an alternative to caustic soda. Effects similar to mercerising are obtained, although the lustre grade is inferior to caustic soda mercerising. Traces of ammonia have to be removed, preferably with dry heat treatment followed by steaming.

This method is not widely used. Only one plant of the data collection reported using this method [ 50, TWG 2019 ].

Two examples of mercerising machines are shown below, one for woven fabric (Figure 2.10) and one for knitted fabric in tubular form (Figure 2.11).



**Figure 2.10: Example of mercerising equipment for woven fabric**



**Figure 2.11: Example of mercerising equipment for knitted fabric in tubular form**



### 2.6.1.1.4 Scouring

Scouring (also known as boiling-off or kier boiling) is aimed at the extraction of impurities present on the raw fibre or picked up at a later stage such as:

- pectins;
- fat and waxes;
- proteins;
- inorganic substances such as alkali metal salts, calcium and magnesium phosphates, aluminium and iron oxides;
- sizes (when scouring is carried out on woven fabric before desizing);
- residual sizes and sizing degradation products (when scouring is carried out on woven fabric after desizing).

Scouring can be carried out as a separate step of the process or in combination with other treatments (usually bleaching or desizing) on all kind of substrates: woven fabric (sized or desized), knitted fabric and yarn.

For yarn and knitted fabric, scouring is usually a batch process which is carried out in the same equipment that will subsequently be used for dyeing (mainly autoclaves or hank dyeing machines for yarn and overflows, jets, etc. for knitted fabric). Woven fabric is scoured in continuous mode using the pad-steam process.

The action of scouring is performed by the alkali (sodium hydroxide or sodium carbonate) together with auxiliaries that include:

- non-ionic (alcohol ethoxylates, alkylphenol ethoxylates) and anionic (alkyl sulphonates, phosphates, carboxylates) surfactants;
- NTA, EDTA, DTPA, gluconic acid, phosphonic acids as complexing agents, which are used to remove metal ions (and, in particular, iron oxides, which catalyse the degradation reaction of cellulose when bleaching with hydrogen peroxide);
- polyacrylates and phosphonates as special surfactant-free dispersing agents;
- sulphite and hydrosulphite as reducing agents (to avoid the risk of formation of oxycellulose when bleaching with hydrogen peroxide).

### 2.6.1.1.5 Bleaching

After scouring, cotton becomes more hydrophilic. However, the original colour stays unchanged due to coloured matter that cannot be completely removed by washing and alkaline extraction.

When the material has to be dyed in dark colours, it can be directly dyed without the need for bleaching. In contrast, bleaching is an obligatory step when the fibre has to be dyed in pastel colours or when it will need to be subsequently printed. In some cases, even with dark colours a pre-bleaching step may be needed, but this is not a full bleaching treatment.

Bleaching can be performed on all kinds of make-ups (yarn, woven and knitted fabric).

The most frequently used bleaches for cellulosic fibres are oxidative bleaches, namely hydrogen peroxide ( $H_2O_2$ ). Sodium hypochlorite ( $NaClO$ ) and sodium chlorite ( $NaClO_2$ ) are still used by a small number of installations.

Apart from these, peracetic acid is also applicable [ 23, Schönberger H. 1994 ]. Also, optical brightening agents are commonly used to obtain a whitening effect.

Out of the 52 plants from the data collection (see Section 3.1) carrying out bleaching, only one reported using sodium hypochlorite. Four plants use sodium chlorite, five use sodium dithionite, one uses paracetic acid and two apply enzyme bleaching. The rest use hydrogen peroxide [50, TWG 2019].

#### *Bleaching with hydrogen peroxide*

Bleaching can be carried out as a single treatment or in combination with other treatments (e.g. bleaching/scouring or bleaching/scouring/desizing can be carried out as single operations).

The textile is treated in a solution containing hydrogen peroxide, caustic soda and hydrogen peroxide stabilisers at pH 10.5-12 (the optimal pH for scavenging of the  $\text{OH}^*$  radical is 11.2, as described in Section 4.4.7.2). Investigations ([24, Bettens L. 1995]) have shown that the bleaching agent of peroxide is not the anion  $\text{HOO}^-$ , but the dioxide radical anion  $\text{OO}^*$  (also known as superoxide). In competition with the formation of the bleaching agent, the  $\text{OH}^*$  radical is formed, which is responsible for attacking and depolymerising the cellulose fibre. The formation of the  $\text{OH}^*$  radical is catalysed by metals such as iron, manganese and copper. The prevention of catalytic damage as a consequence of uncontrolled formation of  $\text{OH}^*$  is mostly taken care of by using complex formers that inactivate the catalyst (stabilisers). Sodium silicate together with Mg salts ( $\text{MgCl}_2$  or  $\text{MgSO}_4$ ) and sequestering/complexing agents (EDTA, DTPA, NTA, gluconates, phosphonates and polyacrylates) are commonly used as stabilisers (see also Section 8.1.5 for more information about stabilisers and Sections 4.1.6.9.2 and 4.4.7.2 for alternative techniques).

Other auxiliaries used in hydrogen peroxide bleaching are surfactants with emulsifying, dispersing and wetting properties. Employed surfactants are usually mixtures of anionic compounds (alkyl sulphonates and alkyl aryl sulphonates) with non-ionic compounds such as alcohol ethoxylates or the biologically degradable fatty alcohol ethoxylates [10, Ullmann's 2011].

Operating temperatures can vary over a wide range from ambient to high temperature. Nonetheless, a good bleaching action occurs when operating at around 60-90 °C.

Bleaching with hydrogen peroxide in neutral conditions (pH range of 6.5-8) is also possible in some cases (e.g. when treating cotton in blends with alkali-sensitive fibres such as wool). At these pH conditions, activators are required to prompt the bleaching activity. Note that below pH 6.5  $\text{H}_2\text{O}_2$  decomposes into  $\text{H}_2\text{O}$  and  $\text{O}_2$  by  $\text{HOO}^- / \text{O}_2^*$  disproportionation. Under these conditions, hydrogen peroxide is wasted (production of inactive  $\text{O}_2$  gas).

A wide range of bleaching processes can be used, including cold pad-batch (see description of the process in Section 2.7.3.1), bleaching under steaming conditions and bleaching processes in long baths.

Because the bleaching agent of peroxide is anionic in nature (hydrophilic behaviour), it is not possible with this bleaching method to selectively destroy the coloured hydrophobic material present on natural fibres without attacking the polymer itself.

#### *Bleaching with sodium hypochlorite*

The high reactivity of this bleaching agent imposes softer operating conditions than hydrogen peroxide (pH 9-11 and temperatures not above 30 °C). Otherwise, there is a risk of damage to the cellulose fibre.

The bleaching stage is followed by an anti-chlorine treatment in order to completely eliminate the hypochlorite and decompose the chloroamines generated during bleaching.

Bleaching with sodium hypochlorite can be carried out in batch (e.g. overflow, jet, jigger, winch beck), semi-continuous (pad-batch) or continuous mode. A two-stage process is also in use in which hypochlorite and hydrogen peroxide are used.

The use of hypochlorite as a bleaching agent is in decline for ecological reasons. It is still applied for yarn and knitted fabric when a high degree of whiteness is required, for articles that need to remain white (e.g. linen) or require a white background or in processes where the initial dye is removed with a bleach treatment (see also Section 4.4.7.1 for alternative techniques).

### *Bleaching with sodium chlorite/chlorate*

Chlorite/chlorate bleaching, although in decline, is still applied for synthetic fibres, cotton, flax and other cellulosic fibres, often in combination with hydrogen peroxide.

The bleaching agent is chlorine dioxide gas ( $\text{ClO}_2$ ), which follows a completely different working mechanism to hydrogen peroxide. Whereas the superoxide radical ion in hydrogen peroxide is hydrophilic and therefore works preferentially in the hydrophilic region of the fibre (attack of the fibre polymer),  $\text{ClO}_2$  absorbs preferentially on the hydrophobic associated material, such as the woody part of bast fibres. For this reason, it is an excellent bleaching agent (ensuring a high degree of whiteness and no risk of damage of the fibre) especially for synthetic fibres and for bast fibres such as flax where, compared to cotton, there is a higher percentage of hydrophobic impurities.

Because chlorine dioxide is unstable as a gas and can only be stored as a solution of approximately 1 % in water, it is generated on site as an aqueous solution. There are two  $\text{ClO}_2$  precursor chemicals currently in general industrial use, namely sodium chlorite and sodium chlorate. Although sodium chlorate is considerably less expensive than sodium chlorite, it is more difficult and expensive to convert to  $\text{ClO}_2$ , which explains why it is less commonly used.

Both sodium chlorite and sodium chlorate are used in strong acid conditions (pH 3.5-4 by adding formic or acetic acid). Chlorine dioxide solutions have a significant corrosive action on construction materials including stainless steel. Sodium nitrate is used as a corrosion inhibitor to protect the stainless steel parts of equipment. It is also necessary to select detergent/wetting agents that can resist acidic conditions. On the other hand, sequestering agents are not necessary because the oxalic acid used for acidification also serves for sequestering metals. The order of introduction of the different auxiliaries has to be controlled to avoid direct contact between the concentrated sodium chlorite/chlorate solution and acids.

The textile material is bleached by padding or in long bath processes. The temperature is normally kept at 95 °C, but cold procedures have also been developed to diminish toxicity and corrosion problems, using formaldehyde as an activator for sodium chlorite.

The advantages of chlorine dioxide bleaching are the high degree of whiteness and the fact that there is no risk of damage to the fibre. The main disadvantages are the high stresses to which the equipment is subjected and the chlorine residues that may be left on the fibre, depending on the way chlorite (or chlorate) is produced and activated. Technologies using hydrogen peroxide as the reducing agent of sodium chlorate are available to produce  $\text{ClO}_2$  without generation of AOX.

### *Bleaching with peracetic acid*

Peracetic acid is produced from acetic acid and hydrogen peroxide. It can be purchased as ready-made product or produced *in situ*. Its optimal bleaching action is reached only in a very narrow pH range between 7 and 8. Below pH 7 the degree of whiteness decreases sharply and above pH 9 depolymerisation of the fibre occurs with consequent damage of the fibre.

Peracetic acid is sometimes applied for synthetic fibres (e.g. polyamide) where hydrogen peroxide cannot be used.

## **2.6.1.2 Environmental issues**

The main environmental issues associated with cotton and other cellulosic fibre pretreatment arise from emissions to water.

The characteristics of the emissions vary according to a number of factors: the make-up, the sequence adopted, the fact that some treatments are often combined in a single step, etc.

The most relevant issues are highlighted below for the various operations involved in pretreatment.

#### 2.6.1.2.1 Desizing and scouring

In a typical mill processing cotton or cotton-blend woven fabric, desizing represents the main emission source in the overall process. As already stated in Section 2.5.1.2, the washing water from desizing may contain up to 70 % of the total COD load in the final effluent, especially in the case of native sizing agents. Neither enzymatic nor oxidative desizing allows size recovery, while for some synthetic sizing agents size recovery is technically feasible, but difficult to apply for companies working on commission (see also Section 4.4.8.1).

Compared to woven cotton fabric, the removal of impurities from yarn and knitted fabric is less significant in terms of pollutant load. Nevertheless, two issues are the COD load associated with the removal of knitting oils (for knitted fabric), spinning oils and preparation agents (when cotton is in the blend with synthetic fibres) as well as the biodegradability of these compounds. Substances such as synthetic ester oils are readily emulsified or soluble in water and easily biodegraded. More problems are posed by the presence of substances that are difficult to emulsify and poorly biodegradable such as silicone oils, which are found in elastane blends with cotton or polyamide.

#### 2.6.1.2.2 Mercerising

Mercerising is responsible for a large amount of strong alkali that is discharged in waste water and needs to be neutralised. The corresponding salt is formed after neutralisation. In this respect, the cold process involves higher emission loads than the hot one. In order to allow the required retention time and make the cooling of the bath in continuous mode possible, a portion of the bath needs to be removed and cooled down in continuous mode. This means that higher volumes of bath are necessary in cold mercerising, which also result in higher emissions if the caustic soda is not recovered. Mercerising baths are usually recovered and reused. When this is not possible, they are used as alkali in other preparation treatments (caustic soda recovery is discussed in Section 4.4.8.2).

#### 2.6.1.2.3 Bleaching with hydrogen peroxide

The decomposition of hydrogen peroxide, which takes place during the bleaching reaction, forms only water and oxygen. However, environmental concerns associated with the use of stabilisers have to be taken into account (see Section 8.1.5). These products may contain complexing agents such as EDTA and DTPA with poor bio-eliminability, which may pass undegraded through the waste water treatment systems. Their ability to form very stable complexes with metal makes the problem even more serious because they can mobilise heavy metals present in the effluent and release them in the receiving water (see also Sections 4.1.6.9.2 and 4.4.7.2 for alternative techniques).

It has been reported ([ 4, EURATEX 2000 ]) that, depending on concentration, pH, time and temperature, effluents containing inorganic chlorides (e.g. NaCl from dyeing and printing, MgCl<sub>2</sub> from finishing) can be oxidised to their chlorites/hypochlorites when they are mixed with hydrogen peroxide bleach waste water. In this way, AOX may be found in waste water even if bleaching is carried out without chlorine-based bleaching agents. However, experimental measurements have shown that this does not play an important role, if any [ 23, Schönberger H. 1994 ].

### 2.6.1.2.4 Bleaching with sodium hypochlorite

For ecological reasons the use of sodium hypochlorite is now limited in Europe to just a few particular cases, connected with knitted fabric and, in some cases, bleaching of yarn when a high degree of whiteness is required. Bleaching with sodium hypochlorite leads, in fact, to secondary reactions that form organic halogen compounds, commonly quantified as AOX.

Trichloromethane (which is suspected of being carcinogenic) accounts for the bulk of the compounds formed, but other chlorinating subsidiary reactions might occur, besides the haloform reaction (see also Section 4.4.7.1).

When bleaching with hypochlorite, emissions of chlorine to air may also occur (although only under strongly acidic conditions [[22, TWG 2002](#)]).

According to the Institute of Applied Environmental Research (Stockholm University), in 1991-1992 dioxins were found in sludge from a textile plant that bleached with sodium hypochlorite. Further investigations showed that pentachlorophenol was present in the hypochlorite [[9, TWG 2001](#)].

### 2.6.1.2.5 Bleaching with sodium chlorite

Sodium chlorite bleaching may also be responsible for AOX generation in the waste water. However, compared to sodium hypochlorite, the amount of AOX formed during chlorite bleaching is much lower (on average only 10 % to a maximum of 20 % of the amount of AOX generated by hypochlorite) and it is not correlated with sodium chlorite concentration or with temperature [[23, Schönberger H. 1994](#)]. Investigations have shown that the formation of AOX is not originated by the sodium chlorite itself, but rather by the chlorine or hypochlorite that is present as an impurity or is used as the activating agent.

As already mentioned, handling and storage of sodium chlorite need particular attention because of toxicity and corrosion risks. Mixtures of sodium chlorite with combustible substances or reducing agents can constitute an explosion hazard, especially when they are subject to heat, friction or impact. Sodium chlorite forms chlorine dioxide when brought into contact with acids. Moreover, sodium chlorite decomposition produces oxygen, which supports combustion.

## 2.6.2 Pretreatments of wool before colouring

Typical wet treatments applied on wool fibre before dyeing are:

- carbonising;
- washing (scouring);
- fulling;
- bleaching.

Other possible treatments are those that fall under the definition of anti-felt and stabilisation treatments. Although they are often carried out before dyeing, they are not obligatory preparation steps. For this reason, they are described under finishing operations (Section 2.9.2.8).

### 2.6.2.1 Principal manufacturing processes

#### 2.6.2.1.1 Carbonising

Sometimes scoured wool contains vegetable impurities that cannot be completely removed through mechanical operations. Sulphuric acid is the chemical substance used for destroying these vegetable particles and the process is called carbonising.

Carbonising can be carried out on floc/loose fibre or on fabric (this operation is not applied in the carpet sector).

*Loose fibre carbonising* is performed only on fibres that are later used to produce fine fabric for garments (worsted fabrics) and usually takes place at the scouring mill.

In typical equipment for carbonisation of loose fibre, the still damp scoured wool is soaked in a solution containing 6-9 % mineral acid (generally sulphuric acid). Excess acid and water are removed by pressing or by centrifugation until on average 5-7.5 % sulphuric acid and 50-65 % water remain. The fibres are then dried at 65-90 °C to concentrate the acid and baked at 105-130 °C (carbonising).

As soon as the wool is dried, it is fed into a machine, which consists of two counter-rotating rolls. These rolls crush the carbonised particles into very small fragments, which are then easily removed. The addition of small quantities of detergent to the sulphuric acid improves the yield and reduces the attack on the wool. In order to prevent the fibre from being gradually degraded, the pH is finally set to 6 by neutralisation with sodium acetate or ammonia.

Sulphuric acid can be replaced by gaseous HCl or by aluminium chloride. The latter releases HCl when it is heated: this method is useful for the carbonisation of wool/synthetic fibre mixtures, such as wool/PES, that are too sensitive to sulphuric acid.

After carbonising, the fibre can be carded and then spun before being dyed or it can be dyed directly in floc form.

*Fabric carbonising* is typical for woollen fabrics. The operation can be carried out by either the traditional system (see Figure 2.12 below) or the solvent-based 'Carbosol' system (see Figure 2.13).

The conventional procedure is largely similar to that used for loose fibre. The fabric can be previously soaked in a water or solvent bath and squeezed, but this step is optional. Then it is impregnated in a concentrated sulphuric acid solution (acidification) and squeezed (hydroextraction) before passing through the carbonising chamber. The carbonised particles are then removed by mechanical action and subsequent washing. In modern carbonising plants, all these steps are carried out in continuous mode.

The 'Carbosol' process uses an organic solvent instead of water. The equipment consists of three units. In the first one the fabric is impregnated and scoured with perchloroethylene, in the second the material is soaked in the sulphuric acid solution and in the third carbonising and solvent evaporation take place. At this stage, the perchloroethylene is recovered by distillation in a closed loop.

The 'Carbosol' system is reported to have several technical advantages over the traditional process. Mainly, the level of acidity of the fabric after carbonising is much lower and the risk of damage to the wool fibre is reduced.

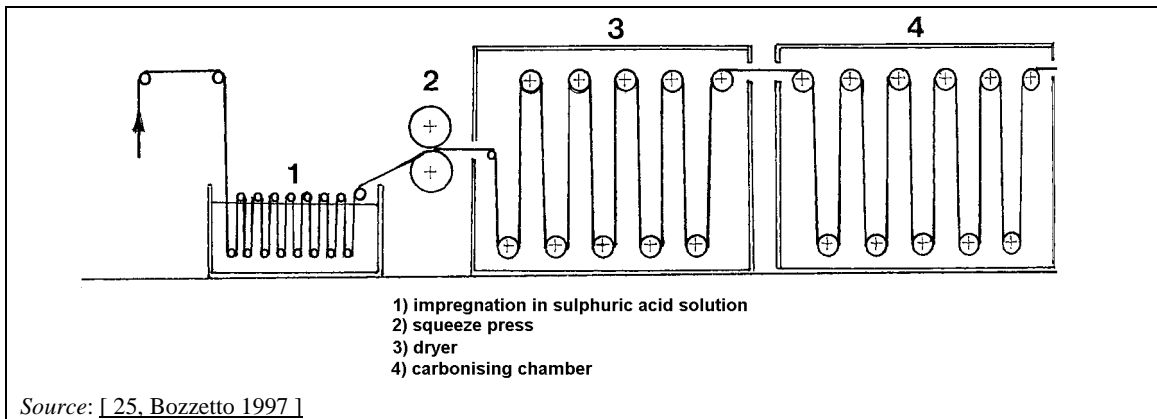


Figure 2.12: Representation of a conventional carbonising installation

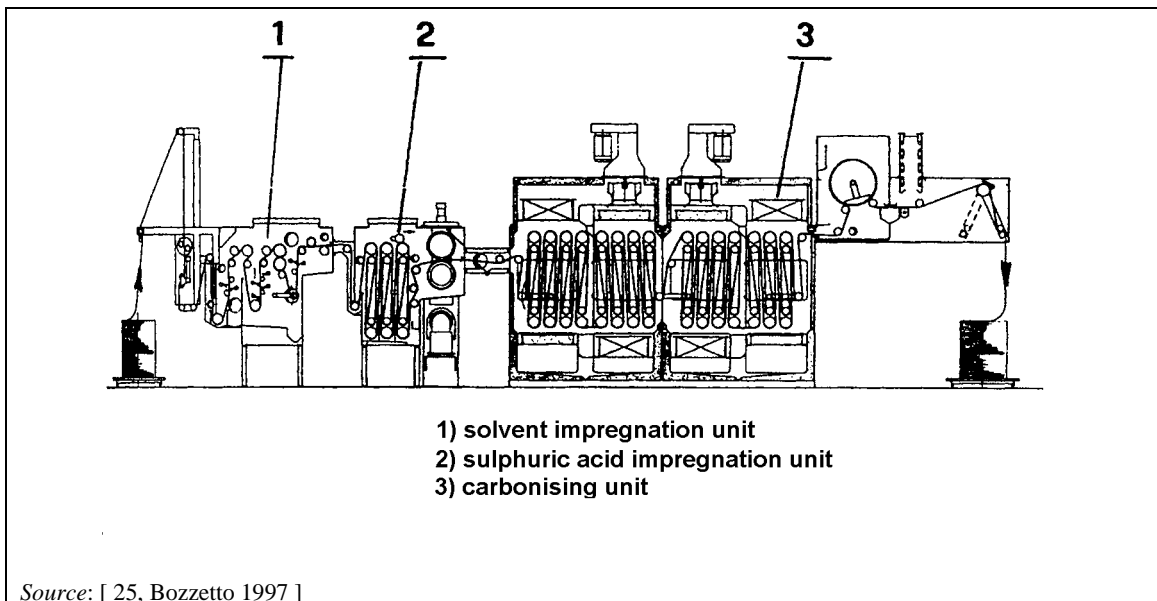


Figure 2.13: 'Carbosol' system

### 2.6.2.1.2 Scouring

Both *yarn* and *fabric* contain, besides accidental impurities, a certain amount of spinning oils and in some cases also sizing agents such as CMC and PVA. All these substances are usually removed before dyeing in order to make the fibre more hydrophilic and allow the penetration of the fibre by dyestuffs. However, this operation is not always necessary. In some cases, if the preparation agents are applied in small amounts and they do not interfere with the dyeing process, a separate scouring/washing step can be omitted.

As pointed out in Section 2.4.1, the percentage of spinning oils on woollen wool is relevant and it is always above 5 %, while on worsted wool it never reaches 2 %.

Typical substances that have to be removed by scouring can be classified as follows:

- Soluble in water.
- Insoluble in water, but emulsifiable thanks to the action of surfactants.
- Insoluble in water and non-emulsifiable (or difficult to emulsify) with surfactants. These substances can be removed only by using organic solvents (in general, halogenated solvents like perchloroethylene).

As a result, the material can be washed (scoured):

- with water; or
- with solvent (dry cleaning).

*Water washing* is carried out in neutral or weakly alkaline conditions (by sodium carbonate or bicarbonate) in the presence of detergents. Commonly used detergents are mixtures of anionic and non-ionic surfactants such as alkyl sulphates and fatty alcohols. In wool carpet yarn production, the scouring process can include simultaneous chemical setting of yarn twist with reductive agents (sodium metabisulphite) and/or application of mothproofing agents (see also Section 2.13.5.1).

Water scouring is normally a batch operation which is carried out in the equipment in which the textile material will be subsequently dyed. This means that an autoclave is the commonly used equipment for yarn, while jets and overflows are the machines typically applied for fabric. In this respect, the carpet sector is an exception. Wool yarn for carpet is scoured on a continuous or semi-continuous basis in tape scouring machines (hanks) or in ‘package to package’ scouring machines (package yarn), where the yarn is passed through a series of interconnected bowls.

*Dry cleaning* is less common and is applied when the fabric is heavily soiled and stained with oils from the weaving or knitting process. The most widely used solvent is perchloroethylene. In some cases, water and surfactants are added to the solvent to provide a softening effect.

Solvent washing can be carried out either in discontinuous mode in a tumbler (generally for knitted fabric) or in continuous mode in open-width systems (for woven and knitted fabric). Impurities are carried away by the solvent, which is continuously purified and recycled in a closed loop (see also Section 2.11.2).

#### 2.6.2.1.3 Fulling

This treatment takes advantage of the typical felting tendency of wool fibre when it is submitted to friction under hot humid conditions and is a typical pretreatment for woollen fabric.

It is usually carried out after carbonising, but in some cases (e.g. heavy woollen fabrics) it can be done directly on raw fabric. The material is kept in circulation in a bath containing fulling auxiliaries. Both acids (pH < 4.5) and alkalis (pH > 8) speed up the fulling process. Fulling auxiliaries available on the market, however, also produce excellent results under neutral conditions. As a result, fulling either in acidic or alkaline conditions is becoming less common. After fulling, the fabric is washed.

Machines specially designed for this process are still in use. However, they have been largely replaced by multifunctional machines, where both fulling and washing can be carried out by simply adjusting the set-up of the equipment.



### 2.6.2.1.4 Bleaching

Wool is bleached with hydrogen peroxide (sodium hypochlorite may discolour and damage the wool). An additional reductive bleaching is, however, indispensable for achieving high levels of whiteness (full bleach). A typical reductive bleaching agent is sodium dithionite (hydrosulphite), which is often used in combination with optical brighteners to enhance its effect.

In the oxidative bleaching step, hydrogen peroxide is applied in the presence of alkali and stabilisers, which slow down the decomposition of the hydrogen peroxide (see also Section 8.1.5).

When wool has been previously subjected to an anti-felt treatment it is preferable to use hydrogen peroxide in weakly acidic conditions.

### 2.6.2.2 Environmental issues

Wool pretreatment gives rise mainly to water emissions, although there are also specific operations (e.g. carbonising with the 'Carbosol' system and dry cleaning) where halogenated (mainly perchloroethylene) solvents are employed. The use of halogenated organic solvents can produce not only emissions to air, but also contamination of soil and groundwater if they are not handled and stored using the necessary precautions. Preventive and end-of-pipe measures include closed-loop equipment and in-loop destruction of the pollutants by means of advanced oxidation processes (e.g. Fenton reaction). See Sections 4.2.1, 4.4.1 and 4.1.7.3.4.1 for more detailed information. The process also involves the generation of exhausted active carbon from the solvent recovery system. This solid waste has to be handled separately from other waste material and disposed of as hazardous waste or sent to specialised companies for regeneration.

Due to the predominantly batch nature of wool pretreatment operations for all types of make-ups, the resulting emissions will be discontinuous and with concentration levels largely influenced by the liquor ratios used. An exception is represented by carpet yarn which can be scoured/bleached and mothproofed on tape or 'package to package' scouring machines, giving rise to continuous flows.

The pollutants that can be found in the waste water originate in part from the impurities that are already present on the fibre when it enters the process sequence and in part from the chemicals and auxiliaries used in the process.

#### **Pollution originating from impurities present on the raw material**

Residues of pesticides used to prevent the sheep becoming infested with external parasites can still be found on scoured wool in amounts which depend on the efficiency of the scouring process. These are mainly organophosphates (OPs) and synthetic pyrethroid (SP) insecticides and insect growth regulators (IGRs), but detectable residues of organochlorine pesticides (OCs) can be observed. They partition between the fibre and the water according to their stronger or weaker lipophilic character and, as a consequence, traces of these compounds are released in the waste water. More information about ectoparasiticides can be found in Sections 2.1.1.10 and 2.3.1.2.

Note that because of their steam volatility some pesticides (OPs) end up in the emissions to air from open machines.

Spinning lubricants (see Section 8.1.2.3), knitting oils (see Section 8.1.2.5) and other preparation agents also represent an important issue in wool pretreatment. These substances are removed during the scouring process, contributing to the COD load and aquatic toxicity in the final effluent. The main concerns (especially in goods imported from third countries outside the EU) are about:

- poorly refined mineral oils (content of aromatic hydrocarbons);
- APEO (non-biodegradable and giving rise to toxic metabolites);
- silicones (non-biodegradable and difficult to remove without scouring assistants);
- biocides (toxic to aquatic life).

The dry spinning route in the carpet sector, described in Section 2.13.5.1, represents one exception because in this case spinning lubricants do not reach the water effluent.

### **Pollution originating from chemicals and auxiliaries used in the process**

Considerable amounts of surfactants are used in pretreatment as detergents, wetting agents, etc. Surfactants with good biodegradability and an acceptable performance are available (see Section 4.1.6.9). The environmental issues arising from surfactants in common use are discussed in Section 8.1.1.

Other pollutants of concern that may be found in water effluent from pretreatment activities are:

- reducing agents from bleaching treatments and chemical setting of carpet wool yarn (sodium metabisulphite): they contribute to oxygen demand in the waste water;
- poorly bio-eliminable complexing agents (e.g. EDTA, DTPA, phosphonates) from hydrogen peroxide stabilisers, etc.;
- insect-resist agents in wool carpet yarn production.

More details regarding environmental issues associated with the above-mentioned substances are given elsewhere in this document, in particular in Section 2.6.1.2 and Section 8.1.5.

## **2.6.3 Pretreatment of silk**

[ 26, Italy 2001 ]

### **2.6.3.1 Scouring**

To prepare a silk yarn for dyeing and silk fabrics for dyeing and printing, it is necessary to partially or completely remove sericin, as well as natural oils and organic impurities. Depending on the percentage of sericin removed during scouring (sericin is present in raw silk in a ratio between 20 % to 25 %), the end-product is defined as unscoured (used only for shirts and suits), 'souple' or degummed.

Scouring can be carried out either on the yarn or on the fabric. It is easier to remove sericin more evenly by performing the operation on the yarn itself. Nevertheless, the operation is generally carried out on the fabric, in order to exploit the protective action of this 'natural size' against possible damage during weaving.

The scouring treatment can be carried out in a neutral, acidic or alkaline solution, depending on the desired results. At the industrial level, treatment in alkaline conditions is by far the most common. It is extremely important to control the temperature.

Scouring baths present a high total organic charge; the concentration of nitrogen organic components in particular is high.

#### *'Unscoured' silk*

The process to produce 'unscoured' silk consists of removing from raw silk fabrics all residual substances from previous operations, with a minimal elimination of sericin (1-2 %), so that the fabric keeps the characteristic stiffness. The operation is carried out in a slightly alkaline soap bath at low temperature.

### *'Souple' silk*

The process is carried out on weft yarns under acidic conditions. The loss of weight is approximately 10 %.

### *Degummed silk*

This treatment is carried out on both yarns and fabrics and ensures a complete elimination of sericin, as well as substances added in previous operations, without modifying the fibroin.

Hydrolytic degradation of the sericin protein macromolecule can be obtained by simply using soaps, by using synthetic surfactants or mixtures of soaps and synthetic surfactants, by means of an enzymatic treatment, or by treating the silk in water at high temperature and under pressure.

In the *degumming process with soap*, yarn and fabric are plunged into two baths (degumming baths). Each bath contains green soap at different concentrations. The treatment is followed by washing with ammonia and rinsing. The process temperature varies between 95 °C and 98 °C. The soap concentration in the degumming bath varies between 10 g/l and 15 g/l. On average, the entire treatment lasts for 2 hours. It is possible to reuse exhausted baths after appropriate addition of soap.

*Degumming with synthetic detergents* implies the partial or total replacement of soap with synthetic non-ionic surfactants (e.g. ethoxylate fatty alcohol). It is also possible to combine a degumming treatment with an oxidising or reducing bleaching and, in some cases, even with dyeing, thus improving water and energy saving. Generally, alkali and detergent mixtures are used at temperatures around 95-98 °C. Such a treatment is suited to continuous processing.

*Degumming under pressure at high temperature* is a specific treatment essentially used to degum yarns. It is necessary to prepare an aqueous bath without surfactants and the temperature should be between 110 °C and 140 °C. A post-treatment washing step is required to eliminate substances used in previous processes.

### 2.6.3.2 Weighting

The weighting operation is carried out mostly on yarns to promote recovery of the weight lost after the removal of the sericin. The treatment consists of the deposition of tin salts or of grafting polymer chains to the functional groups of the fibroin protein chain.

Weighting is defined as 'equal' if the final substrate weight is the same as it was before degumming, and as 'higher' if the weight is higher. Weighted silk is different in touch and in draping. The most frequently applied procedure is a 'mix weighting' process.

#### *Weighting with minerals*

The silk yarn undergoes a treatment using tin tetrachloride in baths at different concentrations (strong or weak baths) in an acidic medium. In a strong bath, silk can increase its weight by about 10 % simply by absorbing the salt. The procedure is followed by accurate washing cycles to eliminate unfixed salt and to hydrolyse the salt present on the fibre. Such operations can be repeated to further increase the silk weight. To ensure fixation of tin salts, weighting is completed with a treatment in a sodium phosphate bi-basic solution, followed by a second treatment in sodium silicate.

Disadvantages of this procedure are the long processing time and the high water and energy consumption. The high amount of tin in the waste water is an environmentally undesirable effect of this process.

#### *Weighting with vinyl monomers*

Grafting vinyl monomers onto silk represents an alternative to the traditional mineral weighting. Such a method not only allows the desired weight increase to be achieved, but also improves

silk characteristics and performance. Co-polymerisation with vinyl monomers is carried out using radical activation methods (redox systems, UV,  $\gamma$  rays and so on).

Methacrylamide (MAA) is one of the most frequently applied monomers at the industrial level. MAA weighting is a simple application. Radical activation is obtained through ammonia or potassium persulphate. Other radical activators, which consist of redox systems described in the literature, are not currently applied at the industrial level.

Silk dyeing behaviour can be modified through the weighting treatment. Studies prove how the dyeing affinity of silk weighted with MAA towards the most widely used dyes changes according to the percentage of acquired weight. They also show that wet-fastness is reduced in dyeing after weighting.

For the weighting of silk for ties, methacrylamide is the only technique used by industry; at present no MAA substitute is available on the market.

#### *Mix weighting*

To achieve a hybrid of the final characteristics of compounds subjected to mineral or MAA weighting, a fairly widely used weighting process at the industrial level is mix weighting with tin/MAA.

### **2.6.4 Pretreatment of synthetic material**

#### **2.6.4.1 Principal manufacturing processes**

Typical operations before colouring are washing and thermofixing (heat-setting).

Washing is necessary to remove from the yarn the preparation agents that have been applied to its surface in the previous treatments (usually 2-3 %, but can be up to 4 % of the weight of the fibre). Most preparation agents (about 95 %) are removed at this stage (ethoxylated fatty alcohols are commonly used as emulsifying agents). Elastomeric fibres (elastane) are an exception because they contain preparation agents mainly made up of silicone oils in the order of 6-7 %. Silicones are more difficult to remove and partly still remain on the fibre (40 % of the initial add-on) after washing.

When pretreating woven fabric, the removal of sizing agents is a crucial step. The extraction of these substances is achieved thanks to the synergistic action of the following:

- Surfactants (non-ionic or mixtures of non-ionic and anionic): they act as wetting and emulsifying agents and promote the solubilisation of the size.
- Complexing agents (e.g. phosphonates): they are used when there is a risk of re-precipitation of the components of the sizing agents. An increase in hardness level can occur, particularly in continuous lines when processing synthetic blends with cellulose fibres (characterised by the presence of Ca, Fe and Mg salts as natural impurities).
- Alkali (caustic soda or sodium carbonate): the alkali is chosen according to the sizing agent employed (for example for the removal of sizing agents based on polyacrylate ammonium salts the use of caustic soda is obligatory, while a polyester sizing agent would precipitate in the same pH conditions).

Thermofixation is also another important operation in synthetic fibres pretreatment. Its position within the process can be different, depending on the make-up and the fibre. As a result, the following sequences are possible:

- thermofixation – washing – dyeing;
- washing – thermofixation – dyeing;
- washing – dyeing – thermofixation.

If white fabrics are to be produced, bleaching of the fabric may be necessary after thermofixation.

### 2.6.4.2 Environmental issues

Potentially harmful impurities and additives are already present on synthetic fibres before they are processed at the finishing mill and they account for a large fraction of the pollutant load coming from pretreatment.

Some of these impurities are produced during the manufacture of the fibre. They are polymer synthesis by-products such as unreacted monomers (for example caprolactam, in the production of PA 6) low-molecular-weight oligomers, and residual catalysts and they are emitted to air during thermal treatments.

Other substances are intentionally added to the fibre to improve subsequent processing. These are the preparation agents used in fibre and yarn manufacturing and the sizing agents.

The average amount of preparation agents applied on man-made fibres (except for elastomeric, where the load can be much higher) ranges between 2 % and 4 % of the weight of the fibre (see also Section 8.1.2).

When the textile is washed, about 80 % of these substances is released to the waste water and the remaining 20 % can be emitted to exhaust air in the subsequent high-temperature treatments (drying and thermofixation). Conversely, when thermofixation is carried out on the grey material before washing (which is the case when fine woven and knitted fabrics are processed), the main percentage of the pollutant load is found in the exhaust air.

Formaldehyde emissions from thermofixation or heat-setting are caused by the incomplete combustion of the natural gas used in the burners. The high temperatures lead to a higher load on the burners [ 58, EURATEX 2020 ], [ 352, Zietlow B. 2020 ].

During high-temperature treatments, the lower-molecular-weight components of the preparation agents (basically lubricants and surfactants) either decompose – resulting in smaller, more volatile molecules – or they react with each other, forming tar. Volatility and tar are undesirable effects because they lead to emissions to air and damage to the yarn.

However, thanks to considerable technological improvements achieved by the technology in the field of synthetic fibres, the fibres/filaments leaving the primary spinning process (fibre production) no longer cause fuming. The remaining problems are connected with those cases where, after the fibre/filament production, lubricants such as coning oils are added to the fibre at a rate of over 2 % or even 3 % of the yarn weight [ 27, VITO 2001 ].

The main concerns, as regards waste water, arise from the discharge of poorly or non-biodegradable substances such as mineral oils, ethylene oxide/propylene oxide adducts, silicone oils, hard surfactants, etc. Furthermore, biocides, which are normally contained in the aqueous formulations, contribute to the aquatic toxicity of the waste water.

Like for emissions to air, the main charging load in waste water also comes from the preparation agents (coning oils, overspray, etc.) that are applied to the fibre/filament after the primary spinning stage. These substances (secondary spinning agents) are applied in significantly higher amounts than primary spinning agents. Moreover, they usually have low affinity with water and are therefore difficult to remove.

For woven fabric, sizing agents also have to be considered. Sizing agents do not give rise to emissions to air during high-temperature treatments, but they may be responsible for poorly biodegradable substances and aquatic toxicity.

Information about alternative preparation agents for man-made fibres is given in Section 4.1.5.1.1.

## 2.7 Dyeing

In the following sections, the general principles of dyeing and the most commonly used dyeing techniques for the different fibres are described. For practical reasons, detailed information concerning dyeing auxiliaries, dyestuffs and dyeing equipment is given in specific annexes (namely Section 8.1.6, Section 8.2 and Section 8.3).

### 2.7.1 General principles of dyeing

Dyeing is a method for colouring a textile material in which a dye is applied to the substrate in a uniform manner to obtain an even shade with a performance and fastness appropriate to its final use. A dyestuff is a molecule which contains a chromophoric group (conjugated system) capable of interacting with light, thus giving the impression of colour.

Textile dyeing involves the use of a number of different chemicals and auxiliaries to assist the dyeing process. Some of them are process-specific, while others are also used in other operations. Some auxiliaries (e.g. dispersing agents) are already contained in the dyestuff formulation, but more commonly auxiliary agents are added at a later stage to the dye liquor. Since auxiliaries in general do not remain on the substrate after dyeing, they are ultimately found in the emissions.

Various dyeing techniques exist:

- spin or dope dyeing (also referred to as mass gel dyeing, in which a dye is incorporated in the synthetic fibre during its production (this technique is the most commonly applied process for PES, PA, PP and PAC fibres [127, TWD Fibres 2020]);
- pigment dyeing, in which an insoluble pigment, without affinity for the fibre, is deposited onto the textile substrate and then fixed with a binder;
- dyeing processes which involve the diffusion of a dissolved or at least partially dissolved dye into the fibre.

This last group of processes is the one that will be discussed in more detail in the following sections. From a molecular point of view, four different steps are involved:

- First, the dye, previously dissolved or dispersed in the dye liquor, diffuses from the liquor to the substrate.
- The second step consists of the accumulation of the dye on the surface of the textile material. This process is controlled by the affinity (substantivity) of the colourant for the fibre.
- The dye diffuses/migrates into the interior of the fibre until this is uniformly dyed. This step is much slower than the transport of the dissolved dye within the dye bath. The penetration of the dye into the fibre requires that the fibre itself is accessible. In the case of hydrophilic fibres the dye penetrates through the available micropores, while in hydrophobic fibres, whose molecular structure does not allow a continuous water phase, cavities need to be developed in order to make the penetration of the dye possible. In general, access to the fibre is enhanced by temperature. Hydrophobic fibres can only be penetrated by the dye above the glass transition temperature, which sometimes lies above 100 °C. During the diffusion into the micropores, an electrostatic barrier, which develops on the surface of the fibre, still has to be overcome. In some cases, large amounts of salt have to be added to the dye bath in order to reduce the electrostatic forces on the surface of the fibre and promote an even penetration of the dye.
- The dye is anchored (fixed) to suitable places within the substrate. Different mechanisms of fixation are known, ranging from chemical reaction of the dye with the

fibre to form a covalent bond (reactive dyes) to formation of Van der Waals and other short-range forces between the fibre and the dye (direct dyes). An important role is also played by hydrogen bonding responsible for long-, medium- and short-distance interactions between fibre and dyestuff, dyestuff and dyestuff, water and fibre and water and soluble substances present in the liquor, such as surfactants. This is more fully explained in Section 8.2.

## 2.7.2 Dyeing processes

Textiles can be coloured at any of several stages of the manufacturing process so the following colouring processes are possible:

- flock or stock dyeing;
- top dyeing: fibres are shaped in lightly twisted roving before dyeing;
- tow dyeing: it consists of dyeing the mono-filament material (called tow) produced during the manufacture of synthetic fibres;
- yarn dyeing;
- piece (e.g. woven, knitted and tufted cloths) dyeing;
- ready-made goods (finished garments, carpet rugs, bathroom sets, etc.).

Dyeing can be carried out in batch or in continuous/semi-continuous mode. The choice between the two processes depends on the type of make-up, the chosen class of dye, the equipment available and the cost involved. Both continuous and discontinuous dyeing involve the following steps:

- preparation of the dye;
- dyeing;
- fixation;
- washing and drying.

### 2.7.2.1 Batch dyeing

In batch dyeing (also called exhaustion dyeing), a certain amount of textile material is loaded into a dyeing machine and brought to equilibrium with a solution containing the dye and the auxiliaries over a period of minutes to hours.

The dyeing process starts with the absorption of the colourant onto the external surface of the fibre, then the diffusion and migration of the colourant through the fibre takes place. The use of chemicals and controlled temperatures accelerates and optimises exhaustion and fixation (rate/level) of the dye. When the dyeing is judged to be the right shade, the spent dye bath is drained and the textile material is washed to remove unfixated dyes and chemicals. Washing is usually carried out in the same equipment. However, separate washing machines can also be used in the case of fabric.

All these operations can be carried out with different degrees of automation. In fully automated dyehouses, all steps going from the preparation of recipes and laboratory trials to dyestuffs and chemicals feeding, material transportation, loading and unloading of the machines and control of dyeing parameters (e.g. level, heating, injection at selected speed, pH, temperature) are performed under computer guidance.



In a manual regime, the dyestuffs and chemicals are dosed and fed to the machines manually. A manual dyeing approach used for wool is to carry out trial laboratory dyeing on a sample of the particular fibre and then to apply 5-10 % less dye in the full-scale dyeing. The final shade is achieved by adding dye in small quantities to achieve the final shade. Depending on the dyestuffs, it may be necessary to cool the dye bath for each of these additions in order to promote even migration of the added dye. Shade matching is carried out by eye, the dyer comparing the dyed material with a reference pattern under standard illumination.

Dyeings which are 'overshade' can be corrected by stripping dyestuff from the fibre using an excess of levelling agent or reducing conditions, and then by adding further colour to achieve the correct shade. This is a very costly and polluting practice and is only used as a last resort in most dyehouses.

An important parameter in discontinuous dyeing is the *liquor ratio* of the equipment. This is the weight ratio between the total dry material and the total liquor. So, for example, a liquor ratio of 1:10 means 10 litres of water for 1 kg of textile material.

This parameter not only influences the amount of water and energy consumed in the dyeing process, but also plays an important role in the level of exhaustion of the dye and in the consumption of chemicals and auxiliaries.

The liquor ratio is related to the exhaustion level of the bath through the equation:  $E = K/(K+L)$ , where:

K (affinity) = 50 to 1 000 for various dye/fibre combinations;

L (liquor ratio) = 5 to 50 for various machines;

E (exhaustion) = 0.5 to 1 (50 % to 100 % exhaustion).

From this equation it can be inferred that when L increases, E decreases and less dye is absorbed onto the fibre when the equilibrium is reached. The effect is more pronounced on low-affinity dyes.

As stated earlier, the liquor ratio also has an influence on the levels of chemicals and auxiliaries consumption. Most chemicals and auxiliaries are dosed on the basis of the amount of bath (on the weight of the bath - o.w.b.) rather than the weight of the fibre (on the weight of the fibre - o.w.f.). For example, in a 1:5 liquor ratio, 50 g/l of salt will mean 250g/kg of fibre, but at a 1:40 liquor ratio, the same 50 g/l of salt corresponds to 2 kg/kg of fibre.

Dyeing machines vary greatly in their liquor ratios, depending also on the type of substrate to be dyed and its hydrophilicity. Equipment manufacturers provide a range of nominal liquor ratios for each type of machine. This is defined as the range of liquor ratios at which the machine can be operated when it is loaded at its optimum/maximum capacity. In each range the lowest values normally refer to synthetic fibres (PES is usually taken as the reference), while the highest figures apply to cotton. This is due to the lower amount of liquor retained by synthetic fibres compared to cotton.

Table 2.6 shows typical ranges of nominal liquor ratios for each type of machine. It should also be noted that each type of machine has its own limitations and range of applicability.

The features of a number of typical machines are described in more detail in Sections 8.3.1 to 8.3.4.1.2, while the latest developments in selected types of machines are reported in Sections 4.5.1.7 to 4.5.1.7.2.2.

**Table 2.6: Discontinuous dyeing equipment and liquor ratios**

Make-up		Process	Equipment	Liquor ratio
Loose/stock fibre (also card sliver and tow)		Loose stock dyeing	Autoclave (loose/stock dyeing)	1:4-1:12 <sup>(1)</sup>
Yarn	Bobbins/ cones	Yarn dyeing	Autoclave (package dyeing)	1:8-1:15
	Hank	Hank dyeing	Hank dyeing machines	1:12-1:25 <sup>(2)</sup>
Woven and knitted fabric, tufted carpet	Rope	Piece dyeing in rope form	Winch beck	1:15-1:40 <sup>(3)</sup>
			Overflow	1:12-1:20
			Jet for fabric for carpet	1:4-1:10 <sup>(3)</sup> 1:6-1:20 <sup>(3)</sup>
			Airflow	1:2-1:5 <sup>(4)</sup>
	Open-width	Piece dyeing in open-width form	Winch (only for carpet)	1:15-1:30 <sup>(3)</sup>
			Beam dyeing	1:8-1:10 <sup>(5)</sup>
			Beam + washing machine	1:10-1:15
			Jig dyeing	1:3-1:6 <sup>(5)</sup>
Ready-made goods (e.g. garments, rugs, bathroom sets)	Piece dyeing	Paddle	1:60 (not exceptional)	
		Drum	Very variable	

<sup>(1)</sup> [ 184, ENco 2001 ]  
<sup>(2)</sup> The typical range is 1:15-1:25. A liquor ratio of 1:12 has been reported for hank carpet wool (semi-worsted).  
<sup>(3)</sup> [ 28, GuT 2001 ]  
<sup>(4)</sup> According to one major supplier (THEN) and textile finishing companies.  
<sup>(5)</sup> [ 29, RIZA 1998 ]  
Source: [ 9, TWG 2001 ]

### 2.7.2.2 Continuous and semi-continuous dyeing

In continuous and semi-continuous dyeing processes, the dye liquor is applied to the textile either by impregnation (by means of foulards) or by using other application systems. Most commonly, textiles are fed continuously in open-width through a dip trough filled with dye liquor. The substrate absorbs an amount of dye solution before leaving the dip trough through rollers that control the pick-up of the dye. Surplus stripped dye flows back into the dye bath. In the carpet industry (and for open goods that must pick up and retain large volumes of liquor), thickening agents are added to the pad liquor to prevent dye migration. Moreover, special application systems are also encountered, where the dyestuff is poured, jet-sprayed, injected or applied in the form of foamed liquor (see Section 8.3.4.2).

Dye fixation is usually achieved in a subsequent stage using chemicals or heat (steam or dry heat). The final operation is washing, which is usually carried out in washing machinery at the end of the same line.

The only difference between continuous and semi-continuous processes is the fact that in semi-continuous dyeing the application of the dye is performed continuously by padding, while fixation and washing are discontinuous.

In general, dyes with low affinity are favoured in continuous dyeing to prevent tailing (attributable to undesirable exhaustion of the padding solution) and to make washing-off of the unfixed dye easier.

In continuous and semi-continuous processes, the liquor ratio is not of practical importance and it is not used as a parameter. In these processes, the factor to be taken into account is the *wet pick-up* % (grams of liquor picked up by 100 grams of substrate) and the concentration of the dye.

An overview of the most common techniques and machinery utilised in continuous and semi-continuous processes is given in Table 2.7.

**Table 2.7: Semi-continuous and continuous dyeing processes and equipment**

Make-up		Process		Equipment
Woven & knitted fabric, tufted carpet	Rope	Continuous		Padding machine for piece in rope form + J-box or conveyor + washing machine
	Open-width	Semi-continuous	Pad-batch (or Carp-O-Roll for carpet)	Padding machine + washing machine
			Pad-roll (or Carp-O-Roll for carpet)	Padding machine + washing machine
			Pad-jig	Padding machine + jigger + washing machine
		Continuous	Pad-steam	Padding machine <sup>(1)</sup> + steamer + washing machine
			Pad-dry	Padding machine <sup>(1)</sup> + stenter frame + washing machine
			Thermosol	See Section 8.3.4.2.6
	<sup>(1)</sup> Different applicators are used to dye carpets on continuous ranges (see also Section 8.3.4.2).			

### 2.7.3 Cellulose fibres dyeing

Cellulose fibres can be dyed with a wide range of dyes, namely:

- reactive dyes;
- direct dyes;
- vat dyes;
- sulphur dyes;
- azoic (naphthol) dyes.

The most common dyestuffs and dyeing techniques for cellulose fibres are summarised in Table 2.8 and are described in more detail further below.

Table 2.8: Summary of the most common dyes and dyeing techniques applied for cellulose fibres

Dyes	Chemicals and auxiliaries / typical application conditions	Technique
Reactive	<p>pH 9.5-11.5 by addition of sodium carbonate and/or sodium hydroxide.</p> <p>Salt is used to increase dye bath exhaustion: higher concentrations are used for low-affinity dyes and for deep shades.</p> <p>Application temperatures vary from 40 °C to 80 °C depending on the class of the dyestuff.</p> <p>In padding processes, urea or cyanoguanidine is usually added to the pad liquor (the process described in Section 4.5.2.6 does not need urea).</p> <p>After dyeing, the material is soaped and then washed off with addition of surfactants to remove unfixed dye.</p>	Batch
		Pad-batch
		Pad-steam
		Pad-dry
Direct	<p>Salt is used to increase bath exhaustion.</p> <p>Mixtures of non-ionic and anionic surfactants are used as wetting/dispersing agents.</p> <p>After-treatment is usually necessary to improve wet-fastness (possible use of fixative cationic agents, formaldehyde condensation products).</p>	Batch
		Pad-batch
		Pad-jig
		Pad-steam
Vat	<p>Alkali and reducing agents (sodium dithionite, sulphylic acid derivatives, thiourea dioxide, and other organic reducing agents) are applied to convert the dye to the sodium leuco form.</p> <p>Poorly degradable dispersants are present in the dye formulation and are further added in other steps of the process.</p> <p>Levelling agents are sometimes necessary.</p> <p>Temperature and the amount of salt and alkali required vary according to the nature of the dye.</p> <p>Dye is fixed to the fibre by oxidation, generally using hydrogen peroxide, but halogen-containing oxidising agents can also be used.</p> <p>After-treatment takes place in a weakly alkaline detergent liquor at boiling temperature.</p> <p>In continuous processes, anti-migration and wetting agents are used.</p>	Batch
		Pad-steam
Sulphur	<p>Reducing agents (Na<sub>2</sub>S, NaHS, glucose-based combination of reducing agents) and alkali are applied to convert the dye into soluble form, unless ready-for-use dyes are used.</p> <p>Dispersants and complexing agents are used in batch dyeing.</p> <p>In batch dyeing, the dye generally absorbs at 60-110 °C, while in the pad-steam process the material is padded at 20-30 °C and then subjected to steaming at 102-105 °C.</p> <p>Oxidation is carried out mainly with hydrogen peroxide, bromate and iodate.</p>	Batch
		Pad-steam
		Pad-dry/ pad-steam
Azoic	<p>Preparation of the naphtholate (caustic soda and, in some cases, addition of formaldehyde is required to stabilise the naphthol on the fibre).</p> <p>Impregnation of the naphtholate by exhaustion or padding processes.</p> <p>Preparation of the diazotised base (with NaNO<sub>2</sub> and HCl).</p> <p>Developing stage (the textile is passed through the cold developing bath or the developing solution is circulated through the stationary textile in the dyeing machine).</p>	Batch
		Padding methods

### 2.7.3.1 Reactive dyes

One third of dyes used for cellulose fibres are reactive dyes. They are mostly applied in the pad-batch and continuous processes for woven fabric, while batch processes are the most common for knitted fabric, loose stock and yarn.

In *batch dyeing*, dye, alkali (sodium hydroxide or sodium carbonate or bicarbonate) and salt are added to the dye bath in one step, at the start of the process, or stepwise. In the stepwise process, the alkali is added only after the dye has absorbed into the fibre. Its amount is determined by the reactivity of the system and the desired depth of shade (cold dyes are applied at lower pH compared to warm and hot dyes). Salt is added to improve bath exhaustion: the concentration employed depends on the substantivity of the dye and on the intensity of the shade. Higher concentrations are required for deep shades and low-affinity dyes, as shown in Table 2.9 below.

**Table 2.9: Salt concentration required for reactive dyes**

Shade	High-affinity dyes	Low-affinity dyes
< 0.5 %	10-30 g/l NaCl	Up to 60 g/l NaCl
> 4 %	~ 50 g/l NaCl	Up to 80-100 g/l NaCl
Source: [ 10, Ullmann's 2011 ], [ 30, US EPA 1996 ]		

After dyeing, the liquor is drained off and the material is rinsed and then washed off with the addition of auxiliaries.

In *pad dyeing processes*, dye and alkali can be added together to the dye liquor or in separate steps into two separate padders (or other types of application systems). When all the chemicals are applied in one step, the stability of the pad liquor is important. In fact, with increasing reactivity of the dye there is a risk that the dye, after a long dwell time in the pad box, will be hydrolysed by the alkali, before reacting with the fibre. For this reason, dye and alkali are commonly metered separately into the padder. In addition, pad boxes are now constructed so that the liquor volume is as low as possible and is replaced on average within 5 minutes [ 10, Ullmann's 2011 ].

Among *semi-continuous processes* the cold pad-batch is by far the most important one for reactive dyes. After the textile has been padded with highly concentrated dye and alkali, it is rolled up into batches. Fixing takes place during storage. Scouring or dyeing actions are accomplished effectively during this low-temperature fixation.

Compared with conventional processing, the cold pad-batch system reduces reliance on large volumes of heated water for application of chemicals and dyes. Furthermore, no salt is required for reactive dyeing [ 31, Cotton Incorporated 2009 ].

In *continuous processes*, padding, fixing, washing-off and drying are carried out in the same process line. Fixation is commonly achieved either by dry-heating or by steaming. The following processes are commonly used:

- pad-steam processes (one common method is the pad-dry-pad-steam process which includes dye application by padding - intermediate drying - alkali application by padding - dye fixation with saturated steam - washing - drying);
- pad-dry thermofix processes (dye and alkali are padded at the same time; then the material can be dried and fixed in a single step or it can be thermofixed after an intermediate drying stage).

In all cases, after fixation the material is always carefully washed off in open-width or in a rope washing machine to completely remove the hydrolysed colourant and is then dried.

In pad-dry thermofix processes, urea is usually added to the padding liquor to act as a solvent for the dye during fixation. Urea melts at 115 °C and binds water above 100 °C. It can therefore be used as solvent for the dye in dry heat. A dyeing process is available that does not require the addition of urea (see Section 4.5.2.6).

Urea is also sometimes used in pad-batch processes as dyeing solvent to increase the solubility of the dye. Since 1992 the use of urea as dyeing solvent has been in decline [ 32, Bettens L. 1999 ]. Highly soluble reactive dyes have been introduced in the market which do not need urea even for deep dyeing with highly concentrated dye liquor.

### 2.7.3.2 Direct dyes

Direct dyes are also important in cellulose fibre dyeing: 75 % of the total consumption of these colourants is used, in fact, to dye cotton or viscose substrates [ 10, Ullmann's 2011 ].

Direct dyes are applied directly from the dye bath together with salt (sodium chloride or sodium sulphate) and auxiliary agents, which ensure a thorough wetting and dispersing effect. Mixtures of non-ionic and anionic surfactants are used for this purpose.

In the *batch process* the dye is made into paste, then dissolved in hot water and added to the dye bath. The electrolyte is then added to the dye bath. After the dye bath has been drained, the fabric is washed with cold water and generally subjected to after-treatment.

*Pad processes* encompass the following techniques:

- pad-steam;
- pad-roll;
- cold pad-batch;
- pad-jig (the material is padded with the dye and then passed through a salt liquor in a jigger).

In all processes the material is rinsed at the end with cold water.

With increasing depth of colour the wet-fastness can decrease to such an extent that after-treatment must generally be carried out [ 10, Ullmann's 2011 ]. Two methods exist:

- removing the unfixed dye by washing with complexing agents or surfactants with a dispersing effect;
- reducing the solubility of the dye by blocking the hydrophilic groups ('enlargement of the molecule').

Various techniques can be applied to achieve this enlargement of the molecule. Namely, the dyed textile can be treated with the following:

- Fixative cationic agents: these are complex substances that form with the anionic dye a salt-like compound less soluble than the original dye. Quaternary ammonium compounds with long hydrocarbon chains, polyamines and polyethylenimine derivatives can be used for this purpose.

- Agents based on formaldehyde condensation products with amines, polynuclear aromatic phenols, cyanamide or dicyandiamide (the use of these condensation products leads to the formation of sparingly soluble adducts with the dye molecules).

Environmental concerns arise when after-treating with formaldehyde condensation products or metal salts. The method using fixative cationic agents is, therefore, the most frequently applied. However, quaternary ammonium compounds are often non-biodegradable, toxic to fish and contain nitrogen.

### 2.7.3.3 Vat dyes

Vat dyes have excellent fastness properties when properly selected and are often used for fabrics that will be subjected to severe washing and bleaching conditions (towelling, industrial and military uniforms, etc.).

Vat dyes are normally insoluble in water, but they become water-soluble and substantive for the fibre after reduction in alkaline conditions (vatting). They are then converted again to the original insoluble form by oxidation and in this way they remain fixed into the fibre.

When applying vat dyes in batch processes, the textile is dyed very rapidly and unevenly due to the high affinity of the dye. Nevertheless, level dyeing can be achieved by:

- adding levelling agents;
- increase of the temperature under a controlled profile ('high-temperature' process and 'semi-pigmentation' method);
- impregnation of the textile with the dye as water-insoluble dispersion, followed by addition of the reductive agent in a subsequent step (pre-pigmentation process).

In all cases, oxidation and after-treatment follow. After-treatment consists of washing the material in a weakly alkaline bath with a detergent at boiling temperature.

*Continuous processes* are used almost exclusively for dyeing woven fabrics and to only a small extent for knitwear. The most commonly applied continuous process is the pad-steam process. The textile is padded with the aqueous dye dispersion in the presence of anti-migrant (polyacrylates, alginates, etc.) and dispersing/wetting agents, if required. After drying, the fabric is passed through a chemical padder, which contains the required amount of alkali and reducing agent, and is fed immediately to a steamer. The material is finally rinsed, oxidised and soaped in an open-width washing machine.

A more rapid, one-step process is also possible (see Section 4.5.4.2), but only for pastel to pale shades.

Voluminous open fabrics can be dyed according to a wet-steam process. Unlike the pad-steam process, this process does not require intermediate drying before steaming.

The following chemicals and auxiliaries are applied in vat dyeing:

- Reducing agents: mainly sodium dithionite (hydrosulphite) and sulphonylic acid derivatives (zinc sulphonylate). The latter, in particular, is used when the pad-steam process is applied. Sulphur-free organic reducing agents such as hydroxyacetone are also now available for some applications.
- Oxidising agents, such as hydrogen peroxide, perborate, or 3-nitrobenzenesulphonic acid.
- Alkali (caustic soda).

- Salt.
- Dispersing agents: they are already present in the dye formulation and are further added in the subsequent steps of the dyeing process.
- Levelling agents: they form adducts with the dye, thus retarding its absorption into the fibre.

#### 2.7.3.4 Sulphur dyes

Sulphur dyes are used in piece dyeing (cellulose and cellulose-polyester blends), yarn dyeing (sewing thread, warp yarn for denim fabric, yarn for coloured woven goods), dyeing of flock, card sliver (wool-man-made-fibre blends) [10, Ullmann's 2011].

Like vat dyes, sulphur dyes are insoluble in water, and, under alkaline conditions, are converted into the leuco form, which is water-soluble and has a high affinity for the fibre. After absorption into the fibre, the colourant is oxidised and converted to the original insoluble state. The reducing agent, salts, alkali and unfixed dye are finally removed from the fibre by rinsing and washing.

Mostly continuous dyeing methods are applied, although batch dyeing (jigger, jet, and winch beck) is also possible.

In *continuous processes* the material is impregnated with dye, reducing agent and wetting agent through a one-bath or a two-bath procedure. With the one-bath procedure (pad-steam process), the reducing agent and the dye are added at the same time. With the two-bath procedure (pad-dry/pad-steam), the material is padded in the liquor containing the dye and the wetting agent, while the reducing agent is applied, if necessary, in a second step, after intermediate drying. The material is then submitted to air-free steaming. After that, rinsing, oxidation and re-rinsing are carried out.

Because the exhaustion is not too high, it is possible to reuse dye baths in continuous processes.

Chemicals and auxiliaries applied to the substrate during the dyeing process are as follows:

- Reducing agents: sodium sulphide, sodium hydrogen sulphide and thiourea dioxide are the most commonly employed (although their use has decreased over the past decades [22, TWG 2002]). Binary systems made of glucose and sodium dithionite, hydroxyacetone and glucose, or formamidine sulphinic acid and glucose, are also used as alternative reducing agents (see Section 4.5.2.1).
- Alkali (caustic soda).
- Salt.
- Dispersing agents (they are necessary in the process steps in which the pigment has not yet been reduced or has been re-formed by oxidation).
- Complexing agents: EDTA or polyphosphates are used in some cases, especially in circulating-liquor dyeing to avoid the negative effects of alkaline-earth ions on dyeing.
- Oxidising agents: mainly hydrogen peroxide and halogen-containing compounds such as bromate, iodate and chlorite.

#### 2.7.3.5 Azoic dyes (naphthol dyes)

Naphthol dyes allow colours with outstanding fastness, but their popularity has declined because of application costs and the complexity of the process for the preparation of the colourant [4, EURATEX 2000].



Dyeing with azoic colourants is a complex process which involves a number of delicate steps:

- Preparation of the naphtholate solution by the hot solution process (the naphthol is dissolved by boiling with caustic soda) or by the cold solution process (the naphthol is solubilised with alcohol or cellosolve, caustic soda and cold water). For certain naphthols, the addition of formaldehyde is also necessary to prevent the formation of free naphthol.
- Application of the naphtholate to the fibre by batch or padding techniques.
- Preparation of the diazotised base by reaction with sodium nitrite and hydrochloric acid (this step can be avoided when using colour-fast salts).
- Formation of the azoic dye into the fibre, by passing the textile, previously impregnated with the naphtholate solution, through a bath containing the diazotised base or the colour-fast salt (addition of buffering agents is necessary to control the pH, in order to increase the coupling capacity).
- After-treatment by rinsing the material to remove the excess naphthol from the fibre.

Azoic dyes (naphthol dyes) are restricted by the REACH Regulation, with an entry (43) in Annex XVII, for both azocolourants and azodyes.

### 2.7.4 Wool dyeing

Wool can be dyed with the following dyestuffs:

- acid (metal-free) dyes;
- chrome dyes;
- 1:1 and 1:2 metal-complex dyes;
- reactive dyes.

The most common dyestuffs and dyeing techniques for wool fibres are summarised in Table 2.10 and are described in more detail further below.

Table 2.10: Summary of the most common dyes and dyeing techniques for wool fibres

Dyestuff	Chemicals and auxiliaries / typical application conditions	Technique
Acid dyes (metal-free)	<ul style="list-style-type: none"> <li>- Strongly acidic conditions for equalising dyes (by formic acid).</li> <li>- Moderately acidic conditions for half-milling dyes (by acetic acid).</li> <li>- More neutral conditions for milling dyes (by acetic acid and sodium acetate or ammonium sulphate).</li> <li>- Salt: sodium sulphate or ammonium sulphate.</li> <li>- Levelling agents other than sulphate and formic acid are not necessary for level-dyeing colourants.</li> </ul>	Batch dyeing
Chrome dyes (mordant)	<ul style="list-style-type: none"> <li>- pH 3 to 4.5.</li> <li>- Sodium sulphate.</li> <li>- Organic acids: acetic and formic acid (tartaric and lactic acids can also be used).</li> <li>- Reducing agent: sodium thiosulphate.</li> <li>- After-chrome with Na or K dichromate.</li> </ul>	Batch dyeing (After-chrome method)
1:1 metal-complex dyes	<ul style="list-style-type: none"> <li>- pH 1.8 to 2.5 (pH 2.5 in the presence of auxiliary agents such as alkanolethoxylates).</li> <li>- Sulphuric or formic acid.</li> <li>- Salt: sodium sulphate.</li> <li>- Ammonia or sodium acetate can be added to the last rinsing bath.</li> </ul>	Batch dyeing
1:2 metal-complex dyes	<ul style="list-style-type: none"> <li>- pH 4.5 to 7.</li> <li>- Ammonium sulphate or acetate.</li> <li>- Levelling agents (non-ionic, ionic and amphoteric surfactants).</li> </ul>	Batch dyeing
Reactive dyes	<ul style="list-style-type: none"> <li>- pH 4.5 to 7.</li> <li>- Formic or acetic acid.</li> <li>- Levelling agent.</li> <li>- After-treatment with ammonia for highest fastness.</li> </ul>	Batch dyeing

#### 2.7.4.1 Acid dyes

Acid dyes are typically applied in acidic conditions, but the pH range used varies depending on the type of acid dye. The greater the affinity of the dyestuff for the fibre, the more the hydrophobic interaction must be repressed by applying the dye at a higher pH.

Therefore *level-dyeing colourants* are applied under strongly acidic conditions (1-3 % formic acid) in the presence of sulphate ions (5-10 % sodium sulphate) to assist migration and levelling. HCOOH and HSO<sub>4</sub><sup>-</sup> compete with the sulphonated dyes acting as levelling agents. As a result, other levelling agents are not generally required and the rate of dye uptake is controlled initially by increasing the temperature of the dye bath slowly (1 °C/min) and then extending the time at the boil to allow the dye to migrate from areas of high initial uptake.

*Fast acid dyes* (also known as half-milling dyes or perspiration-fast dyes) exhibit superior fastness properties to level-dyeing acid dyes, while retaining some of the migration properties. Application is from a moderately acidic dye bath (1-3 % acetic acid) in the presence of sodium sulphate (5-10 %) and levelling agent to assist migration.

*Acid milling dyes* (including 1:2 metal-complex dyes mentioned later) have good affinity for the fibre and do not migrate well at the boil. They are therefore applied at more neutral pHs (5-7.5 with acetic acid) in the presence of sodium acetate (2 g/l) or ammonium sulphate (4 %) and levelling agent (1-2 %). Sodium sulphate is usually avoided as it has little effect on migration and can promote uneven dye adsorption.

Levelling agents play an important role in acid dyeing. A number of non-ionic, cationic, anionic and amphoteric surfactants belong to this category.

### 2.7.4.2 Chrome dyes

A number of techniques have been developed for the application of chrome dyes. The *Chrome mordant* process relies on chroming the fibre prior to dyeing with a chromable dye; the *Metachrome* process applies both dye and chromium salt simultaneously. Both processes have been largely superseded by the *Afterchrome* process in which the dye is applied first and the fibre is then chromed in a separate step, utilising the exhausted dye bath and thus conserving water.

Application of the dyestuff takes place from a moderately acidic dye bath (1 % acetic acid), often with an addition of formic acid towards the end of the boiling period to promote exhaustion of the dye. The dye bath is then cooled back from the boil to approximately 80 °C, the pH is lowered to approximately 3.5 with formic acid and the pre-dissolved chromium salt added. The dye bath is then returned to the boil and boiling continued for 20-30 minutes. Chromium is added to the dye bath as either sodium or potassium dichromate. In solution the chroming species present vary according to the pH, with the dichromate anion  $\text{Cr}_2\text{O}_7^{2-}$  predominating at pHs between 3 and 7. Although it is the chromium (VI) anion which is initially adsorbed by the wool, the dye complex is formed with chromium (III), formed by the action of reducing groups in the fibre itself. Strong acids have an activating effect on this process; organic acids (tartaric, lactic, formic acid) or thiosulphate can also be used to enhance the degree of conversion of Cr(VI) (see also Section 4.5.3.1).

At the EU level, 20 to 30 Cr-complex dyes containing chromium (III) have been registered (REACH), mainly used to dye wool; however, they can also be used to dye silk and polyamides [ 58, EURATEX 2020 ].

It should be noted that both sodium and potassium dichromate are listed in Annex XIV to REACH [ 7, EU 2006 ], which means that in the EU an authorisation is necessary to use these substances. At the time of drafting this document, only one authorisation was granted to use sodium dichromate as mordant in wool dyeing.

### 2.7.4.3 Metal-complex dyes

Application of *1:1 metal-complex dyes* (i.e. one metal ion is joined to one dye molecule) is carried out at pH 1.8-2.5 with sulphuric acid or at pH 3-4 with formic acid, in the presence of sodium sulphate (5-10 %) and other organic levelling agents. Owing to these particular operating conditions, this class of dyestuffs is particularly suitable for piece-dyeing of carbonised wool.

*1:2 metal-complex dyes* (i.e. one metal ion is joined to two dye molecules) form the most important group in this class and may be divided into two subgroups: weakly polar and strongly polar 1:2 complexes. Application is usually carried out in moderately acidic conditions:

- pH range 4-7 (with acetic acid) in the presence of ammonium acetate, for weakly polar complexes;
- pH range 5-6 (with acetic acid) in the presence of ammonium sulphate, for strongly polar complexes.

The use of levelling agents is very common when dyeing with metal-complex dyes. The groups of substances used for acid dyes also apply in this case.

#### 2.7.4.4 Reactive dyes

Reactive dyes are generally applied at pH values of between 5 and 6, depending on the depth of shade, in the presence of ammonium sulphate and specialised levelling agents (amphoteric substances, which form complexes with the dye at low dye bath temperatures and then break down as the dyeing temperature increases).

The dyeing method may include a temperature hold step at 65-70 °C, during which the dye bath is maintained at this temperature for 30 minutes in order to allow the dye to migrate without fibre reaction. When dyeing of the very highest fastness is required, the fibre is rinsed under alkali conditions (pH 8-9 with ammonia) to remove unreacted dyestuff.

#### 2.7.5 Silk dyeing

Silk is dyed with the same dyes as wool, excluding 1:1 metal-complex dyes. In addition, direct dyes can be used. The dyeing pH is slightly higher than with wool. For reactive dyeing, 20-60 g/l of salt and 2-5g/l of soda ash are needed for fixation [9, TWG 2001].

#### 2.7.6 Synthetic fibres dyeing

##### 2.7.6.1 Polyamide fibres

Polyamide fibres (PA 6 and PA 6,6) are easily dyed with various types of dyes. Due to their hydrophobic characteristics, they can be dyed with disperse dyes (non-ionic), but, thanks to the presence of the groups NH-CO- and NH<sub>2</sub>- in the polymer chain, acid, basic, reactive and 1:2 metal-complex dyes (ionic) can also be used. However, in practice, acid levelling dyes are increasingly used.

The most common dyestuffs and dyeing techniques for polyamide fibres are summarised in Table 2.11 and are described in more detail further below.

Table 2.11: Summary of the most common dyes and dyeing techniques for polyamide fibres

Dyestuff	Chemicals and auxiliaries / typical application conditions	Technique
Disperse	<ul style="list-style-type: none"> <li>- pH 5 by acetic acid.</li> <li>- Dispersing agents (sulphoaromatic condensation products or non-ionic surfactants).</li> <li>- Dyeing is conducted at near-boiling temperature.</li> </ul>	Batch
Acid dyes	<ul style="list-style-type: none"> <li>- pH conditions from acid to neutral depending on the affinity of the dye.</li> <li>- Optimal bath exhaustion and level dyeing are achieved by either pH or temperature control methods (levelling agents are also used).</li> <li>- In the acidic range, electrolytes retard the exhaustion.</li> <li>- With levelling dyes, wet-fastness is often unsatisfactory and after-treatment with synthanes can be necessary.</li> </ul>	Batch
1:2 metal-complex dyes	<ul style="list-style-type: none"> <li>- Dyes containing sulphonic groups are preferred because they are more water-soluble and produce better wet-fastness.</li> <li>- To improve absorption of low-affinity dyes (especially for disulphonic), dyeing is carried out in weakly acidic conditions using acetic acid.</li> <li>- High-affinity dyes are applied in a neutral or weakly alkaline medium using amphoteric or non-ionic levelling agents.</li> </ul>	Batch
Reactive dyes	<ul style="list-style-type: none"> <li>- In principle, the reactive dyes used for wool are also suitable for PA.</li> <li>- Dyeing is conducted at near-boiling temperature in weakly acidic conditions.</li> <li>- After-treatment is performed at 95 °C using a non-ionic surfactant and sodium bicarbonate or ammonia.</li> </ul>	Batch

Before dyeing, fabrics are generally pre-fixed to compensate for material-related differences in affinity and to reduce the sensitivity to creasing during the dyeing process. Pre-fixing can be performed in a stenter frame.

#### 2.7.6.1.1 Disperse dyes

Disperse dyes used for polyamide fibres are mainly azo compounds and anthraquinones. They are applied especially for lighter shades.

The material is dyed in acidic conditions (pH 5) by acetic acid. A dispersing agent is always added to the liquor.

#### 2.7.6.1.2 Acid dyes

As with acid dyeing of wool, with increasing dye affinity, the hydrophobic interaction in the initial phase is repressed to achieve uniform absorption. This means that for high-affinity dyes the liquor is sufficiently alkaline at the start and then slowly decreased to optimise exhaustion. The level of acidity of the liquor is regulated either by dosing with acids during dyeing or by adding acid donors (e.g. ammonium sulphate, sodium pyrophosphate or esters of organic acids) at the start of the process (see also Section 4.5.1.6).

Optimal exhaustion and uniform dyeing can also be achieved by controlling the temperature profile.

Auxiliary agents (anionic, cationic, non-ionic surfactants) are normally used to improve the levelling effect.

The wet-fastness of dyeing with acid dyes on polyamide fibres is often unsatisfactory. After-treatment with syntans (synthetic tanning agents) is often necessary. The syntans are added to the exhausted bath or to fresh liquor at pH 4.5 by formic or acetic acid. The material is treated at 70-80 °C and is then rinsed.

#### **2.7.6.1.3 Metal-complex dyes**

Among 1:2 metal-complex dyes, molecules containing sulphonic groups are the most suitable for polyamide fibres.

The absorption of the dye increases with decreasing pH. Dyeing conditions vary from weakly acidic by addition of ammonium sulphate and acetic acid to neutral or moderately alkaline for high-affinity dyes. For high-affinity dyes, amphoteric or non-ionic levelling agents are usually added.

#### **2.7.6.1.4 Reactive dyes**

In principle, the reactive dyes used for wool are also suitable for polyamide. The dyeing process is carried out in weakly acidic conditions (pH 4.5-5). The process is started at 20-45 °C and then the temperature is increased to near boiling. Non-ionic surfactants and sodium bicarbonate or ammonia are used in the after-treatment step.

#### **2.7.6.2 Polyester fibres**

Articles made of pure PES are dyed almost exclusively using batch dyeing techniques and, among these, dyeing under high-temperature conditions is the most commonly applied. The most common dyestuffs and dyeing techniques for polyester fibres are summarised in Table 2.12 below.

Dyeing polyester fibres under atmospheric conditions (below 100 °C) was also frequently done in the past with the aid of carriers. Since these substances are ecologically harmful (see Section 2.7.8.1 and Section 8.1.6.7), dyeing below 100 °C is no longer in use today for pure PES fibres, unless carrier-free dyeable fibres are employed (see Section 4.5.4.1).

Concerning high-temperature dyeing, the process is usually carried out in acidic conditions (pH 4-5) with addition of acetic acid under pressure at 125-135 °C. In these conditions, levelling agents are necessary to prevent excessively rapid absorption.

Provided that alkali-stable dyes are used, dyeing in an alkaline medium (pH 9-9.5) is also possible. This technique has been developed in order to counteract the migration and deposition of oligomers typical of PES fibres (see Section 2.1.1.1). In fact, oligomeric components (cyclic trimers of ethylene terephthalate are especially harmful) tend to migrate out of the fibre during dyeing, thus forming with the dye agglomerates that can deposit on the textile or on the dyeing equipment. To achieve level effects, ethoxylated products are used as levelling agents.

The thermosol process is another applied technique, although it is primarily used for PES/cellulose blends. The dye is padded on the textile together with an anti-migration agent. A drying step at 100-140 °C is carried out. Then the dye is fixed (200-225 °C for 12-25 seconds).

For light shades, the material needs only to be rinsed or soaped after dyeing. For dark shades, in order to ensure high light-fastness, an after-clearing step is normally necessary. This usually consists of an alkaline reductive treatment followed by post-rinsing in weakly acidic conditions. Information about alternative processes is reported in Section 4.5.4.2.

PES fibres can be dyed with cationic dyestuffs, provided that acidic components (e.g. sulphated aromatic polycarboxylic acid) are used as co-monomers during the manufacturing of the fibre (creation of anionic sites).

**Table 2.12: Summary of the most common dyes and dyeing techniques for polyester fibres**

Dyestuff	Chemicals and auxiliaries / typical application conditions	Technique
Disperse	<ul style="list-style-type: none"> <li>- pH 4-5 by acetic acid.</li> <li>- Levelling agents (aliphatic carboxylic esters, ethoxylated products, combinations of alcohols, esters or ketones with emulsifying agents).</li> <li>- Possible addition of complexing agents (EDTA) for dyes sensitive to heavy metals.</li> </ul>	Batch dyeing at 125-135 °C under pressure (HT)
	<ul style="list-style-type: none"> <li>- This technique requires the use of carriers unless modified polyester fibres are employed.</li> </ul>	Batch dyeing below 100 °C
	<ul style="list-style-type: none"> <li>- pH 4-5 by acetic acid.</li> <li>- Thickeners such as polyacrylates and alginates are added to the padding liquor in order to prevent migration of the dye during drying.</li> <li>- After-treatment with a solution containing sodium hydrosulphite and sodium hydroxide (dispersing agents are added to the last washing bath).</li> </ul>	Thermosol process

### 2.7.6.3 Acrylic fibres

So-called PAC fibres are hydrophobic and contain anionic groups in the molecule. As a result, they can be dyed with disperse and cationic dyes. With the introduction of cationic co-monomers in the polymer, the fibre can also be dyed with acid dyes.

The most common dyestuffs and dyeing techniques for polyamide fibres are summarised in Table 2.13 and are described in more detail further below.

**Table 2.13: Summary of the most common dyes and dyeing techniques for polyacrylic fibres**

Dyestuff	Chemicals and auxiliaries / typical application conditions	Technique
Disperse	<ul style="list-style-type: none"> <li>- Dyeing conditions correspond to those used for polyester.</li> <li>- Addition of carriers is not required.</li> </ul>	See Table 2.12
Cationic	<ul style="list-style-type: none"> <li>- Acetic acid (pH 3.6-4.5).</li> <li>- Salt (sodium sulphate or sodium acetate).</li> <li>- Retardant auxiliaries (usually cationic agents).</li> <li>- Non-ionic dispersing agents.</li> </ul>	Batch
	<ul style="list-style-type: none"> <li>- Acetic acid (pH 4.5).</li> <li>- Dye solvent.</li> <li>- Steam-resistant, readily-soluble dyes (usually liquid) are required.</li> </ul>	Pad-steam process with pressurised steam
	<ul style="list-style-type: none"> <li>- Dye solvent.</li> <li>- Rapidly diffusing dyes are required.</li> </ul>	Pad-steam process with saturated steam

*Batch dyeing* is commonly applied for cable or stock (package dyeing), yarn in hank form or packages and for fabric. Piece dyeing can be performed on beam, overflow, paddle (for knitwear, ready-made bath sets), or drum (for socks).

Stock, cable and tops can be also dyed on special machines, using the pad-steam process, preferably with pressurised steam to obtain short fixing times. Piece goods, especially

upholstery material (velour), are also dyed according to the pad-steam process, but in this case fixing is carried out with saturated steam. This implies longer fixing times, which means that rapidly diffusing cationic dyes and dye solvents are required.

#### 2.7.6.3.1 Disperse dyes

Disperse dyes are used to produce light to medium-deep shades. The dyeing techniques correspond to those used on polyester fibres. However, dyeing can be performed at temperatures < 100 °C without carriers. Furthermore, due to the good migration properties of disperse dyes, levelling agents are not required.

#### 2.7.6.3.2 Cationic dyes

Typical recipes used in *batch dyeing* include an electrolyte (sodium acetate or sodium sulphate), acetic acid, a non-ionic dispersant and a retarding agent. Dyeing is conducted by controlling the temperature in the optimum range for the treated fibre. Finally, the bath is cooled down and the material is rinsed and submitted to after-treatment.

*Continuous processes* commonly applied are as follows:

- Pad-steam process (fixation with pressurised steam at more than 100 °C) - this process has the advantage of reducing the fixing time. Pad liquor typically contains a steam-resistant cationic dye, acetic acid and a dye solvent.
- Pad-steam process (fixation with saturated steam at 100-102 °C) - this process requires a longer fixing time. Rapidly diffusing cationic dyes and dye solvents, which exhibit a carrier effect, are required.

When dyeing with basic dyes, special levelling agents (also called retarding agents) are widely used to control the absorption rate of the colourant on the fibre, thus improving level dyeing.

#### 2.7.6.4 Cellulose acetate (CA) and cellulose triacetate (CT)

In contrast to the other regenerated cellulose fibres, CA and CT are hydrophobic and therefore they can be dyed with disperse dyes under conditions which are very similar to those applying to PES fibres.

Cellulose acetate is dyed by the exhaustion method with disperse dyes in the presence of non-ionic or anionic dispersing agents in weakly acidic conditions (pH 5-6). Dyeing is normally done at 80-85 °C. However, a series of less wet-fast dyes already absorb onto the fibre at 50-60 °C, whereas more wet-fast dyes require temperatures up to 90 °C.

Compared to CA, CT dyeing and finishing characteristics are more similar to purely synthetic fibres. CT, like CA, is dyed with disperse dyes in a weakly acidic medium in the presence of levelling auxiliaries. Applied dyeing techniques for CT are:

- batch dyeing process, usually at 120 °C, but if these conditions are not possible a dyeing accelerant (based on butyl benzoate or butyl salicylate) is required;
- thermosol process.



### 2.7.7 Fibre blends dyeing

Natural/synthetic fibre blends are becoming more and more important in the textile industry because this allows the favourable technological properties of synthetic fibres to be combined with the pleasant feel of natural fibres.

Of the worldwide consumption of PES fibres, 55-60 % is used in blends with cellulose fibres or wool. About 40 % of polyamide is used in blends, while 50 % of polyacrylic fibres are used especially in blends with wool for knitwear [ 10, Ullmann's 2011 ].

Fibre blends can be produced according to three different methods:

- fibres of different types in the form of staple fibres are mixed at the yarn manufacturing stage, during spinning;
- fibres of different types are separately spun and the resulting yarns are wound together to give a mixed yarn;
- fibres of different types are separately spun and combined together only at the weaving stage where one or more fibre yarns are used as warp and the other ones as weft.

Dyeing of blend fibres is always longer and more difficult as an operation compared to pure fibre dyeing. Despite these disadvantages, dyeing tends to be placed as close as possible towards the end of the finishing process. In fact, this enables the dyer to satisfy the requests of the market without the need to store large amounts of material already dyed in flock or yarn form in all available shades.

When dyeing blend fibres, the following methods can be applied:

- the two fibres are dyed in the same tone ('tone on tone') or in two different shades using the same dyes;
- only one fibre is dyed (the colourant is not absorbed by the other ones);
- the different fibres are dyed in different tones.

For 'tone on tone' dyeing, it is sometimes possible to use the same dye for the different fibres. When dyes of different classes are employed, the dyeing process is easier to control when the selected colourants have affinity only for one fibre and not for the other one. In reality, however, this situation is exceptional and the dyeing of fibre blends remains a complex operation.

Blend fibre dyeing can be done in batch, semi-continuous and continuous processes. Batch processes include:

- dyeing in one bath and one step (all dyes are added in the same bath in one single step);
- dyeing in one bath and in two steps (dyes are added to the same bath in subsequent steps);
- dyeing in two baths (dyes are applied in two steps in two different baths).

The most common fibre blends are discussed in the following sections.

#### 2.7.7.1 Polyester-cellulose blends

A large part of the entire production of PES (around 45 %) is used to make this mixture. Polyester-cellulose blends are used for all types of clothing and for bed linen. The cellulose component is usually cotton, but viscose staple fibres and occasionally linen are also used. The

preferred mixing ratio is 67:33 PES to cellulose (for textiles worn close to the skin), 50:50 and 20:80 [10, Ullmann's 2011].

In dyeing PES-cellulose mixtures, disperse dyes are used for the polyester component, while the cellulose portion is usually dyed with reactive, vat and direct dyes. Pigment dyeing is also commonly used for light shades.

Disperse dyes stain cellulose fibres only slightly and they can easily be removed by subsequent washing or, if necessary, by reductive after-treatment. Most of the dyes used for cellulose only stain PES slightly or not at all.

PES-cellulose blends are commonly dyed in continuous processes. Nevertheless, for yarn and knitwear, batch dyeing is of major importance.

In *batch dyeing*, the application of dyes can be done in one or two steps in one bath or in two different baths in subsequent stages. The disperse dye is generally applied in high-temperature (HT) conditions without the use of carriers.

In the one-bath/one-step procedure, special auxiliaries, so-called acid donors, are used, which lower the pH when the temperature is increased. In this way, it is possible to fix the reactive dyes in alkaline conditions and then reach the optimal dyeing conditions (pH 5-6) for disperse dyes by increasing the temperature. Alternatively, it is advantageous to operate at pH 8-10 using alkali-stable disperse dyestuffs, which also avoids oligomer problems.

The one-bath/one-step procedure is preferred, being more economical, but presents more difficulties. For example, the presence of salt increases the tendency of disperse dyes to stain the cotton fibre of the blend. Low-salt reactive dyes are claimed to show good performance and high reproducibility in this application (see Section 4.5.2.4).

In *continuous processes* the dyes are usually applied in one bath. The fabric is subsequently dried and disperse dye is fixed to the PES component by the thermosol process. Afterwards, the second dye is developed according to the procedure typical of each class of dye, using in general pad-steam, pad-jig or pad-batch processes.

Table 2.14 presents a summary of the most frequently applied processes. Dyes are applied according to application conditions typical of their class.

**Table 2.14: Summary of the most common dyestuffs and dyeing techniques for polyester-cellulose blends**

Technique		Disperse /vat	Disperse/ reactive	Disperse /direct	Pigment	
Batch	One-bath process	NA	NA	Y K	W <sup>(1)</sup>	
	Two-bath process	NA	Y K	NA	NA	
	One-bath two-step process	Y K	Y K	Y K	NA	
Continuous	I stage	NA	NA	NA	NA	
	Application of all dyes in one bath by padding + drying followed by:	Thermosol + pad-jig	W	NA	NA	NA
		Thermosol + pad-batch	NA	W	NA	NA
		Thermosol + pad-steam	W	W	NA	NA
<sup>(1)</sup> Pigment dyeing includes padding with the pigment, a binder and auxiliaries, drying and polymerisation at 140 °C for 5 min.						
NB: Y: yarn; W: woven fabric; K: knitted fabric; NA: not applicable.						

### 2.7.7.2 Polyester-wool blends

Polyester-wool blends are widely used, especially for woven goods and knitwear. The most frequently found ratio is 55:45 PES to wool.

Wool cannot be dyed at the high temperatures typical of the HT dyeing process for PES fibres and PES-cellulose blends. The dyeing time is also as short as possible so that the wool is not damaged. For large production volumes, it is therefore preferable to dye wool and PES separately in top form, and blending the two fibres at the yarn manufacturing stage. However, quick changes in fashion and short-term planning frequently do not allow separate dyeing.

When dyeing polyester-wool blends, disperse dyes are used for polyester and anionic (acid and metal-complex dyes) for wool.

Only disperse dyes that stain wool as slightly as possible or are easily removed by washing can be used for dyeing wool-polyester blends. Disperse dyes, in fact, tend to stain wool and a reductive after-treatment is not always possible (appropriately stable dyes are required).

PES/WO blends are typically dyed according to the following batch processes:

- at boiling temperature with carriers;
- at 103-106 °C with little carrier;
- at 110-120 °C with the addition of formaldehyde as a wool protective agent and with low amounts of carriers or none at all (HT conditions).

Because of the environmental concerns associated with the use of carriers (see Sections 8.1.6.7 and 2.7.8.1), the first dyeing technique is avoided when possible. In this respect, carrier-free dyeable fibres are also available, which can be dyed at boiling temperature without the use of carriers (see Section 4.5.4.1 for more information about carrier-free dyeable fibres and Section 4.5.4.1 for environmentally optimised carriers).

The one-bath process method is preferred in practice; the two-bath process is applied when deep shades and high fastness are required. The material is first dyed with disperse dyes. A reductive intermediate treatment may be applied before dyeing the wool part. In both dyeing methods, after dyeing, an after-treatment is applied to remove any disperse dye attached to the wool, if the dye used for wool can withstand it. The material is treated with ethoxylated fatty amine in weakly acidic liquor at 60 °C.

### 2.7.7.3 Polyamide-cellulose blends

Since PA fibres have an affinity for almost all dyes used for cellulose, different possibilities are available for dyeing this blend:

- direct and disperse dyes (pH 8);
- acid or 1:2 metal-complex dyes (pH 5-8);
- vat dyes (exhaust and pad-steam process are used);
- reactive dyes.

Application conditions are those typical of each class of dye, as described in Sections 2.7.3 to 2.7.6.

#### 2.7.7.4 Polyamide-wool blends

Blends with polyamide to wool ratios varying from 20:80 to 60:40 are used. This blend is particularly important in the carpet sector. More detailed information is therefore reported in the specific section dedicated to this sector (see Section 2.13.5).

As general information about the dyeing processes suitable for this type of blend, both fibres have affinity for acid and 1:2 metal-complex dyes. However, since PA is more accessible to the dye than wool, it is dyed more deeply, particularly in the case of light colours. To counteract this effect, special levelling agents (also called PA reserving/blocking agents) are used (mainly aromatic sulphonates). These auxiliaries have a relatively high affinity for the PA fibre and retard the absorption of the colourant into this part of the blend.

Dyeing is performed in the presence of acetic acid and sodium sulphate. Due to the limited fastness of acid dyes, 1:2 metal-complex dyes are required for dark shades [10, Ullmann's 2011].

#### 2.7.7.5 Acrylic-cellulose blends

PAC-cellulose blends are used for household textiles (drapery and table linen) and imitation fur ('peluche', in which the pile consists of PAC fibres and the back is made of cotton). The percentage of PAC in the mixtures varies between 30 % and 80 %.

PAC can be dyed with cationic or disperse dyes, while direct, vat or reactive dyes can be used for the cellulose component.

The following methods are the most commonly used for dyeing this blend:

- *continuous dyeing* with cationic and direct dyes according to the pad-steam process (to avoid precipitation of cationic and anionic dyes present in the pad liquor at relatively high concentration, a combination of anionic and non-ionic surfactants are added to the solution);
- *batch dyeing* (usually according to the one-bath two-step method) with cationic and vat dyes or with cationic and reactive dyes.

#### 2.7.7.6 Acrylic-wool blends

Among synthetic fibres, PAC fibres are the most suitable for obtaining blends with wool that keep a wool-like character. This makes this blend widely used, especially for knitwear and household textiles. The blending ratio of PAC to wool varies from 20:80 to 80:20.

Metal-complex, acid and reactive dyes are the dyestuffs typically used for the wool part, while PAC is dyed with cationic dyes.

Cationic dyes stain wool fibre. As a matter of fact, cationic dyes attach first to wool and then migrate to PAC fibre at higher temperature. Even if well-reserving dyes (i.e. dyeing only PAC fibres) are selected, dyeing is conducted for a sufficiently long time (from 60 to 90 minutes) in order to obtain a good wool reserve (i.e. undyed wool) [10, Ullmann's 2011].

PAC-wool blends can be dyed using the following exhaustion methods:

- one-bath one-step;
- one-bath two-step;
- two-bath.

The first one allows shorter dyeing times and lower consumption of water. However, it is not always applicable because the simultaneous presence in the dye bath of anionic and cationic compounds can result in the precipitation of the formed adducts on the fibre. Precipitation can be prevented by using dispersing agents and selecting adequate dyes.

When dyeing with the one-bath two-step method, the use of reserve agents is not necessary. In fact, wool absorbs the cationic dye and slowly releases it, acting as a retarding agent (exerting a retardant effect on PAC).

### 2.7.8 Environmental issues

Potential sources and types of emissions associated with dyeing processes are summarised in Table 2.14 below.

**Table 2.15: Overview of the typical emissions generated in dyeing processes**

Operations	Emission sources	Type of emission
Colour kitchen operations	Dye preparation	Discontinuous, low-concentration emissions to water at the end of each batch (cleaning step)
	Auxiliaries preparation	Discontinuous, low-concentration emissions to water at the end of each batch (cleaning step)
	Dispensing of dyes and auxiliaries (manual)	Indirect pollution from inaccurate dosing and handling of chemicals (spillage, poor shade repeats, etc.)
	Dispensing of dyes and auxiliaries (automatic)	No emission, provided that the system is regularly calibrated and verified for accuracy
Batch dyeing	Dyeing	Discontinuous, low-concentration emissions to water at the end of each cycle
	Washing and rinsing operations after dyeing	Discontinuous, low-concentration emissions to water at the end of each cycle
	Cleaning of equipment	Discontinuous, low-concentration emissions to water
Semi-continuous and continuous dyeing	Application of the colourant	No emission from the process unless the dye bath is drained
	Fixation by steam or dry-heat	Continuous emissions to air (generally not significant, except for specific situations such as the thermosol process, drying of carrier-dyed fabrics)
	Washing and rinsing operations after dyeing	Continuous, low-concentration emissions to water
	Discharging of leftovers in the chassis and feed storage container	Discontinuous, concentrated emissions to water at the end of each lot
	Cleaning of equipment	Discontinuous, low-concentration emissions to water (it can contain hazardous substances when reductive agents and hypochlorite are applied)

As the table shows, most of the emissions are emissions to water. Due to the low vapour pressure of the substances in the dye bath, emissions to air are generally not significant and can be regarded more as problems related to the workplace atmosphere (fugitive emissions from dosing/dispensing chemicals and dyeing processes in 'open' machines). A few exceptions are

the thermosol process, pigment dyeing and those dyeing processes where carriers are employed. As an example, textile auxiliaries containing formaldehyde can be used in the thermosol process with quantities usually below 300 ppm. Alternatives without formaldehyde can be used, if product specifications (such as lightfastness) can be met [352, Zietlow B. 2020].

In pigment dyeing, the substrate is not washed after pigment application and therefore the pollutants are quantitatively released to air during drying. Emissions from carriers are to air and water. In the first part of the following discussion the environmental issues related to the substances employed will be described, while in the second part the environmental issues related to the process will be mentioned.

### 2.7.8.1 Environmental issues related to the substances employed

Water-polluting substances in the above-mentioned emissions may originate from:

- the dyes themselves (e.g. toxicity, metals, colour);
- auxiliaries contained in the dye formulation;
- basic chemicals (e.g. alkali, salts, reducing and oxidising agents) and auxiliaries used in dyeing processes;
- contaminants present on the fibre when it enters the process sequence (residues of pesticides on wool are encountered in loose fibre and yarn dyeing and the same occurs with spin finishes present on synthetic fibres).

#### Dyes

Spent dye baths (discontinuous dyeing), residual dye liquors and water from washing operations always contain a percentage of unfixed dye. The rates of fixation vary considerably among the different classes of dyes and may be especially low for reactive dyes (in the case of cotton) and for sulphur dyes. Moreover, large variations are found even within a given class of colourants. This is particularly significant in the case of reactive dyes. Fixing rates above 60 % cannot be achieved, for example, in the case of copper (sometimes nickel) phthalocyanine reactive dyes especially used for turquoise-green and some marine shades. In contrast, the so-called double anchor reactive dyes can achieve extremely high rates of fixation (see Section 4.5.2.4).

The degree of fixation of an individual dye varies according to type of fibre, shade and dyeing parameters. Therefore fixation rate values can be given only as approximations. However, they are useful to give an idea of the amount of unfixed dyes that can be found in waste water. Information from different sources is given in Table 2.16 below.

**Table 2.16: Percentage of non-fixed dye that may be discharged in the effluent for the principal classes of dyes**

Dyestuffs	EPA	OECD	ATV	Bayer ( <sup>1</sup> )	Euratex	Spain
Acid dyes for wool for polyamide	10 20	> 7-20	> 7-20	NI	> 5-15	5-15
Basic dyes	1	2-3	2-3	2	NI	0-2
Direct dyes	30	5-20	5-30	10	5-35	5-20
Disperse dyes for acetate for polyester 1 bar for polyester HT	25 15 5	> 8-20	> 8-20	> 5	> 1-15	> 0-10
Azoic dyes	25	5-10	5-10	NI	10-25	10-25
Reactive dyes ( <sup>2</sup> ) for cotton for wool	> 50-60	> 20-50	> 5-50	> 5-50	20-45 3-10	> 10-35
Metal-complex	10	2-5	2-5	5	2-15	5-15
Chrome dyes	NI	NI	1-2	NI	NI	5-10
Vat dyes	25	5-20	5-20	NI	5-30	5-30
Sulphur dyes	25	30-40	30-40	NI	10-40	15-40

(<sup>1</sup>) Now Dystar (including BASF).  
(<sup>2</sup>) New reactive dyestuffs with higher fixation rates are now available (see Section 4.5.2.4).  
NB:  
EPA: US Environmental Protection Agency.  
OECD: Organisation for Economic Co-operation and Development.  
ATV: Abwasser Technische Vereinigung (Waste Water Technical Association).  
NI: No information.  
Source: [ 4, EURATEX 2000 ], [ 9, TWG 2001 ], [ 30, US EPA 1996 ]

As stated earlier, as a consequence of incomplete fixation, a percentage of the dyestuff used in the process ends up in the waste water.

Dyestuffs are not biodegradable in oxidative conditions, although some of them may degrade under other conditions (e.g. azo dyes may cleave under anoxic and anaerobic conditions). Less water-soluble dyestuff molecules (typically, disperse, vat, sulphur, some direct dyestuffs and pigments) can be largely bio-eliminated from waste water by coagulation/precipitation or absorption/adsorption to the activated sludge. The quantity of activated sludge in the waste water treatment plant and the quantity of dyestuff to be eliminated are key factors in determining the efficiency of removal of a dyestuff from the effluent.

Another factor to take into consideration is the colour strength of the colourant. For example, with reactive dyestuffs a smaller amount of colourant is needed to achieve a given shade compared to other classes of dyes (e.g. direct, vat and sulphur dyes). As a result, a smaller amount of dyestuff will need to be removed from the waste water.

Dyestuffs that are poorly bio-eliminable (unless they are subjected to destructive treatment techniques) will pass through a biological waste water treatment plant and will ultimately end up in the discharged effluent. The first noticeable effect in the receiving water is the colour. High doses of colour not only cause aesthetic impact, but can also interrupt photosynthesis, thus affecting aquatic life. Other effects are related to the organic content of the colourant (normally expressed as COD and BOD, but it could be better expressed as organic carbon, using TOC and DOC as parameters), its aquatic toxicity and the presence in the molecule of metals or halogens that can give rise to AOX emissions.

These issues are discussed in more detail for each class of dyestuff in Section 8.2. Only some general key issues are considered in this section.

*AOX emissions*

Vat, disperse and reactive dyes are more likely to contain halogens in their molecules.

The content of organically bound halogens can be up to 12 % by weight for some *vat dyes*. Vat dyes, however, usually show a very high degree of fixation. In addition, they are insoluble in water and the amount that reaches the effluent can be eliminated with high efficiency in the waste water treatment plant through adsorption on the activated sludge.

*Reactive dyes*, on the contrary, may have low fixation degrees (the lowest level of fixation is observed with phthalocyanine in batch dyeing) and their removal from waste water is difficult because of the low biodegradability and/or low level of adsorption of the dye onto activated sludge during treatment. The halogen in MCT (monochlorotriazines) reactive groups is converted into a harmless chloride during the dyeing process. In calculating the waste water burden, it is therefore assumed that the MCT reactive groups react completely by fixation or hydrolysis so that they do not contribute to AOX emissions. However, many commonly used polyhalogenated reactive dyes, such as DCT (dichlorotriazine), DFPC (difluorochloropyrimidine) and TCP (trichloropyrimidine), contain organically bound halogens even after fixation and hydrolysis. Bound halogens are also found in discharges of dye concentrate (pad, kitchen) and non-exhausted dye baths that may still contain unreacted dyestuff.

For the other classes of colourants the AOX issue is not relevant because, with few exceptions, the halogen content is usually below 0.1 %.

Dyestuffs containing organically bound halogens (except fluorine) are measured as AOX. The only way to limit AOX from dyeing is by dye selection, by more efficient use of dyes or by treating the resulting effluent by decolouration. Effluent decolouration can be achieved using destructive techniques, such as free radical oxidation or non-destructive techniques (e.g. coagulation, adsorption).

However, it should be noted that AOX from dyes do not have the same effect as the AOX derived from chlorine reactions (haloform reaction, in particular) arising from textile processes such as bleaching, wool shrink-resist treatments, etc.

Dyestuffs are not biodegradable compounds and the halogens in their molecules should not give rise to the haloform reaction (main cause of hazardous AOX).

*Heavy metals emissions*

Metals can be present in dyes for two reasons. First, metals are used as catalysts during the manufacture of some dyes and can be present as impurities. Second, in some dyes the metal is chelated with the dye molecule, forming an integral structural element.

Dye manufacturers are now putting more effort into reducing the amount of metals present as impurities. This can be done by selection of starting products, removal of heavy metals and substitution of the solvent where the reaction takes place.

ETAD (Ecological and Toxicological Association of Dyes and Organic Pigments Manufacturers) has established limits for the content of heavy metals in dyestuffs. The values have been set to ensure that emission levels from a 2 % dyeing and a total dilution of the dye of 1:2 500 will meet the known waste water requirements [33, BASF 1994].

Examples of dyes containing bound metals are copper and nickel in phthalocyanine groups, copper in blue copper-azo-complex reactive dyes and chromium in metal-complex dyes used for wool silk and polyamide. The total amount of metallised dye used is decreasing, but there remain domains (certain shades such as greens, certain levels of fastness to light) where phthalocyanine dyes, for example, cannot be easily substituted.



The presence of the metal in these metallised dyes can be regarded as a less relevant problem compared to the presence of free metal impurities. Provided that high exhaustion and fixation levels are achieved and that measures are taken to minimise losses from handling, weighing, drum cleaning, etc., only a little unconsumed dye should end up in the waste water. Moreover, since the metal is an integral part of the dye molecules, which themselves are non-biodegradable, there is very little potential for them to become bio-available.

It is also important to take into account that treatment methods such as filtration and adsorption on activated sludge, which remove the dye from the waste water, also reduce almost proportionally the amount of bound metal in the final effluent. Conversely, other methods such as advanced oxidation may free the metal.

#### Toxicity

Dyestuffs showing aquatic toxicity and/or allergenic effects are highlighted in Section 8.2. Here it is also important to mention that about 60 % to 70 % of the dyes used nowadays are azo dyes [4, EURATEX 2000]. Under reductive conditions, these dyes may produce amines and some of them are carcinogenic and subject to restriction as per the REACH Regulation (EC/1907/2006).

#### Auxiliaries contained in dye formulations

Depending on the dye class and the application method employed (e.g. batch or continuous dyeing, printing), different additives are present in the dye formulations. Since these substances are not absorbed/fixated by the fibres, they are completely discharged in the waste water. Typical additives are listed in Table 2.17 below.

**Table 2.17: Ecological properties of dye formulation additives**

Additive	Chemical composition	COD (mg O <sub>2</sub> /kg)	BOD <sub>5</sub> (mg O <sub>2</sub> /kg)	TOC elimination ( <sup>1</sup> )
Dispersants	- Lignin sulphonates - Naphthalene sulphonate's condensation products with formaldehyde - Ethylene oxide / propylene oxide copolymers	1 200 650	50 50	15 % 15 %
Salts	Sodium sulphate, sodium chloride	NI	NI	NI
Powder binding agents	Mineral- or paraffin oils (+ additives)	NI	NI	NI
Anti-foaming agents	Acetyl glycols	NI	NI	NI
Anti-freeze agents	- Glycerine - Glycols	1 200 1 600	780 10	90 % 95 %
Thickening agents	- Carboxymethyl cellulose - Polyacrylates	1 000	0	30 %
Buffer systems	Phosphate, Acetate	NI	NI	NI

(<sup>1</sup>) Statistical elimination test (Zahn-Wellens Test).  
NB: NI: No information.  
Source: [19, Jacobs et al. 1998]

While these additives are not toxic to aquatic life, they are in general poorly biodegradable and not readily bioeliminable. This applies in particular to the dispersants present in the formulations of vat, disperse and sulphur dyes. These dyes are water-insoluble and need these special auxiliaries in order to be applied to the textile in the form of aqueous dispersions. These dispersants consist mainly of naphthalene sulphonate-formaldehyde condensation products and lignin sulphonates, but sulphomethylation products derived from the condensation of phenols with formaldehyde and sodium sulphite can also be found. Naphthalene sulphonate

formaldehyde condensates manufactured from low-quality naphthalene can be contaminated with quinoline (CAS number: 91-22-5), which is listed in the amendment for REACH Annex XVII (Appendix 12, see Commission Regulation (EU) 2018/1513 of 10 October 2018 amending Annex XVII to Regulation (EC) No 1907/2006). Other not readily eliminable additives are acrylate and CMC-based thickeners and anti-foaming agents.

The difference between liquid and powder formulations should also be mentioned. Dyes supplied in liquid form contain only a third of the amount of dispersing agent normally contained in powder dyes (see Table 2.18). The reason for this difference stems from the manufacturing process of powder dyes: the very small particles generated during grinding must be protected during the subsequent drying process and this is possible only by adding high proportions of dispersing agents.

**Table 2.18: Proportion of additives and dye in powder and liquid dyes**

Formulation component	Powder formulation	Liquid formulation
Dye	30-50 %	20-40 %
Dispersing agent	40-60 %	10-30 %
Salts	0-20 %	NA
Powder binding agents	0-5 %	NA
Anti-foaming agents	0-5 %	0-5 %
Anti-freeze agent	NA	10-15 %
Thickening agent	NA	0-5 %
Water	5-10 %	40-60 %
NB: NA: Not applicable. <i>Source: [19, Jacobs et al. 1998]</i>		

Note that liquid formulations include liquid dispersions and true solutions (solutions without solubilising aids), whereas powder dyes can be supplied as dusting, free-flowing, non-dusting powders or granulates.

Typically, textile auxiliaries containing formaldehyde in quantities usually below 300 ppm are used. Alternatives without formaldehyde can be used, if product specifications (such as lightfastness) can be met [352, Zietlow B. 2020].

### Basic chemicals and auxiliaries used in the dyeing process

Regarding the environmental concerns associated with the chemicals and auxiliaries used in dyeing processes, it is worth mentioning the following key issues.

#### *Sulphur-containing reducing agents*

In some cases the sulphide is already contained in the dye formulation and in other cases it is added to the dye bath before dyeing. In the end, however, the excess sulphide ends up in the waste water. Sulphides are toxic to aquatic organisms and increase the COD load. In addition, sulphide anions are converted into hydrogen sulphide under acidic conditions, thereby giving rise to problems of odour and corrosivity.

Sodium hydrosulphite (also called sodium dithionite) is another sulphur-containing reducing agent, which is commonly used not only in sulphur and vat dyeing processes, but also as a reductive after-cleaning agent in PES dyeing. Sodium hydrosulphite is less critical than sodium sulphide. However, during the dyeing process sodium dithionite is converted into sulphite (toxic to fish and bacteria) and in some cases this is further oxidised into sulphate.

In the waste water treatment plant sulphite is normally oxidised into sulphate, but this can still cause problems. Sulphate, in fact, may cause corrosion of concrete pipes or may be reduced under anaerobic conditions into hydrogen sulphide.

Hydroxyacetone, although it produces an increase in COD load, is recommended to lower the sulphur content in waste water, but it cannot replace hydrosulphite in all applications. Organic reducing agents with improved reducing effects have been developed (see Sections 4.5.2.1, 8.2.9 and 8.2.10 for further details).

Consumption of the reducing agent by the oxygen present in the machine (partially flooded dyeing machines) needs also to be taken into account. Instead of applying only the amount of reducing agent required for the reduction of the dyestuff, a significant extra amount of reducing agent often needs to be added to compensate for the amount consumed by the oxygen contained in the machine. This obviously increases the oxygen demand of the effluent.

### *Oxidising agents*

Sodium dichromate and potassium dichromate have a harmonised classification carcinogenic 1B, mutagenic 1B and toxic for reproduction 1B according to the CLP Regulation. Both sodium and potassium dichromate are listed in Annex XIV to REACH and their use is therefore subject to authorisation. At the time of drafting this document, only one authorisation was granted to use sodium dichromate as mordant in wool dyeing.

During the dyeing processes with chrome dyes, Cr(VI) is reduced to Cr(III) if the process is under control. Nevertheless, emissions of Cr(VI) may still occur due to inappropriate handling of dichromate during dye preparation (care must be taken as dichromate is carcinogenic and may cause health problems for workers handling it). Emissions of trivalent chromium in the waste water can be minimised (see Section 4.5.3.1), but cannot be avoided, unless alternative dyestuffs are applied (see Section 4.5.3.1).

The use of bromate, iodate and chlorite as oxidising agents in vat and sulphur dyeing processes and the use of hypochlorite as a stripping agent for decolouring faulty goods or for cleaning dyeing machines (e.g. before subsequent lighter-coloured dyeing) may produce AOX emissions. However, only hypochlorite and elemental-chlorine-containing compounds (e.g. certain chlorite products that contain Cl<sub>2</sub> or use chlorine as an activator for formation of chlorine dioxide gas) are likely to give rise to hazardous AOX.

### *Salt*

Salts of various types are used in dyeing processes for different purposes (e.g. to promote level dyeing or increase dye exhaustion). In particular, large amounts of salt are used in cotton batch dyeing processes with reactive dyes. The amount of salt employed is relatively significant compared to other classes of dyestuffs, for example direct dyes (see Table 2.19), and efforts have been made by dye manufacturers to solve this problem (see Section 4.5.2.4).

**Table 2.19: Amount of salt employed in cotton batch dyeing processes with reactive and direct dyes**

Shade	Dye o.w.f.	Amount of salt applied with direct dyes	Amount of salt applied with reactive dyes
Paste/light	< 1.5 %	2.5-7.5 g/l	30-60 g/l
Medium	1.0-2.5 %	7.5-12.5 g/l	70-80 g/l
Dark	> 2.5 %	12.5-20 g/l	80-100 g/l

Source: [ 30, US EPA 1996 ]

In addition to the use of salt as a raw material, neutralisation of commonly employed acids and alkalis produces salts as by-products.

Salts are not removed in conventional waste water treatment systems and they are therefore ultimately discharged in the receiving water. Although the mammalian and aquatic toxicity of the commonly employed salts are very low, in arid or semi-arid regions their large-scale use can produce concentrations above the toxic limit and increase the salinity of the groundwater.

### Carriers

The use of these auxiliaries, which were widely employed in the past, has now been reduced due to ecological and health problems. They are still an issue in dyeing of polyester-wool blends.

Carriers may already be added to the dyes by manufacturers. In this case, textile finishers will have little knowledge of the loads discharged [ 32, Bettens L. 1999 ], [ 34, Tebodin 1991 ].

Carriers (see Section 8.1.6.7) include a wide group of organic compounds, many of them steam-volatile, poorly biodegradable and toxic to humans and aquatic life. However, as the active substances usually have high affinity for the fibre (hydrophobic types), 75-90 % are absorbed by the textile and only the emulsifiers and the hydrophilic-type carriers such as phenols and benzoate derivatives are found in the waste water. The carriers that remain on the fibre after dyeing and washing are partially volatilised during drying and fixing operations and can give rise to emissions to air. Traces can still be found on the finished product, thus representing a potential problem for the consumer.

Alternative options are described in Sections 4.5.4.1 and 4.5.4.1.

### Other auxiliaries of environmental interest

Other substances that may be encountered in the dyeing auxiliaries and that may give rise to water pollution are shown in Table 2.20.

**Table 2.20: Substances of environmental interest in the dyeing auxiliaries**

Substance	Function
Fatty amine ethoxylates	Levelling agent
Quaternary ammonium compounds	Retarders for cationic dyes
Polyvinylpyrrolidone	Levelling agent for vat, sulphur and direct dyes
Cyanamide-ammonia salt condensation products	Auxiliaries for fastness improvement
Acrylic acid-maleic acid copolymers	Dispersing agent
Ethylenediamine tetraacetate (EDTA)	Complexing agent
Diethylenetriaminepentaacetate (DTPA)	
Ethylenediaminetetra(methylenephosphonic acid) (EDTMP)	
Diethylenetriaminepenta(methylenephosphonic acid) (DTPMP)	
NB: Some alkylphenol ethoxylates (e.g. NPE) are banned under the REACH Regulation; also, APEOs are listed in various Manufacturing Restricted Substances Lists (see Section 4.1.6.9.1).	

These are water-soluble hard-to-biodegrade compounds which can pass untransformed or only partially degraded through waste water treatment systems.

In addition, some of them are toxic (e.g. quaternary amines) or can give rise to metabolites which may affect reproduction in the aquatic environment.

### 2.7.8.2 Environmental issues related to the process

Both water and energy consumption in dyeing processes are a function of the dyeing technique, operating practices and machinery employed.

**Batch dyeing processes** generally require higher water and energy consumption than continuous processes. This is due to a number of different factors.

The higher *liquor ratios* involved in batch dyeing represent one of these factors. As previously mentioned in Section 2.7.2, higher liquor ratios mean not only higher water and energy use, but

also a higher consumption of those chemicals and auxiliaries that are dosed based on the volume of the bath.

Consistently with the quality of the different types of substrates, all equipment manufacturers can now offer machines with reduced liquor ratios. Terms like ‘low liquor ratio’ and ‘ultra-low liquor ratio’ are commonly used to define the performance/features of modern machines.

For dyeing fabric in rope form, nominal reference values for ‘*low liquor ratio machines*’ are in the range of 1:5-1:8 for cotton and correspondingly 1:3-1:4 for PES. The liquor ratio can be higher for other types of substrates/fibres.

The term ‘*ultra-low liquor ratio*’ is used to define machines that can be operated at liquor ratios as low as the minimum volume required to completely wet the substrate and avoid cavitation of the pumps. This term applies only to machines for dyeing fabric in rope form.

It is important to show the difference between the *nominal* and the *real* liquor ratio. As already stated in Section 2.7.2, the nominal liquor ratio is the liquor ratio at which a machine can be operated when it is loaded at its maximum/optimal capacity. It is often the case that the machine is underloaded compared to its optimal capacity. This often occurs in commission companies where a high production flexibility is required to serve variable lot sizes according to customer demand. Modern machines can still be operated at approximately constant liquor ratio whilst being loaded at a level as low as 60 % of their nominal capacity (or even 30 % of their nominal capacity with yarn dyeing machines - see Section 4.5.1.7). In this way, the same benefits achievable with low liquor ratios can be kept even with reduced loading. It is obvious, however, that when a machine is loaded far below its optimal capacity (e.g. below 60 % of its nominal capacity for fabric dyeing machines) the *real liquor ratio* will differ greatly from the nominal liquor ratio. This will result not only in lower environmental performances (higher water, energy and chemical consumption), but also in higher operating costs.

In conclusion, the use of low liquor ratio machinery, or selection of the most adequate machine for the size of the lot to be processed, is fundamental to the resultant environmental performance of the process.

Having said that, high energy and water consumption in batch dyeing is not only the result of high liquor ratios.

Another factor to take into consideration is the *discontinuous nature of the batch dyeing operating mode*, especially with regard to operations such as *cooling, heating, washing and rinsing*.

Furthermore, *shade matching* can be responsible for higher water and energy consumption, especially when dyeing is carried out without the benefit of laboratory instruments. In a manual regime, the bulk of the dyestuff is normally applied in the first phase to obtain a shade which is close to that required in the final product. This is followed by a number of matching operations, during which small quantities of dye are applied to achieve the final shade. Shades which are difficult to match may require repeated shade additions with cooling and reheating between each addition [ 184, ENco 2001 ].

Increased energy and water consumption may also be caused by inappropriate *handling techniques* and/or poorly performing *process control systems*. For example, in some cases displacement spillage may occur during immersion of the fibre in the machine, while the potential for overfilling and spillage exists where the machines are only equipped with manual control valves, which fail to control the liquor level and temperature correctly (see also Section 4.1.3.2.4).

**Continuous and semi-continuous dyeing processes** consume less water, but this also means a higher dyestuff concentration in the dye liquor. In discontinuous dyeing the dye concentration

varies from 0.1 g/l to 1 g/l, while in continuous processes this value is in the range of 10 g/l to 100 g/l. The residual padding liquor in the padders, pumps and pipes is discarded when a new colour is started. The discharge of this concentrated effluent can result in a higher pollutant load compared with discontinuous dyeing, especially when small quantities of material are processed. However, modern continuous dyeing ranges have steadily improved in recent years. The use of small pipes and pumps and small pad-bath troughs helps to reduce the amount of concentrated liquor to be discharged. In addition, it is possible to minimise the discard of leftovers, by using automated dosing systems, which meter the dye solution ingredients and deliver the exact amount needed (see also Sections 4.1.6.7 and 4.5.1.1 for more detailed information).

In both continuous and batch dyeing processes, final washing and rinsing operations are water-intensive steps that need to be taken into consideration. Washing and rinsing operations actually consume greater quantities of water than dyeing itself (see Sections 4.1.3.4 and 4.1.3.4.2 for water and energy conservation techniques in batch and continuous processing and Sections 4.1.3.2.4 and 4.5.1.7 for equipment optimisation in batch processing).

## 2.8 Printing

### 2.8.1 Printing processes

Printing, like dyeing, is a process for applying colour to a substrate. However, instead of colouring the whole substrate (cloth, carpet or yarn) as in dyeing, print colour is applied only to defined areas to obtain the desired pattern. This involves different techniques and different machinery with respect to dyeing, but the physical and chemical processes that take place between the dye and the fibre are analogous to dyeing.

A typical printing process involves the following steps:

- Colour paste preparation: when printing textiles, the dye or pigment is not in an aqueous liquor. Instead, it is usually finely dispersed in a printing paste, in high concentration.
- Printing: the dye or pigment paste is applied to the substrate using different techniques, which are discussed below.
- Fixation: immediately after printing, the fabric is dried and then the prints are fixed mainly with steam or hot air (for pigments). Note that intermediate drying is not carried out when printing carpets (too much energy would be needed for removing the highly viscous liquor).
- After-treatment: this final operation consists of washing and drying the fabric (it is not necessary when printing with pigments or with other particular techniques such as transfer printing).

When describing the different printing techniques, a distinction should be made between printing with pigments, which have no affinity for the fibre, and printing with dyes (reactive, vat, disperse, etc.).

#### 2.8.1.1 Printing with pigments

Pigment printing has gained in importance and for some fibres (e.g. cellulose fibres) it is by far the most commonly applied technique. Pigments can be used on almost all types of textile substrates and, thanks to the improved performance of modern auxiliaries, it is possible to obtain high-quality printing using this technique.

Pigment printing pastes contain a thickening agent, a binder and, if necessary, other auxiliaries such as fixing agents, plasticisers, anti-foaming agents, etc.

More information regarding the characteristics of the auxiliaries used can be found in Section 8.1.7.2

After applying the printing paste, the fabric is dried and then the pigment is normally fixed with hot air (depending on the type of binder in the formulation, fixation can also be achieved by storage at 20 °C for a few days). The advantage of pigment printing is that the process can be done without subsequent washing (which, on the other hand, is needed for most of the other printing techniques).

#### 2.8.1.2 Printing with dyes

##### Printing paste preparation

The process traditionally starts with the preparation of the paste. Compared to pigment printing, the composition of the pastes is more complex and variable, being determined not by the dye

used, but by the printing technique, the substrate, the application and the fixation methods applied.

Apart from the dye, printing pastes contain a thickening agent (see also Section 8.1.7.1) and various other auxiliaries, which can be classified according to their function as follows:

- oxidising agents (e.g. m-nitrobenzenesulphonate, sodium chlorate, hydrogen peroxide);
- reducing agents (e.g. sodium dithionite, formaldehyde sulphonylates, thiourea dioxide, tin(II) chloride);
- discharging agents for discharge printing (e.g. anthraquinone);
- substances with a hydrotropic effect, like urea;
- dye solubilisers, which are polar organic solvents like glycerine, ethylene glycol, butyl glycol, thiodiglycol, etc.;
- ‘resists’ for reactive resist printing (e.g. sulphonated alkanes);
- defoamers (e.g. silicon compounds, organic and inorganic esters, aliphatic esters).

All the necessary ingredients are metered (dosed) and mixed together in a mixing station. Since between 5 and 10 different printing pastes are usually necessary to print a single pattern (in some cases up to 20 different pastes are applied), the preparation of the pastes is done in automatic stations in order to reduce losses due to incorrect measurement. In modern plants, with the help of special devices, the exact amount of printing paste required is determined and prepared in continuous mode for each printing position, thus reducing leftovers at the end of the run.

It is common practice in many print houses to filter the printing pastes before application, using for example a filter cloth. This operation is especially important for thickeners to prevent free particles from blocking the openings of the screens.

### **Printing (paste application)**

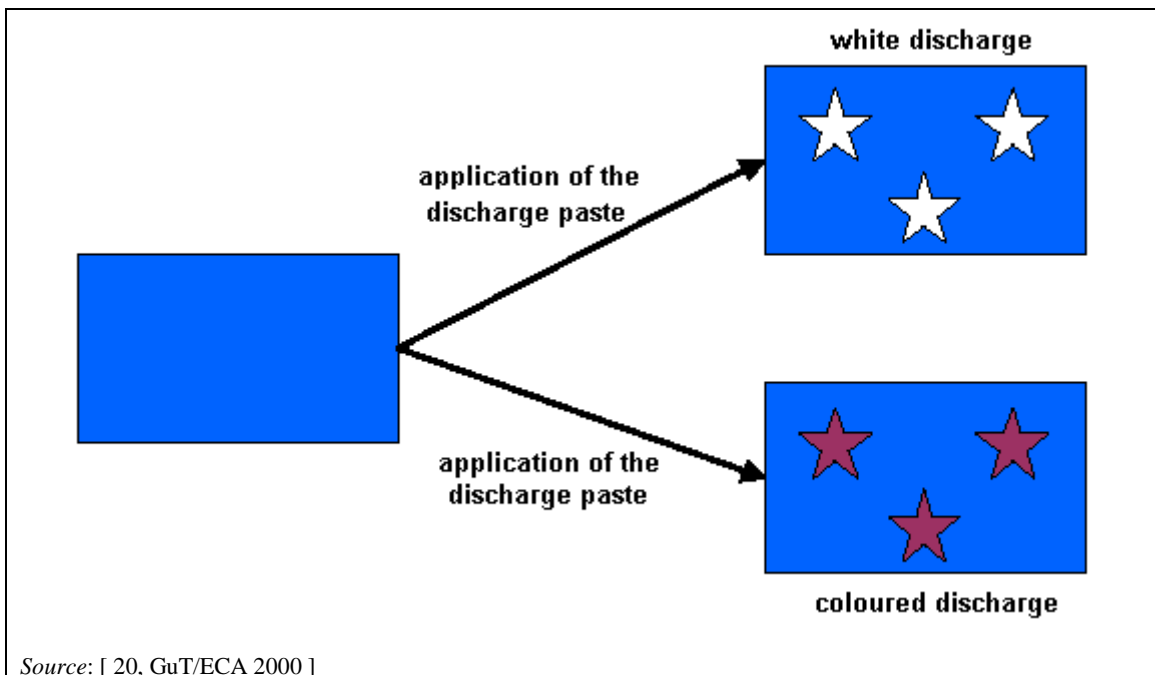
After preparation, the paste is applied to specific areas of the textile using one of the following techniques:

- direct printing (which also includes digital and transfer printing);
- discharge printing;
- resist printing.

In the case of *direct printing* the dye is applied to specific areas of a pretreated textile substrate, which can be white or pre-dyed (in light colours).

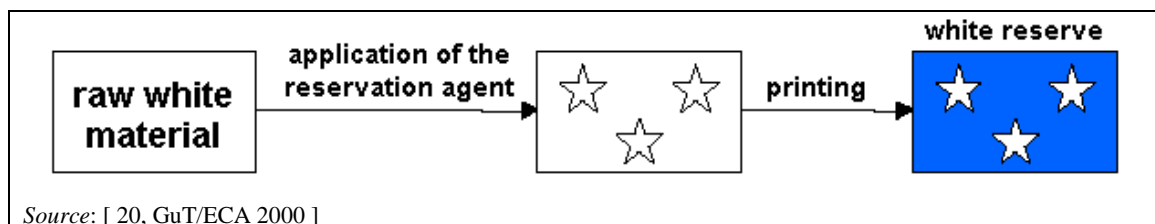
It is known as *discharge printing* if in the fixation process that follows the application of the printing paste there is local destruction of a dye applied previously. If the etched (discharge), previously dyed area becomes white, then the process is called *white discharge*. If, on the contrary, a coloured pattern has to be obtained in the etched area after the destruction of the previously applied dye, then the process is called *coloured discharge*. In this case, the printing paste contains a reduction-resistant dye along with the chemicals needed to destroy the previous one. As a result, the pre-dyed background is destroyed according to a pattern and the dye, which is resistant to reduction, takes its place. Figure 2.14 below shows a representation of discharge printing.





**Figure 2.14: Schematic representation of discharge printing**

In the case of *resist printing*, a special printing paste (called 'resist') is printed onto certain areas of the fabric to prevent dye fixation (see a schematic representation in Figure 2.15 below). In the case of *physical resist*, the material is printed with a difficult-to-wet resin that inhibits the penetration of a dye applied in a second stage. On the other hand, with a *chemical resist*, dye fixation is prevented by a chemical reaction. Depending on the way the process is carried out, the resists are referred to as pre-printing, intermediate or over-printing resists. One common procedure is the wet-on-wet process in which the resist paste is initially printed, then the material is overprinted with full cover screen and finally fixed and washed. Over-printing resists can be applied only if the dye, already present in the previously dyed and dried fabric, is still in its unfixed form, as in the case of developing dyes.



**Figure 2.15: Schematic representation of resist printing**

The difference between *transfer printing* and the techniques described earlier is that with this technique the surface of the fabric is not directly printed on. Instead, the pattern is first created on an intermediate carrier (e.g. paper) using selected disperse dyes and then it is transferred from there to the fabric. The dye is usually fixed by placing the printed paper in contact with the fabric into a thermal pressure system. Under the influence of the heat, the dye sublimates and diffuses from the carrier into the fibre of the textile substrate. There is no need for further treatment such as steaming, washing, etc. This technique is applied for polyester, polyamide and some acrylic fibres, using selected disperse dyestuffs according to the specific type of fibre.

**Fixation**

After printing, the fabric is dried. Water evaporation leads to an increase in dye concentration and at the same time prevents the colours from smearing when the fabric is transported over the guide rollers. At this stage the dye is not yet fixed.

The aim of the subsequent fixation step is to transport as much as possible of the dye, which is retained by the thickener, into the fibres. This is especially important with dyes, such as vat dyes, for example, that are printed in the insoluble form and are converted into the corresponding soluble state only after reaction with the reducing agents during the fixation process.

Fixation is usually carried out with steam. Water vapour condenses on the printed material, causes the thickener to swell, heats the printing machine and provides the necessary transport medium for the diffusion of the dye. The distribution of the dye between fibre and thickener is an important factor in determining the degree of fixation of the dye, which is called the 'retaining power' of the thickener. The thickener, in fact, is often composed of polysaccharides and therefore competes with cellulose in retaining the dye. This is the main reason why the fixation rate of a given dye is 10 % lower in printing than in dyeing.

**After-treatment**

The last step of the printing process consists of washing and drying the fabric. When printing with insoluble dyes such as vat dyes this operation also serves as a means to reconvert the dye to the original oxidised state. In this case, after an initial rinsing with cold water, the printed material is treated with hydrogen peroxide. The process is completed with a soap treatment with sodium carbonate at the boiling point.

As already explained, washing is not necessary with pigment printing and transfer printing. This holds for any dyeing/printing system where thickeners are not needed and where the dyestuff is (nearly) completely fixed (e.g. printing carpet tiles with digital jet printing techniques, see Section 4.6.1.2).

**Ancillary operations**

At the end of each batch and at each colour change, various cleaning operations are carried out:

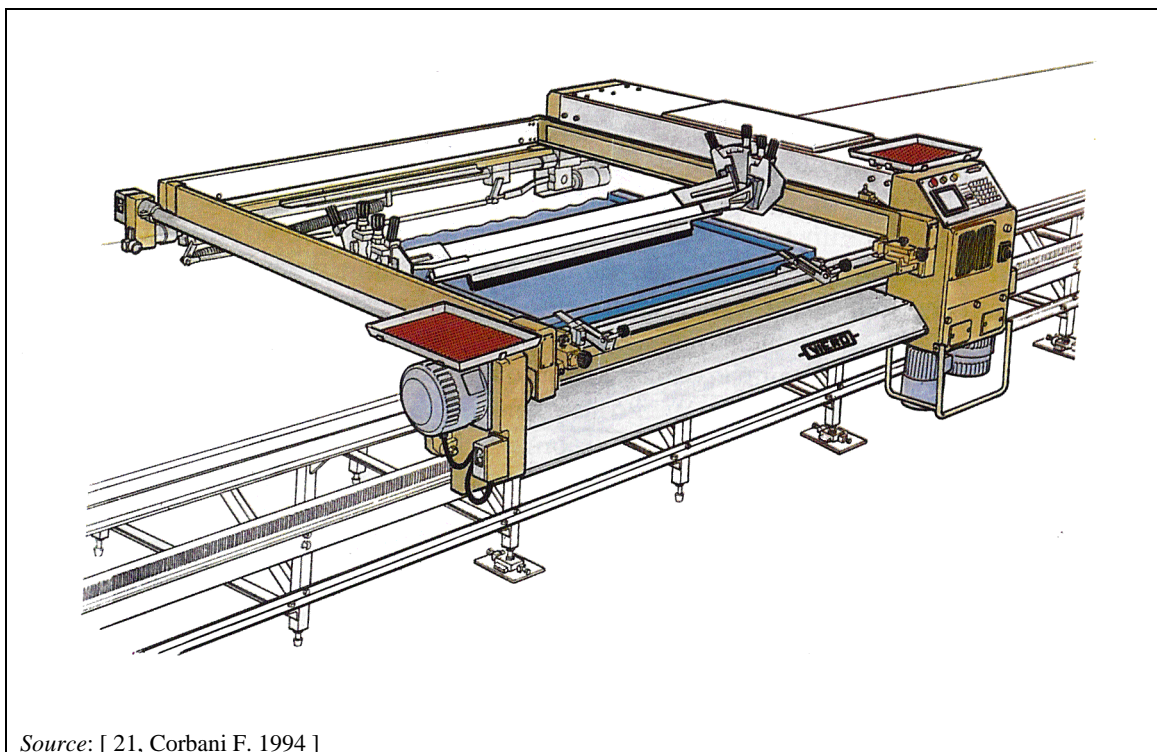
- The rubber belt, to which the fabric is glued during printing (see description below), is cleaned in continuous mode with water to remove excess adhesive and printing paste. Some machines are equipped with water recirculation systems.
- The printing gears (all systems responsible for feeding and applying the paste to the substrate) are cleaned by first removing as much as possible of the paste residues and then rinsing with water. In some companies, the paste residues are directed back to the appropriate printing paste batch containers for reuse (see Section 4.6.1.7).
- The remaining paste in the containers, in which the paste is prepared (paste vats), is in general previously cleaned up by means of sucking systems before being washed out with water. The residual printing paste collected in this manner is then disposed of.

## 2.8.2 Printing technology

A variety of different machines can be used for printing fabrics. The most commonly used are described below.

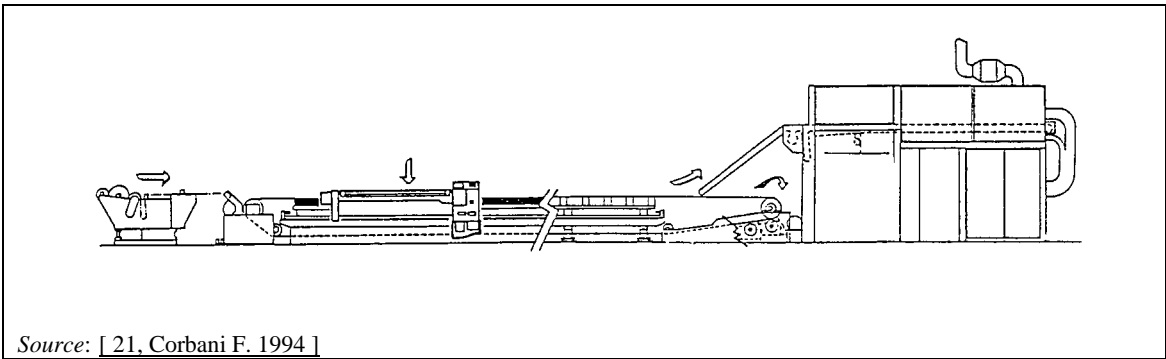
### 2.8.2.1 Flat-screen printing

Flat-screen and rotary-screen printing are both characterised by the fact that the printing paste is transferred to the fabric through openings in specially designed screens. The openings on each screen correspond to a pattern and, when the printing paste is forced through by means of a squeegee, the desired pattern is reproduced on the fabric. A separate screen is made for each colour in the pattern. Figure 2.16 below shows an example of a flat-screen printing machine.



**Figure 2.16: Flat-screen printing with automatic squeegee system**

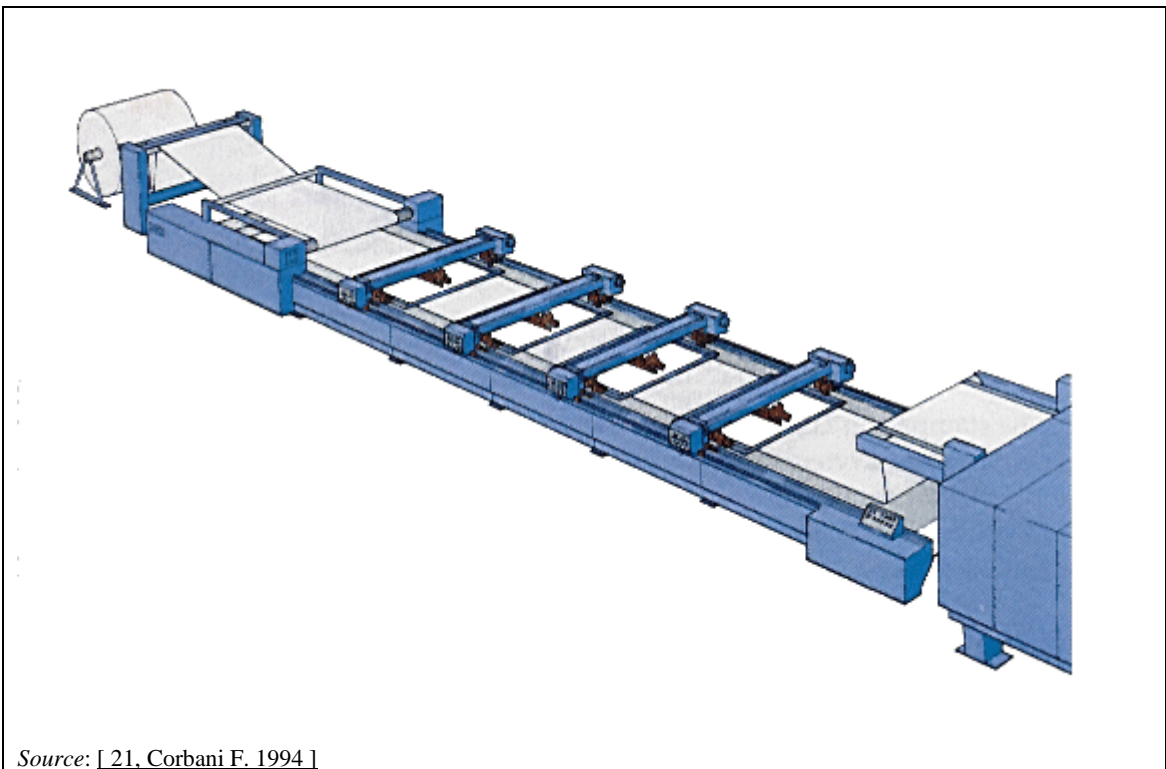
Flat-screen printing machines can be manual, semi-automatic or completely automatic. One type of machine, which is still commonly found in print houses, can be described as follows. The fabric is first glued to a moving endless belt. A stationary screen at the front of the machine is lowered onto the area that has to be printed and the printing paste is wiped with a squeegee. Afterwards the belt, with the fabric glued onto it, is advanced to the pattern-repeat point and the screen is lowered again. The printed fabric moves forward step by step and passes through a dryer. The machine prints only one colour at a time. When the first colour is printed on the whole length of the fabric, the dried fabric is ready for the second cycle and so on until the pattern is completed. Figure 2.17 below shows a representation of a flat-screen printing machine.



Source: [ 21, Corbani F. 1994 ]

**Figure 2.17: Representation of a flat-screen printing machine**

In other fully mechanised machines all the colours are printed at the same time (see Figure 2.18 below). A number of stationary screens (from 8 to 12, but some machines are equipped with up to 24 different screens) are placed along the printing machine. The screens are simultaneously lifted, while the textile, which is glued to a moving endless rubber belt, is advanced to the pattern-repeat point. Then the screens are lowered again and the paste is squeezed through the screens onto the fabric. The printed material moves forward one frame at each application and as it leaves the last frame it is finally dried and ready for fixation.



Source: [ 21, Corbani F. 1994 ]

**Figure 2.18: Representation of a mechanised screen printing machine with stationary screens mounted in a frame**

In both machines, the continuous rubber belt, after pulling away the fabric, is moved downward in continuous mode over a guide roller and washed with water and rotating brushes to remove the printing paste residues and the glue, if necessary. After this, the belt is sent back to the gluing device. In some cases, the glue is applied in liquid form by a squeegee, while in other machines the belts are pre-coated with thermoplastic glues. In this case, the textile is heated and then it is squeezed by a roller or simply pressed against the rubber-coated belt, causing the glue to soften and instantly adhere.

After printing, the screens and the application system are washed out. It is common practice to squeeze the colour from the screens back into the printing paste mixing containers before washing them.

### 2.8.2.2 Rotary-screen printing

Rotary-screen printing machines use the same principle described earlier, but, instead of flat screens, the colour is transferred to the fabric through lightweight metal foil screens, which are made in the form of cylinder rollers (see Figure 2.19 and Figure 2.20 below). The fabric moves along in continuous mode under a set of cylinder screens while at each position the printing paste is automatically fed to the inside of the screen from a tank and is then pressed through onto the fabric. A separate cylinder roller is required for each colour in the design.

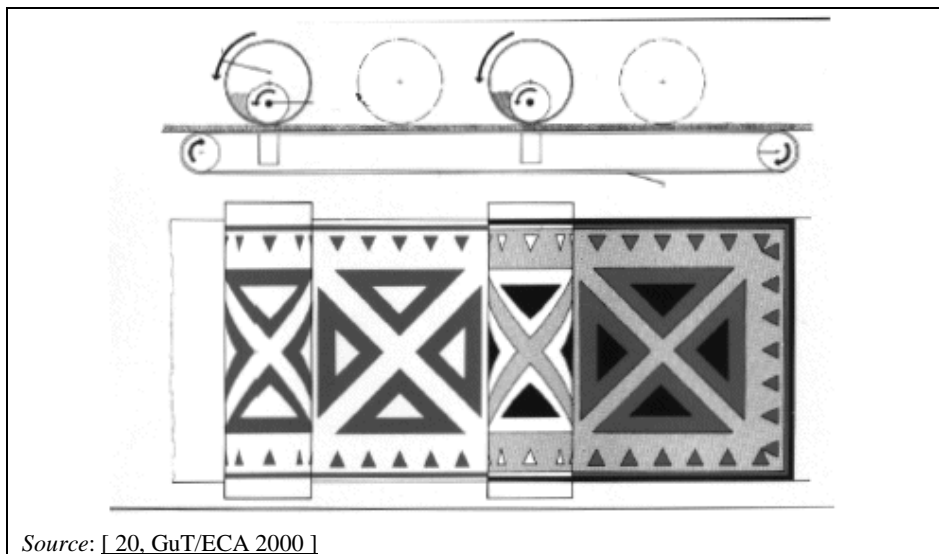


Figure 2.19: Representation of the rotary-screen printing process

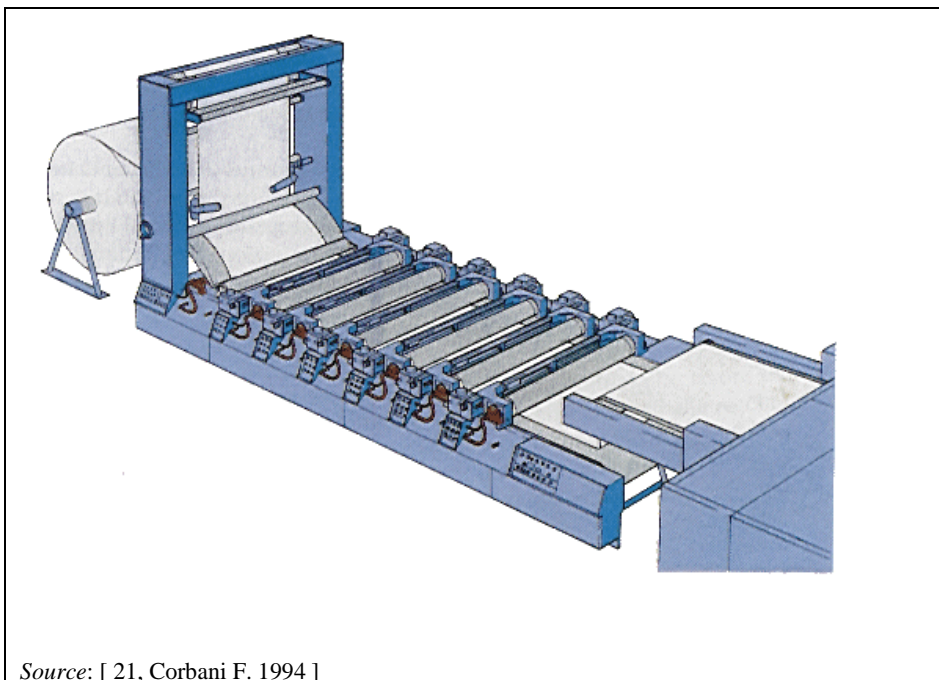
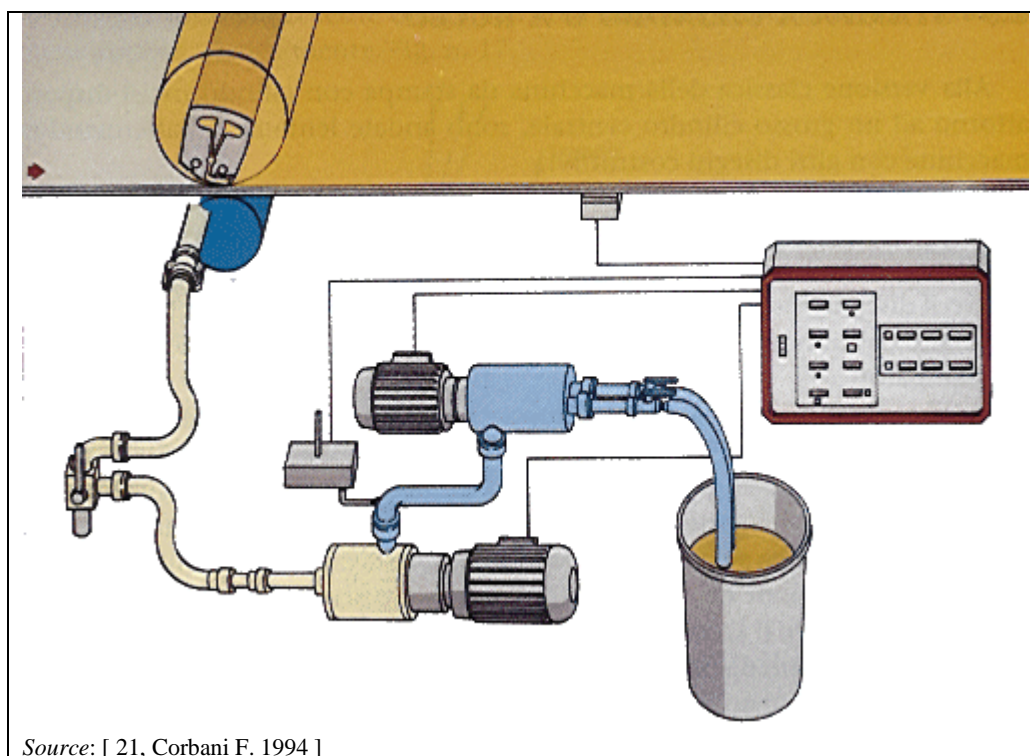


Figure 2.20: Representation of a rotary-screen printing machine

A conventional paste feeding system for rotary-screen printing machines is represented in Figure 2.21. A suction pipe leads from the paste vat to a pump, from where a printing hose leads to the squeegee (dye pipe with squeegee). From here the paste is directed inside the cylinder roller. The fill volume of this so-called printing paste input system is relatively high and as a consequence the amount of paste residue that has to be removed at each colour change is also fairly significant. Various systems have been introduced in order to lower the volume configuration of this equipment, which also reduces the amount of such wastes (see Section 4.6.1.5). Another possibility, which has also been implemented in some companies, is to recover and reuse these residues for making up new recipes (see Sections 4.6.1.6 and 4.6.1.7).



**Figure 2.21: Printing paste feeding system for a rotary-screen printing machine**

Rotary-screen printing machines are equipped with both gluing and washing devices analogous to those described earlier for flat-screen printing. The belt is washed in order to remove the residues of paste and adhesive. Not only the belt, but also the screens and the paste input systems (hoses, pipes, pumps, squeegees, etc.) are cleaned at each colour change.

### 2.8.2.3 Roller printing

In roller printing, the printing paste is supplied from reservoirs to rotating copper rollers, which are engraved with the desired design (see Figure 2.22 and Figure 2.23 below). These rollers are brought into contact with a main cylinder roller that transports the fabric. By the contact between the rollers and the fabric, the design is transferred to the fabric. As many as 16 rollers can be available per print machine, each roller imprints one repeat of the design. As the roller spins, a doctor blade in continuous mode scrapes the excess paste back to the colour trough. At the end of each batch, the paste reservoirs are manually emptied into appropriate printing paste batch containers and squeezed out. The belt and the printing gear (roller brushes or doctor blades, squeegees and ladles) are cleaned with water.

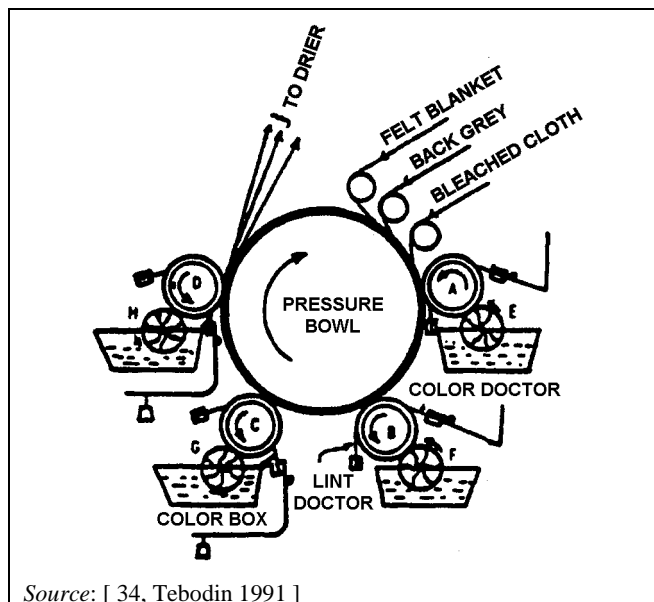


Figure 2.22: Roller printing machine

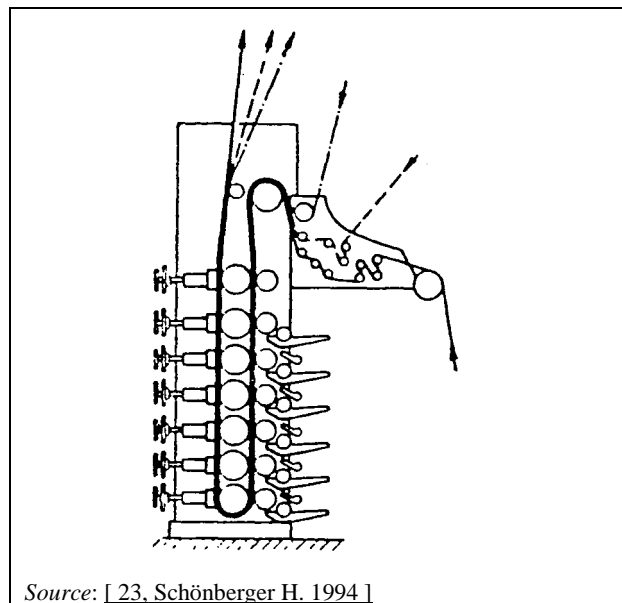
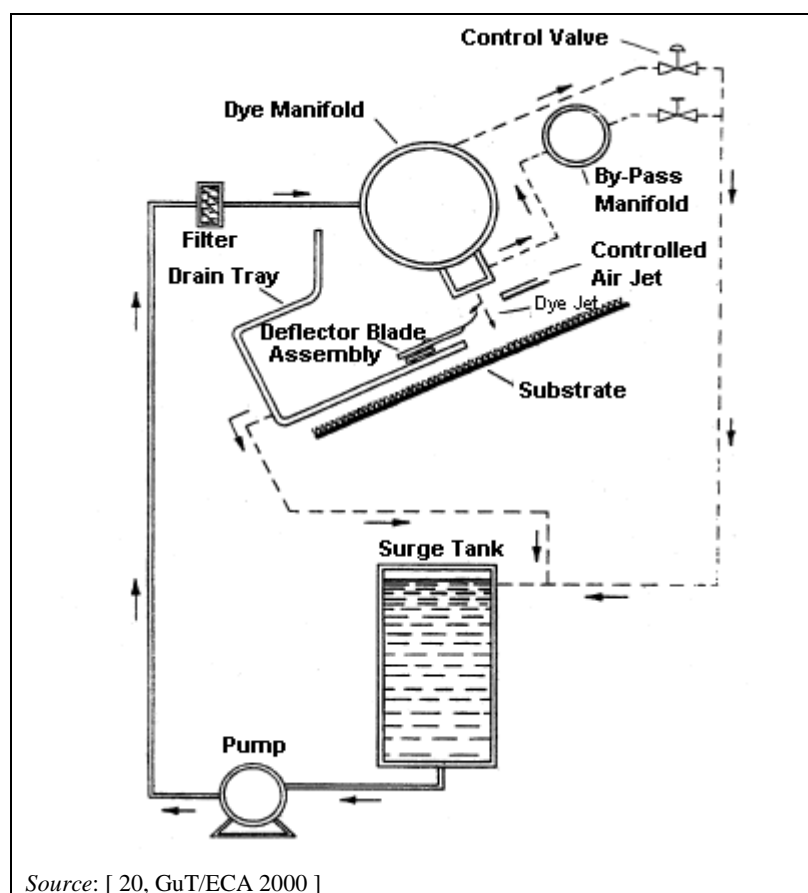


Figure 2.23: More recent example of a roller printing machine

#### 2.8.2.4 Jet printing

Jet printing is a non-contact application system originally developed for printing carpets, but now increasingly used in the textile sector.

The injection of the dye into the substrate is accomplished by switching on and off a dye jet by means of a controlled air stream. As the fabric moves along, no parts of the machine are in contact with the face of the substrate. Air streams are used to maintain continuously flowing dye jets, deflected into a catcher or drain tray. This dye is drained back to the surge tank, filtered and recirculated. When a jet is requested to fire, the air jet is momentarily switched off, allowing the correct amount of dye to be injected into the textile substrate. The dye is supplied in continuous mode to the main storage tank to compensate for the amount of dye consumed. A schematic representation of a jet printing machine is given in Figure 2.24 below.



**Figure 2.24: Schematic representation of a jet printing machine**

Spray printing systems and first-generation jet printing methods cannot be controlled to produce a pre-specified pattern. Thus the equipment is first employed to produce a wide range of effects and only then can selections be made from these by the designer or marketing staff.

An early improvement was made by the first digital carpet printers. These machines are based on the 'drop on demand principle', namely the use of switchable electromagnetic valves placed in the dye liquor feed tubes, to allow the jetting of discrete drops of dye liquor in a predetermined sequence according to the desired pattern.

In these machines, although the amount of dye applied can be digitally controlled at each point of the substrate, further penetration of the dye into the substrate is still dependent on capillary action of the fibre and fibre surface wetting forces. This can lead to problems of reproducibility (e.g. when the substrate is too wet) and means that it is still necessary to use thickeners to control the rheology of the dye liquor.

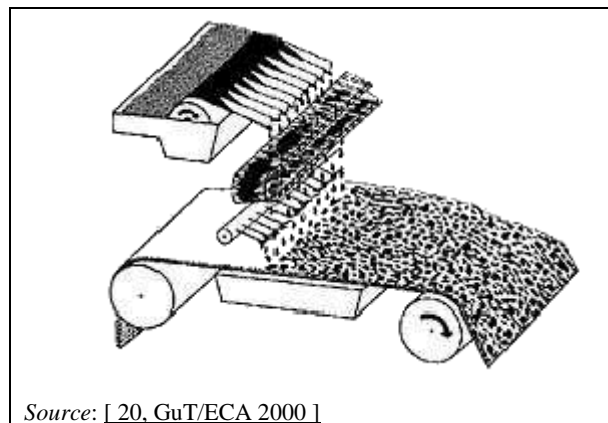
The latest improvement in jet printing of carpet and bulky fabrics is now represented by machines in which the colour is injected with surgical precision deep into the face of the fabric without any machine parts touching the substrate. Here, the control of the quantity of liquor applied to the substrate (which may vary for example from lightweight articles to heavy quality fabrics) is achieved by varying not only the 'firing time' but also the pumping pressure.

The carpet is accumulated into a J-shaped box ('J-box'), and is then steamed and brushed. When it reaches the printing table, it is stopped. The jets are mounted on a sliding frame that can itself be moved in the direction of the warp while the carpet remains stationary during the printing process.



Ink-jet printing is another digital printing technique with its origins in paper printing technology that is now also increasingly used in the textile industry. In ink-jet printing, colour is applied to the surface of the substrate without variation in firing time, pressure or velocity. For this reason, it can only be applied for flat, light fabrics, especially silk (see Section 4.6.1.3).

The TAK (an acronym of the two German machine producers: Textile Ausrüstungs and Kusters) printing system can still be found in the carpet industry (see Figure 2.25). With this technique, irregular patterns can be produced. The carpet, previously dyed with a ground shade, is provided with coloured spots through dripping. The size and the frequency of the coloured spots can be varied by adjusting the overflow groove placed along the carpet width.



**Figure 2.25: Schematic representation of the TAK system**

### 2.8.2.5 Transfer printing

The pattern is first created on an intermediate carrier (e.g. paper) using selected disperse dyes and then it is transferred from there to the fabric by applying high temperature and pressure (using a heat press or a calender). Transfer printing is used for synthetic fibres.

See also Section 4.6.1.4.

[ 35, RICARDO 2019 ], [ 36, Sinocolor 2019 ]

### 2.8.3 Environmental issues

Emission sources typical of printing processes are:

- printing paste residues;
- waste water from wash-off and cleaning operations;
- volatile organic compounds from drying and fixing.

### 2.8.3.1 Printing paste residues

Printing paste residues are produced for different reasons during the printing process and the amount can be particularly relevant (Section 3.7.5 provides information about consumption and emission levels). Two main causes are, for example, incorrect measurements and the common practice of preparing excess paste to prevent a shortfall.

Moreover, at each colour change, printing equipment and containers (dippers, mixers, homogenisers, drums, screens, stirrers, squeegees, etc.) are cleaned. Printing pastes adhere to every implement due to their high viscosity and it is common practice to use dry capture systems to remove them before rinsing with water. In this way, these residues can at least be disposed of in segregated form, thus minimising water contamination.

Another significant but often forgotten source of printing paste residues is the preparation of sample patterns. Sometimes they are produced on series production machines, which means high specific amounts of residues are produced.

There are techniques available that can help to reduce paste residues (see Section 4.6.1.5) and techniques for recovery/reuse of the surplus paste (see Sections 4.6.1.6 and 4.6.1.7). Their efficiency is, however, limited due to a number of inherent technological deficiencies of analogue printing technology. Most of these deficiencies are related to the analogue transfer of the pattern, the unavoidable contact between the surface of the substrate and the applicator (screen) and the need for thickeners in the formulation (paste rheology), which limits the ultimate potential for paste reuse.

Digital printing offers a solution to these problems (see Sections 4.6.1.2 and 4.6.1.3).

### 2.8.3.2 Waste water from wash-off and cleaning operations

Waste water in printing processes is generated primarily from final washing of the fabric after fixation, cleaning of application systems in the printing machines, cleaning of colour kitchen equipment and cleaning of belts.

Waste water from cleaning operations accounts for a large share of the total pollutant load, even more than water from wash-off operations.

Emission loads to water are mainly attributable to dyestuff printing processes because in the case of pigment printing, although considerable amounts of waste water arise from cleaning operations, pigments are completely fixed on the fibre without the need for washing off.

Pollutants that are likely to be encountered in waste water are listed in Table 2.21 below.

**Table 2.21: Pollutants that are more likely to be encountered in waste water from printing processes**

Pollutant	Source	Remarks
Organic dyestuff	Unfixed dye	The related environmental problems depend on the type of dyestuff concerned (these are discussed in Section 8.2)
Urea	Hydrotropic agent	High levels of nitrogen contribute to eutrophication
Ammonia	In pigment printing pastes	High levels of nitrogen contribute to eutrophication
Sulphates and sulphites	Reducing agent by-products	Sulphites are toxic to aquatic life and sulphates may cause corrosion problems when the concentration is > 500 mg/l
Polysaccharides	Thickeners	High COD, but easily biodegradable
CMC derivatives	Thickeners	Poorly biodegradable and poorly bioeliminable
Polyacrylates	Thickeners Binder in pigment printing	Poorly biodegradable, but > 70 % bioeliminable (OECD 302B test method)
Glycerin and polyols	Anti-freeze additives in dye formulation Solubilising agents in printing pastes	
m-Nitrobenzene sulphonate and its corresponding amino derivative	In discharge printing of vat dyes as oxidising agent In direct printing with reactive dyes, it inhibits chemical reduction of the dyes	Poorly biodegradable and water-soluble
Polyvinyl alcohol	Blanket adhesive	Poorly biodegradable, but > 90 % bioeliminable (OECD 302B test method)
Multiple-substituted aromatic amines	Reductive cleavage of azo dyestuff in discharge printing	Poorly biodegradable and poorly bioeliminable
Mineral oils / aliphatic hydrocarbons	Printing paste thickeners (half-emulsion pigment printing pastes are still occasionally used)	Aliphatic alcohols and hydrocarbons are readily biodegradable Aromatic hydrocarbons are poorly biodegradable and poorly bioeliminable

### 2.8.3.3 Volatile organic compounds from drying and fixing

Drying and fixing are other important emission sources in printing processes. The following pollutants may be encountered in the exhaust air [5, UBA 2001 ]:

- aliphatic hydrocarbons (C<sub>10</sub>-C<sub>20</sub>) from binders;
- monomers such as acrylates, vinylacetates, styrene, acrylonitrile, acrylamide, butadiene;
- methanol from fixation agents;
- other alcohols, esters, polyglycols from emulsifiers;
- formaldehyde from fixation agents;
- ammonia (from urea decomposition and from ammonia present, for example, in pigment printing pastes);
- N-methylpyrrolidone (NMP) from emulsifiers;
- phosphoric acid esters;
- phenylcyclohexene from thickeners and binders.

(Note: NMP is a SVHC, subject to restriction #71 under Annex XVII to REACH (as of May 2020) due to potential harm to workers' health.)

A more comprehensive list of pollutants potentially present in the exhaust air from heat treatment after printing, with an indication of the potential source, is given in Section 8.6.

## 2.9 Finishing (functional finishing)

### 2.9.1 Finishing processes

The term 'finishing' covers all those treatments that serve to impart to the textile the desired end-use properties. These can include properties relating to visual effect, handle and special characteristics such as waterproofing and non-flammability.

Finishing may involve mechanical/physical and chemical treatments. Moreover, among chemical treatments, one can further distinguish between treatments that involve a chemical reaction of the finishing agent with the fibre and chemical treatments where this is not necessary (e.g. softening treatments).

Some finishing treatments are more typical for certain types of fibre (for example, easy-care finishes for cotton, antistatic treatment for synthetic fibres and mothproofing and anti-felt treatments for wool). Other finishes have a more general application (e.g. softening).

In this document, particular attention is given to chemical finishes because these are the processes with the most significant polluting potential.

In the case of fabric (including carpets in piece form), the finishing treatment often takes place as a separate operation after dyeing. However, this is not a rule: in carpets, for example, mothproofing can be carried out during dyeing and, in pigment dyeing, resin finishing and pigment dyeing are combined in the same step by applying the pigment and the film-forming polymer in the dyeing liquor.

In more than 80 % of cases, the finishing liquor, in the form of an aqueous solution/dispersion, is applied by means of padding techniques. The dry fabric is passed through the finishing bath containing all the required ingredients, and is then passed between rollers to squeeze out as much as possible of the treating solution before being dried and finally cured. Washing as a final step tends to be avoided unless absolutely necessary.

In order to reduce the pick-up, other so-called minimum application techniques are gaining importance. These are topical application methods like:

- kiss-roll (or slop-padding) application (the textile is wetted by means of a roller, which is immersed in a trough and which applies a controlled amount of liquor on only one side of the textile);
- spray application;
- foam application.

In the case of foulard application the pick-up is approximately 70 %, while with minimum application systems this can be about 30 %. In the minimum application techniques, however, the liquors are more concentrated by a factor of 2 to 3 in order to allow the same amount of active ingredient to be applied.

In the wool yarn carpet sector, the functional finishes are applied to the yarn or to the loose fibre either during the dyeing process or in the subsequent rinsing or finishing bath.

Apart from particular cases where there are problems of incompatibility between the different auxiliaries, both with padding and long liquor application techniques (batch processes), all the finishing agents necessary to give the textile material the desired properties are applied in a single bath rather than in different steps.

## 2.9.2 Chemical finishing treatments

### 2.9.2.1 Easy-care treatments

Easy-care finishings are applied to cellulose-containing fibres to impart characteristics such as easy-to-wash, creasing resistance during wash and wear, no ironing or minimum ironing.

Easy-care recipes consist of various ingredients:

- cross-linking agent;
- catalyst;
- additives (softeners, hand builder most commonly, but also water-repellents, hydrophilising agents, etc.);
- surfactants as a wetting agent.

Information about the typical substances used can be found in Section 8.1.8.1. In the easy-care process, the fabric, after being padded, is dried in open-width form in a stenter frame and is finally cured. The most common curing method is the dry cross-linking process, in which the fabric is cured in a dry state in a curing apparatus or on the stenter immediately after drying. For more information on cross-linking agents with improved environmental performance, see Section 4.7.2.1).

### 2.9.2.2 Water- and oil-repellent treatments (hydrophobic and oleophobic treatments)

Water-repellent treatments are applied to fabrics for which waterproofing properties are required but which also need air and water-vapour permeability.

This may be obtained by:

- precipitation of hydrophobic substances such as paraffin emulsions together with aluminium salts (e.g. wax-based repellents);
- chemical transformation of the surface of the fibre by addition of polymers that form a cross-linked water-repellent film (e.g. silicone repellents, resin-based repellents, fluorochemical repellents).

Oil-repellent treatments are applied to fabrics for which oil-proofing is required. This may be obtained by chemical transformation of the surface of the fibre by addition of polymers that form a cross-linked oil-repellent film (mainly fluorochemical-based repellents) [[37, Manich et al. 2018](#)].

In addition to providing protection against water, oil and soil, these finishes also extend the life of products and keep them looking newer for longer. Water and oil repellence has historically been achieved with textile finishes that contain a polymer to which long-chain perfluoroalkyl groups have been attached. These long-chain fluorinated polymers often contain residual raw materials and trace levels of long-chain perfluoroalkyl acids (PFAAs) as impurities. The residual raw materials and the product themselves may degrade in the environment to form long-chain PFAAs.

Since the 1950s, long-chain PFAAs, as well as polymers and surfactants containing long-chain perfluoroalkyl functionality that may degrade to form long-chain PFAAs, have been widely used in numerous industries and commercial applications. As a result of the widespread use, long-chain PFAAs including PFOA and PFOS have been detected globally in the environment, wildlife and humans. PFOA and PFOS, the most widely known and studied long-chain PFAAs,

have been shown to be persistent in the environment, have a long elimination half-life in wildlife and humans, and have toxicological properties of concern. Due to these properties, regulatory actions have been put in place or are being considered to manage these substances [ 37, Manich et al. 2018 ]. In the EU, PFOA and its salts have been listed in Annex XVII to REACH [ 7, EU 2006 ] since 2017 and in category A (Elimination) in the Stockholm Convention on Persistent Organic Pollutants. PFOS and its derivatives are priority hazardous substances [ 38, EC 2008 ] and PFOS is prohibited by the POP Regulation ( EU/2019/1021 ) [ 39, EU 2019 ].

Furthermore, the ‘Chemicals Strategy for Sustainability Towards a Toxic-Free Environment’ [ 40, COM 2020 ] proposes a set of actions to address the use of and contamination with PFAS. Those aim to ensure, in particular, that the use of PFAS is phased out in the EU, unless it is proven essential for society, by:

- banning all PFAS as a group in firefighting foams as well as in other uses, allowing their use only where they are essential for society;
- addressing PFAS with a group approach, under relevant legislation on water, sustainable products, food, industrial emissions, and waste;
- addressing PFAS concerns on a global scale through the relevant international fora and in bilateral policy dialogues with third countries;
- establishing an EU-wide approach and provide financial support under research and innovation programmes to identify and develop innovative methodologies for remediating PFAS contamination in the environment and in products;
- providing research and innovation funding for safe innovations to substitute PFAS under Horizon Europe.

[ 40, COM 2020 ]

Section 4.7.5.1 gives some examples of alternatives to fluorochemical-based repellents.

The characteristics of the substances used as water-repellents are described in Section 8.1.8.5.

### 2.9.2.3 Softening treatments

Softeners are used not only in finishing processes, but also in batch dyeing processes, where they are applied in the dye baths or in the subsequent washing baths.

The application of softening agents does not involve curing processes. In continuous or semi-continuous processes, the impregnated fabric is dried in the stenter frame.

The substances used as softening agents are described in Section 8.1.8.6.

### 2.9.2.4 Flame-retardant treatments

Flame-retardant finishing has become more and more important and is compulsory for some articles. Flame-retardant treatments should protect the fibre from burning, without modifying the handle, the colour or the look of the fabric.

They are generally applied to cotton, silk, flax, viscose and synthetic fibres like polyester, polyamide, acrylics and their blends (e.g. they are important in the furniture sector for upholstery fabric, carpets, curtains, automotive products or baby products). In some specific cases, in particular in the carpet sector (e.g. contract market, aviation), they can also be required for wool, even though this fibre is already inherently partially flame-resistant.

Flame-retardant properties are achieved by the application of a wide range of chemicals, which either react with the textile or are used as additives. Substances that are usually used as flame-retardant finishing treatments are described in Section 8.1.8.4.

There are other approaches available to produce textile products with flame-retardant properties including:

- the addition of specific chemicals in the spinning solution during fibre manufacturing;
- the development of modified fibres with inherent flame-retardant properties;
- back-coating of finished textile-covered articles (e.g furniture, mattresses), whereby a fire-resistant layer is attached to one side of the finished textile.

[ 41, FLAREX 2020 ]

### **2.9.2.5 Anti-static treatments**

The process consists of treating the fabric with hygroscopic substances (anti-static agents) which increase the electrical conductivity of the fibre, thus avoiding the accumulation of electrostatic charge.

These finishing treatments are very common for synthetic fibres, but they are also applied to wool in the carpet sector for floor coverings that have to be used in static-sensitive environments.

The substances commonly used as anti-static agents are described in Section 8.1.8.3.

### **2.9.2.6 Mothproofing treatments**

The mothproofing of wool and wool blends is mainly restricted to the production of textile floor coverings, but some high-risk apparel is also treated (for example military uniforms). For apparel application, mothproofing is usually carried out in dyeing. Floor coverings may be mothproofed at different stages of the production process, such as during raw wool scouring, spinning, yarn scouring, dyeing, finishing or later in the backing line.

The biocides used in mothproofing treatments are described in Section 8.1.8.2.

### **2.9.2.7 Bactericidal and fungicidal treatments**

These finishes may be applied to chemicals (to preserve auxiliaries and dye formulations) and to apparel, for example in odour suppressant for socks and for the treatment of floor coverings for the healthcare sector and to provide anti-dust-mite finishes. More and more textile products (clothing and underwear) are being treated with anti-microbial agents.

The products used are biocides; these are mentioned in Section 8.1.8.2.

### **2.9.2.8 Anti-UV treatments**

The anti-UV protection consists of nano-dispersion of titanium dioxide and is applied on fabrics by padding. Dosing of chemicals is done automatically, in a closed-circuit system connected to the bath of the pad to avoid possible human contact. During the drying process, the temperature is controlled in order to avoid migration to air of non-fixed nanoparticles. Titanium dioxide was added in 2019 to the Annex VI to the CLP Regulation (on harmonised classification, labelling



and packaging of substances and mixtures), as a category 2 carcinogen when inhaled for mixtures placed on the market in powder form containing 1% or more of titanium dioxide particles with a diameter  $\leq 10 \mu\text{m}$ .

The most relevant environmental impacts associated with the product used are related to the potential waste water pollution by nano-TiO<sub>2</sub> coming from the liquid bath of the padding process, since the nano-TiO<sub>2</sub> could disrupt aquatic ecosystems' carbon and nitrogen cycles. However, this impact is minimised by the automated control of the dosing and dispensing of chemicals and the reduction of the volume of the padding liquor [ 42, LEITAT 2016 ].

### 2.9.2.9 Anti-felt treatments

Anti-felt finishing is applied in order to provide anti-felt properties to the good. This will prevent shrinking of the finished product when it is repetitively washed in a washing machine.

Two treatments, which are also complementary, are applied:

- oxidising treatment (subtractive treatment);
- treatment with resins (additive treatment).

These treatments can be applied at any stage of the process and on all different make-ups. They are most commonly applied on combed tops for specific end-products (e.g. underwear).

#### 2.9.2.9.1 Oxidising treatments

In the oxidising treatment, the specific chemicals used attack the scales of the cuticles and chemically change the external structure of the fibre.

This treatment has traditionally been carried out using one of the following chlorine-releasing agents:

- sodium hypochlorite;
- sodium salt dichloroisocyanurate;
- active chlorine (no longer used).

The oldest process is the one using sodium hypochlorite. However, since the development of active chlorine is difficult to control, wool fibre characteristics can be significantly changed, also giving irregular results. Dichloroisocyanurate is more advantageous here because it has the ability to release chlorine gradually, thereby reducing the risk of fibre damage.

The process with dichloroisocyanurate consists of impregnating the material in a bath (35 °C) containing the oxidant, sodium sulphate and an auxiliary (surfactant). After 20-30 minutes the material is rinsed, then it is submitted to an anti-chlorine treatment with 2-3 % sodium bisulphite and rinsed again.

All these chlorine-based agents have encountered restrictions because they react with components and impurities (soluble or converted into soluble substances) in the wool, to form absorbable organic chlorine compounds (AOX).

Alternative oxidising treatments have therefore been developed. In particular, peroxydisulphate, permanganate, enzymes and corona discharge come into consideration. However, the only alternative to chlorine-based agents readily available today is peroxydisulphate.

The process with peroxy sulphate compounds is similar to the chlorine treatment, but does not involve the use of chlorine and does not generate chloramines. The material is treated with the oxidising agent in acid liquor at room temperature until the active oxygen has been largely consumed.

Both with chlorine-based agents and peroxy sulphate, sodium sulphite is then added as an anti-oxidant to the same liquor at slightly alkaline pH. This is a reductive after-treatment to avoid damage and yellowing of the wool fibre at alkaline pH.

The goods are subsequently rinsed. If necessary, they are treated with a polymer (see treatments with resins below).

#### 2.9.2.9.2 Treatments with resins (additive processes)

In additive processes, polymers are applied to the surface of the fibre with the aim of covering the scales with a 'film'. However, this treatment must be regarded as a pseudo felt-free finishing process, as it is not the felting propensity that is reduced, but merely the effect thereof.

The polymer must have a high substantivity for wool. Cationic polymers are the most suitable for this treatment because, after the previous oxidative and reductive pretreatment, the wool surface becomes anionic.

The polymer may, in some cases, be sufficiently effective on its own to make pretreatment unnecessary. However, the combination of subtractive and additive processes has the greatest technical effect.

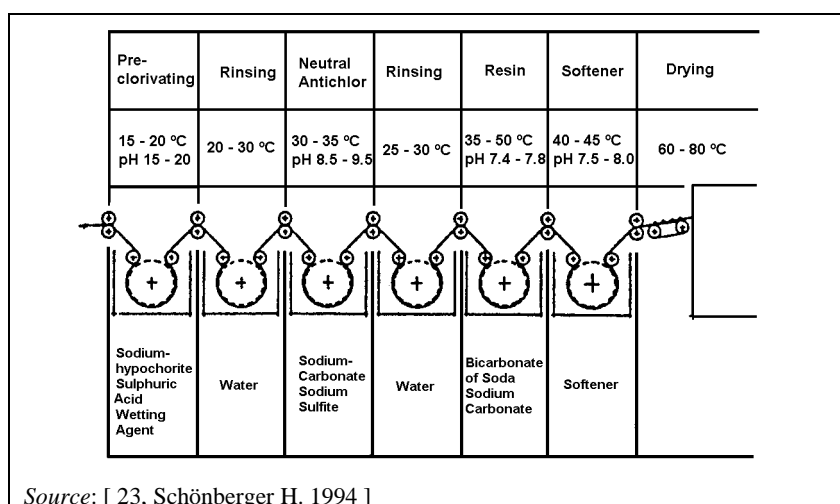
#### 2.9.2.9.3 Combined treatments: Hercosett process

The oldest combination process is the so-called Hercosett process, which consists of chlorine pretreatment followed by application of a polyamide-epichlorohydrin resin.

Whilst the Hercosett process can be carried out in batch or continuous mode, the latter is predominant nowadays.

The continuous process consists of the following steps (see Figure 2.26):

- chlorine treatment in an acid medium (using chlorine gas or sodium hypochlorite);
- reduction of chlorine using sulphite in the same bath;
- rinsing;
- neutralisation with sodium carbonate;
- rinsing;
- resin application;
- softener application;
- drying and polymerisation.



**Figure 2.26: Schematic representation of the Hercosett process**

The Hercosett process has been widely used for years as anti-felt finishing of wool in different states (loose fibre, combed tops, yarn, knitted and woven fabric) due to its low cost and high quality effects. However, the effluent shows high concentrations of COD and AOX. The formation of AOX is attributable not only to the oxidant, but also to the resin. In fact, the typical resin applied in the Hercosett process is a cationic polyamide whose manufacturing process involves the use of epichlorohydrin, which is another source of the chlorinated hydrocarbons in the effluent.

Alternative resins have been developed, based on polyethers, cationic aminopolysiloxanes, synergic mixtures of polyurethanes and polydimethylsiloxanes, but they may have some limitations concerning their applicability.

A continuous shrink-proof finishing process has been developed, without the use of chlorine in oxidising steps or in the resins used. No detailed information had been provided at the time of publishing the BREF [ 43, Johnson et al 2009 ].

It should also be noted that a more environmentally friendly low-chlorine Hercosett process (oxidising step) has been developed (see Section 4.7.6.1).

### 2.9.3 Environmental issues

Among textile finishing processes, the chemical ones are those that are more significant from the point of view of the emissions generated. As in dyeing, the emissions are relatively different between continuous and discontinuous processes. Therefore, this distinction will be used in the discussion of the main environmental issues associated with finishing. Anti-felt treatments represent a peculiar type of finishing both in terms of applied techniques and emissions. The environmental issues related to this process are therefore described in Section 2.9.2.8 together with the process itself.

#### Environmental issues associated with continuous finishing processes

With some exceptions (e.g. application of organophosphorous flame retardant), continuous finishing processes do not require washing operations after curing. This means that the possible emissions of relevance to water pollution are restricted to the system losses and to the water used to clean all the equipment. In a conventional foulard, potential system losses at the end of each batch are:

- the residual liquor in the chassis;
- the residual liquor in the pipes;
- the leftovers in the batch storage container from which the finishing formulation is fed to the chassis.

Normally these losses are in the range of 1-5 %, based on the total amount of liquor consumed; it is also in the finisher's interest not to pour away expensive auxiliaries. However, in some cases, within small commission finishers, losses of up to 35 % or even 50 % may be observed. This depends on the application system (e.g. size of foulard chassis) and the size of the lots to be finished. In this respect, with application techniques such as spraying, foam application and slop-padding (to a lesser extent due to the high volume of residues in the system), system losses are much lower in terms of volume (although more concentrated in terms of active substances).

Residues of concentrated liquors are reused, if the finishing auxiliaries applied show sufficient stability, or otherwise disposed of separately as waste destined for incineration (see Section 4.1.7.2).

Although the volumes involved are small compared with the overall waste water volume produced by a textile mill, the concentration levels are very high, with active substance contents in the range of 5-25 % and COD of 10 g/litre to 200 g/litre. In the case of commission finishing mills working mainly on short batches, the system losses can make up a considerable amount of the overall organic load. In addition, many substances are difficult to biodegrade or are not biodegradable at all and sometimes they are also toxic (e.g. biocides have a very low COD, but are highly toxic).

The range of pollutants that can be found in the waste water varies widely depending on the type of finish applied. The typical pollutants and the environmental concerns associated with the use of the most common finishing agents are discussed in Section 8.1.8. In particular, the release of the following substances in the environment gives rise to significant concerns:

- ethylene urea and melamine derivatives in their 'not cross-linked form' (cross-linking agents in easy-care finishes);
- organophosphorous and polybrominated organic compounds (flame-retardant agents);
- polysiloxanes and derivatives (softening agents);
- alkyl phosphates and alkyl ether phosphates (anti-static agents);
- fluorochemical repellents.

Concerning the anti-UV treatment with  $\text{TiO}_2$  (see Section 2.9.2.8), waste water treatment plants are capable of removing the majority of  $\text{TiO}_2$  nanomaterials but  $\text{TiO}_2$  particles measuring between 4 nm and 30 nm have still been found in the treated effluent. These nanomaterials are then released to the surface waters where they can interact with living organisms.  $\text{TiO}_2$  nanomaterials that are absorbed in the treatment plants may still end up in the environment if the biomass is landspread. Though the release of  $\text{TiO}_2$  nanomaterials to the environment has been shown, it is difficult to quantify how much is released. Once in the environment, even less is known about how organisms are affected by nano- $\text{TiO}_2$  [42, LEITAT 2016].

### **Environmental issues associated with discontinuous processes**

The application of functional finishes in 'long liquor' (liquor used in the preceding process, e.g. dyeing or rinsing) by means of batch processes is used mainly in yarn finishing and in the wool carpet yarn industry in particular. Since the functional finishes are generally applied either in the dye baths or in the rinsing baths after dyeing, this operation does not entail additional water consumption with respect to dyeing. For the resulting emissions to water, as with batch dyeing, the efficiency of the transfer of the active substance from the liquor to the fibre is the key factor which influences the emission loads. The efficiency depends on the liquor ratio and on many

other parameters such as pH, temperature and the type of emulsion (micro- or macro-emulsion). Maximising the efficiency is particularly important when biocides are applied in mothproofing finishing. As mothproofing agents are not water-soluble, they are applied from emulsions. The degree of emulsification and the pH are critical in the application of mothproofing agents (i.e. the efficiency of the process is higher when the active substance is applied from micro-emulsions and at acidic pH). Note here that the finishing agents are dosed based on the weight of the fibre and not on the amount of bath (in g/litre).

The pollutants that may be encountered in waste water vary depending on the finishing agents applied; Section 8.1.8 gives more details. The main issues worth mentioning are the application of mothproofing agents (emissions of biocides) and the low level of exhaustion of softeners (emissions of poorly biodegradable substances).

### **Emission to air**

In the drying and curing operation, emissions to air are produced due to the volatility of the active substances themselves as well as that of their constituents (e.g. monomers, oligomers, impurities and decomposition by-products). Furthermore, emissions to air (sometimes accompanied by odours) are associated with the residues of preparations and fabric carry-over from upstream processes (for example, polychlorinated dioxins/furans may arise from the thermal treatment of textiles that have been previously treated with chlorinated carriers or perchloroethylene).

The emission loads depend on the drying or curing temperature, the quantity of volatile substances in the finishing liquor, the substrate and the potential reagents in the formulation. The range of pollutants is very wide and depends on the active substances present in the formulation and again on the curing and drying parameters. In most cases, however, the emissions produced by the single components of the finishing recipes are additive. As a result, the total amount of organic emissions in the exhaust air (total organic carbon and specific problematic compounds such as carcinogenic and toxic substances) can easily be calculated by means of emission factors given for the finishing recipes by manufacturers (see also Section 4.1.6.4). Note, however, that Germany is the only Member State where there is a fully developed system in which the manufacturers provide the finisher with such information on the products supplied.

Another important factor to consider regarding emissions to air is that the directly heated (methane, propane, butane) stenters themselves may produce relevant emissions (non-combusted organic compounds, CO, NO<sub>x</sub>, formaldehyde). Emissions, for example, of formaldehyde up to 300 g/h (2-60 mg/m<sup>3</sup>) have been observed in some cases, which were attributable to inefficient combustion of the gas in the stenter frame [5, UBA 2001]. It is therefore obvious – when speaking about emissions to air – that the environmental benefit obtained by the use of formaldehyde-free finishing recipes is totally lost if the burners in the stenter frames are poorly adjusted and produce high formaldehyde emissions.

Formaldehyde emissions are expected from the following [reference to DE – action 3] [58, EURATEX 2020 ]:

- Easy-care treatments due to use of cross-linking agents releasing formaldehyde. The compounds are needed to meet the product requirements (e.g. for surgical clothing). Low-formaldehyde recipes emit significantly higher amounts of methanol.
- Water- and oil-repellent treatments due to the use of melamine formaldehyde resins to bind the repellence chemicals on the textile, achieving high washing fastness. The fluorocarbon resin compounds also emit a small amount of formaldehyde when it is self-cross-linking. Low-formaldehyde recipes emit significantly higher amounts of methanol.
- Flame-retardant treatments due to the use of melamine formaldehyde resins used to meet product requirements of some personal protective equipment. Formaldehyde is used as a cross-linking agent in the production of these resins in order to fix a certain

percentage of phosphorus and to achieve flameproof properties for both natural and synthetic fibres. Formaldehyde is also used to stabilise methylol resins against self-reaction during storage.

Ammonia emissions are expected from the flame-retardant treatments due to the cross-linking (fixation to the fibre, permanence) or curing of pre-polymers containing nitrogen and phosphorus used as the halogen-free flame retardants. Ammonia is emitted during heat treatment (see Section 4.7.4.2). (DE – action 3 contribution in [ 58, EURATEX 2020 ])

The active substances in the most common finishing agents and the possible associated emissions to air are discussed in Section 8.1.8. Moreover, a more comprehensive list of pollutants that can be found in the exhaust air from heat treatments in general is reported in Section 8.6.

## 2.10 Coating and laminating

### 2.10.1 Coating and laminating processes

Usually, coated and laminated textiles consist of a textile substrate - typically a woven, knitted, or non-woven textile fabric - combined with a thin, flexible film of natural or synthetic polymeric substances.

A coated fabric usually consists of a textile substrate on which the polymer is applied directly as a viscous liquid. The thickness of the film is controlled by applying it via a blade or similar aperture.

A laminated fabric usually consists of one or more textile substrates, which are combined with a pre-prepared polymer film or membrane by adhesives or heat and pressure.

The basic techniques for coating/laminating fabrics require the following conditions:

- the fabric to be coated/laminated is supplied full width on a roll;
- the fabric is fed under careful tension control to a coating or laminating heat zone;
- after application of the coating auxiliaries, the fabric is passed through an oven to cure the composite and remove volatile solvents before cooling and rolling up.

#### Flame lamination

In the textile industry, the flame lamination of foams is a widely used technique: a pre-prepared thin thermoplastic foam sheet is exposed to a wide-slot flame burner located before the laminating rolls. No drying or curing oven is required in this process. Emissions to air produced during this treatment are highly irritant and may trigger an allergic reaction in susceptible persons.

In principle, the main characteristic of flame lamination is the generation of thermal plasma, which generates a surface modification of the joining materials. The joining materials (mainly foamed plastic) are used to build up adhesive strength between the media. No additional adhesives are necessary [ 44, ÖKOPOL 2011 ].

#### Hot-melt lamination

[ 44, ÖKOPOL 2011 ], [ 45, Weydts et al. 2019 ]

Generally, lamination is defined as the production of composite materials by the adhesion of different substrates. In hot-melt lamination, melted solvent-free polymers are applied to textile fabrics by appropriate aggregates.

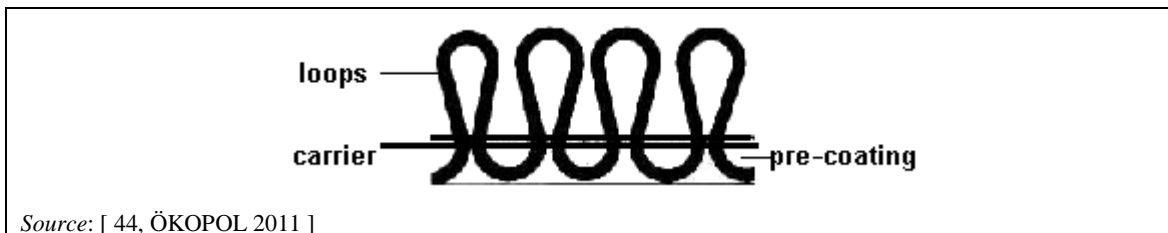
Thermoplastic or reactive adhesives, e.g. reactive polyurethanes (PUR), thermoplastic copolyester, copolyamide, EVA (ethylene-vinyl acetate copolymer) polymers, as well as non-cross-linking polyurethanes are used.

In a first step, the hot-melt adhesives must be melted. Normally, non-reactive thermoplastics like EVA are melted at temperatures between 150 °C and 180 °C in a melting tank. An extruder is used for copolyester and copolyamide (the operational temperature range is approximately 190 °C to 230 °C), although some polyamide can be used in a melting tank too. Reactive PUR adhesives are melted in drums with a drum-melter, in hobbocks or in tanks under an inert gas atmosphere, as cross-linking of the PUR adhesives is initiated by moisture. The operational temperature of moisture-reactive adhesives is between 80 °C and 150 °C.

Technologies for coating and laminating of textile fabrics are roller coating, spray coating and slot die coating.

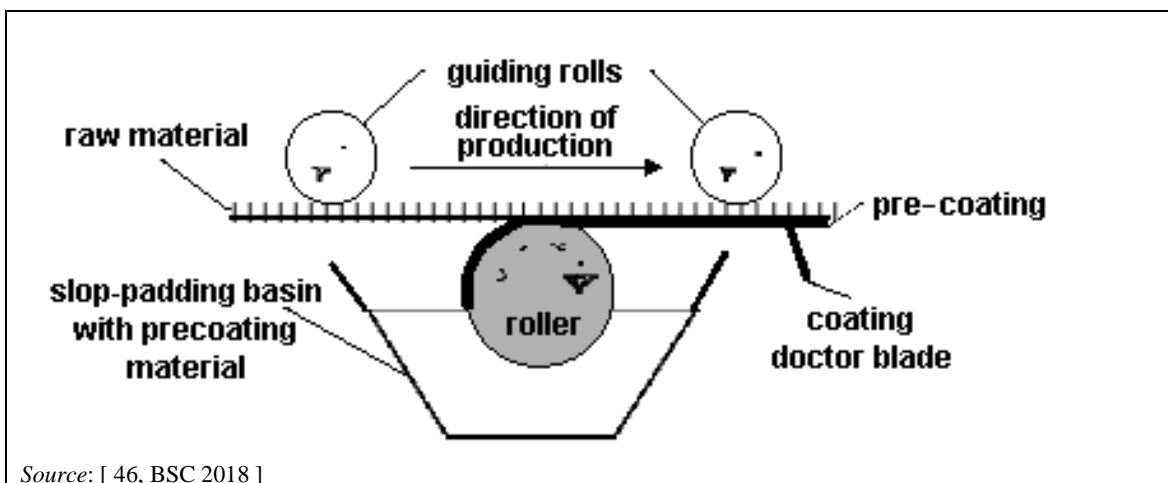
Multi-roller and gravure roller technology as well as hot-melt screen printing coating are part of contact coating methods. When using the multi-roller equipment, the adhesive is charged between the first two rollers, metered out by the second roller and then applied to the substrate on the counter-pressure roller. In embossing cylinder processing, the melted mass is carried by rollers or doctor finishing machines into the indentation of the cylinder and transferred to the textile fabric via the counter-pressure roller. The polymer melt in hot-melt screen printing coating is applied through a heat-resistant screen with a doctor blade, resulting in dot coating.

Figure 2.27 below shows a representation of the multi-roller process, the embossing cylinder process and a third method, the disperse powder coating process.



**Figure 2.27: Coating methods: Multi-roller (top left), embossing cylinder (centre right) and disperse powder coating (bottom)**

Compact or open breathable adhesive layers can also be applied with the help of slot dies (see Figure 2.28 below). Heat treatment (infrared) of reactive PUR or adhesives with sufficiently long operating times before roll laminating is not necessary.



**Figure 2.28: Slot die coating**

As an alternative to contact coating, spray coating can be used for fleecy substrates or substrates with low density. Spray coating and slot die coating are closed systems, i.e. the adhesive has no contact with the environment between melting and application. This prevents input of particles like dust or fibres leading to breakdowns during processing.

To prevent the cooling of the thermoplastic adhesives, an infrared radiator (80-160 °C) can be installed in front of the laminating calendar or nip roller.

In continuous operation, cleaning of feeding tubes and application devices using reactive adhesives is not necessary. If the adhesives have no contact with air, they can be reused at any time. For thermoplastic adhesives, cleaning of feeding systems is not necessary at all.



Contamination of the application equipment during operation is possible. Cleaning intervals depend on the adhesives used and the textile substrates. During longer production stoppages, for reactive polyurethanes, all the adhesive is rinsed with a non-reactive product to avoid curing. For this purpose, adhesive producers offer solvent-free, liquid, surface-active cleaning products.

The typical coating compounds and auxiliaries used are described in Section 8.1.9. For more information on environmental performance and operational data related to this technique, see Section 4.8.1).

### 2.10.2 Carpet back-coating

The backing process is an important production step which is applied to improve the stability of textile floor coverings. Moreover, backing may have a positive influence on properties such as soundproofing, stepping elasticity and heat insulation.

One can distinguish the following types of coatings:

- pre-coating;
- foam coating;
- textile back-coating;
- heavy coating;
- reinforcement;
- back finish.

#### **Pre-coating**

A common feature of tufted carpets is that they are pre-coated after tufting to permanently anchor the needled pile loops in the carrier layer (Figure 2.29). The pre-coating material used consists of:

- x-SBR latex, which is a dispersion containing a copolymer produced from styrene, butadiene and carbonic acid;
- fillers;
- water;
- additives (e.g. thickeners, anti-foaming agents, foam stabilisers).

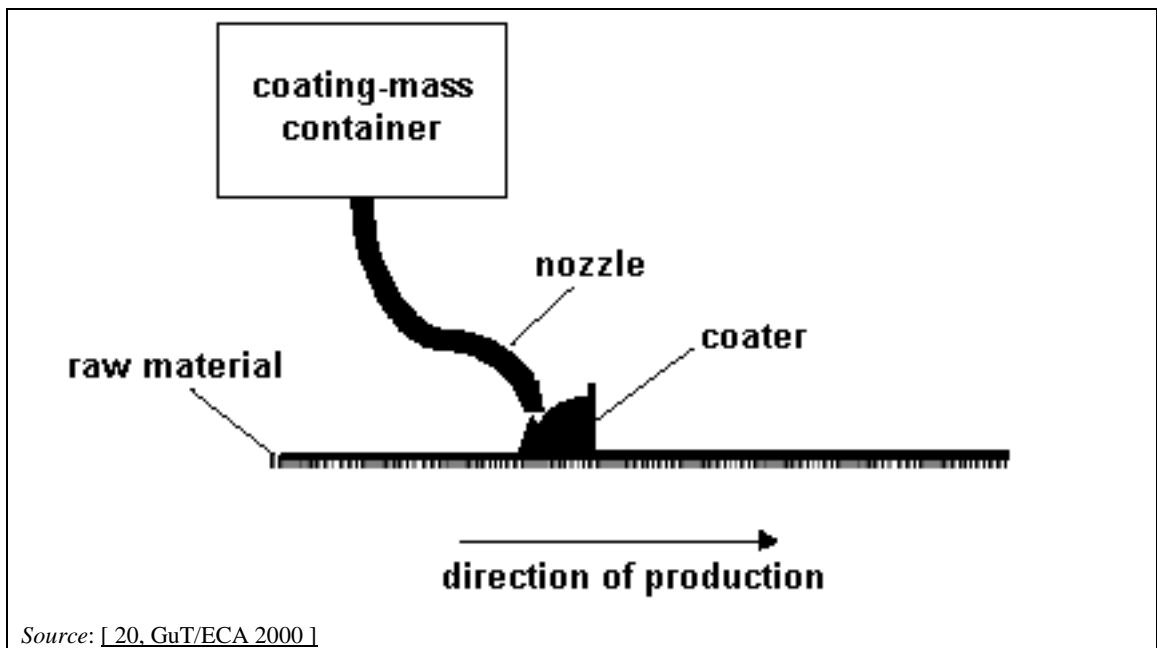


Figure 2.29: Pre-coated tufted carpet

The pre-coating can be applied:

- unfoamed, by means of slop-padding (Figure 2.30);
- foamed, by means of the doctor-blade technique (Figure 2.31).

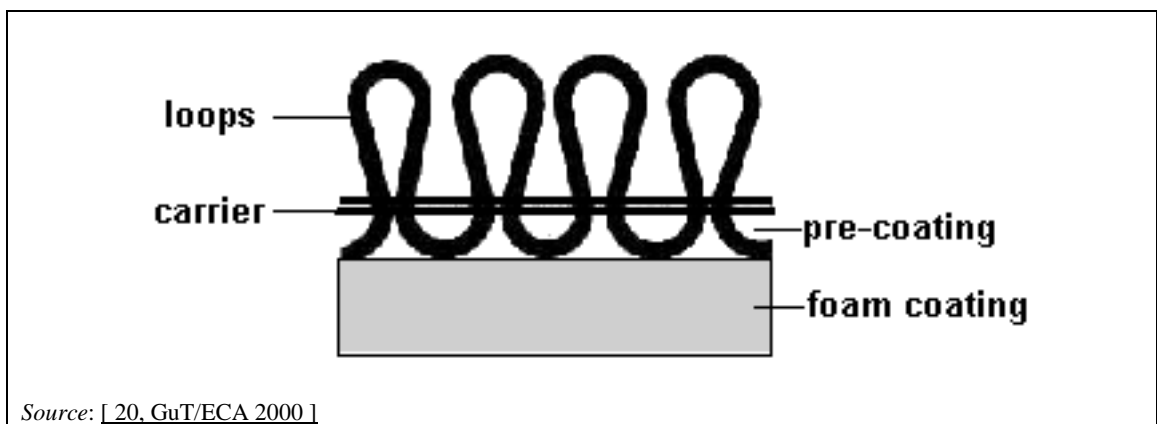


Figure 2.30: Pre-coating application by slop-padding

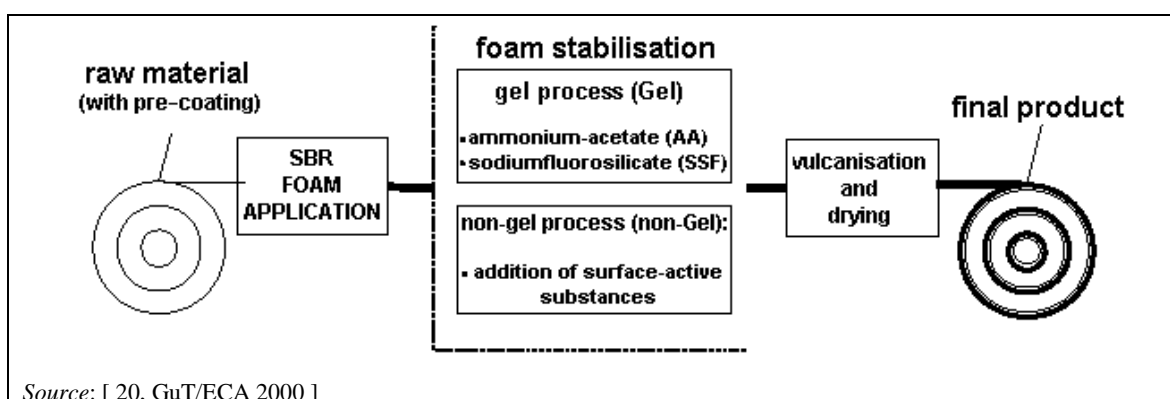
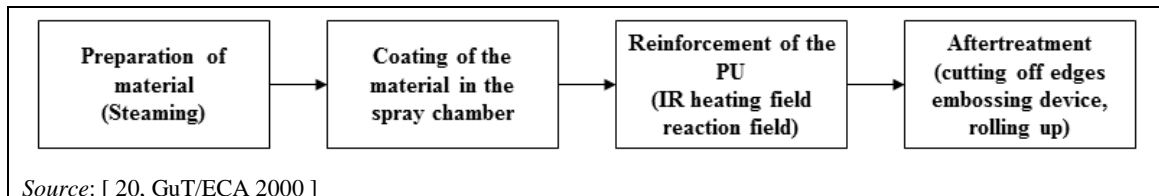


Figure 2.31: Pre-coating application by the doctor-blade technique

During the subsequent drying stage, thanks to the formation of hydrogen bonds, the polymer chains are woven into a three-dimensional web and an elastic plastic layer is produced.

### SBR foam coating

Foam coating methods consist of the application of a foam layer onto a pre-coated carpet, as Figure 2.32 shows.



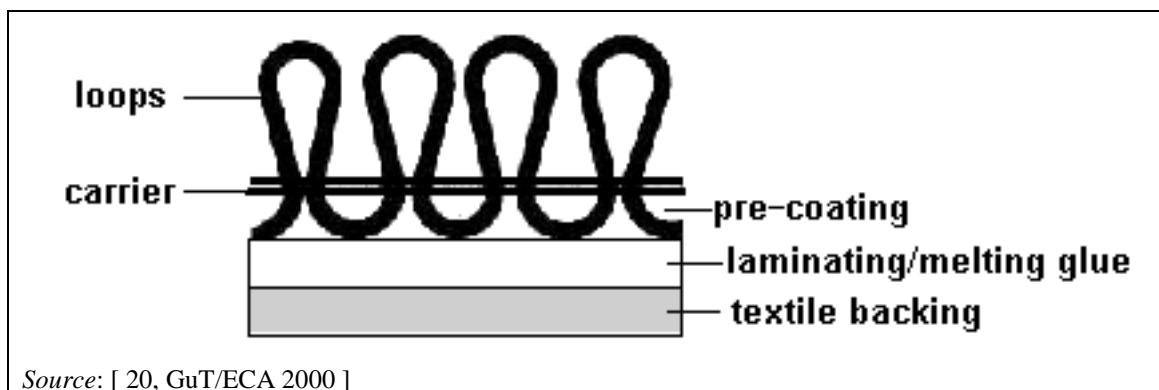
**Figure 2.32: Foam-coated tufted carpet**

The foam finish is achieved in two steps: foam application and foam solidification through drying. The lattice is foamed with air and then applied by means of a doctor blade onto the pre-coated carpet.

The SBR foam is stabilised until it is solidified in the vulcanisation oven. For this stabilisation, two methods are used:

- the non-gel process, which uses surfactants as foam stabilisers;
- the gel process, which uses ammonium acetate (AA gel system) or silicon fluoride (SF gel system) as gelling agents.

The overall process is schematised in Figure 2.33.



**Figure 2.33: Representation of the SBR foam coating process**

The foam is composed of:

- the SBR colloidal dispersion;
- a paste, which contains a number of active additives;
- inactive fillers (mainly chalk, which is added to the ready-made paste);
- water;
- thickeners (e.g. polyvinyl alcohol, methyl cellulose, polyacrylates);
- colourants and pigments;
- anti-oxidants and ozone stabilisers.

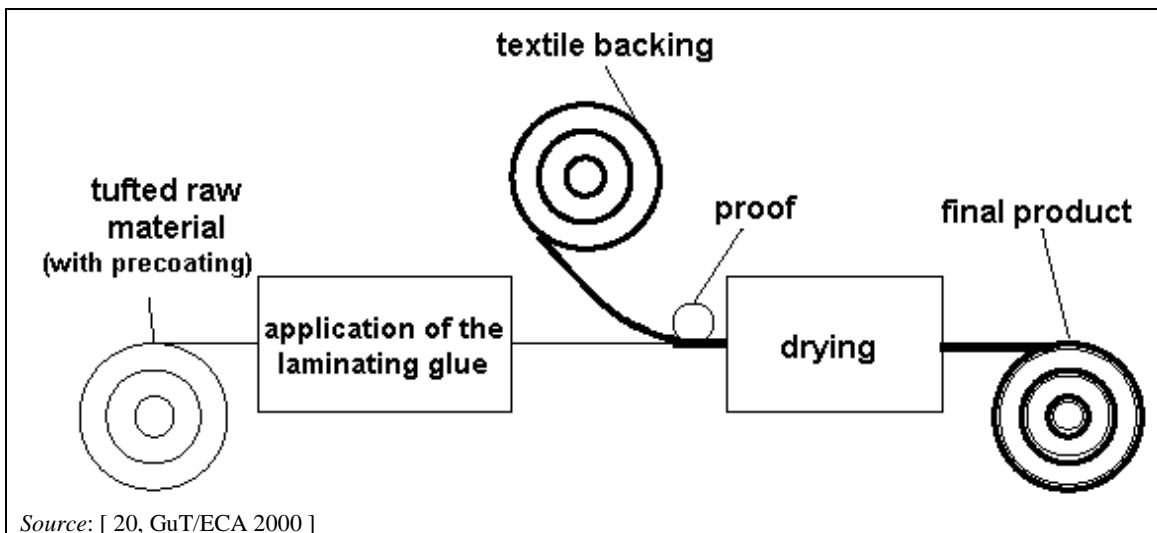
Some of the active components of the paste are responsible for the environmental impact of this coating method. In order to better identify the emission sources, they can be divided as shown in Table 2.22 below.

**Table 2.22: Additives in the coating paste**

Type of additives	Additives	Remarks
Polymerisation additives	Foam stabilisers	
	Cross-linkers	Usually sulphur, but also peroxides
	Vulcanisation accelerators	Mercaptobenzothiazoles (e.g. zinc mercaptobenzothiazole) Dithiocarbamates (e.g. zinc diethyldithiocarbamate or zinc dibenzylthiocarbamate or zinc dibutylthiocarbamate (the most commonly used one))
	Activators	Usually a combination of ZnO and stearic acid (one source reports that ZnO is not necessary for non-gel and some SF applications [ 22, TWG 2002 ])
Processing additives	Foaming agents and stabilisers	Surfactants
	Gelling agents	e.g. Ammonium acetate (AA gel system) or silicon fluoride (SF gel system)
	Hydrophobic substances in order to improve the foam surface and the water-repellent properties	Paraffin dispersions and silicone emulsions
	Complexing agents, to chelate metal ions (they behave as catalysts for ageing the foam layer)	e.g. EDTA, DTPA, polyphosphates
	Antioxidants	
	Thickeners	Organic polymers based on polyacrylates and cellulose (e.g. CMC)
Functional additives	UV stabilisers	
	Anti-static agents	
	Flame-retardant agents (e.g. Al <sub>2</sub> O <sub>3</sub> )	

### PU foam coating

Polyurethane is another method for foam coating. The ICI polyurethane coating process is the most commonly applied. The carpet is prepared by steaming and then reaches the spray chamber where the components of the polyurethane (diisocyanate and an alcohol) are sprayed. The CO<sub>2</sub> produced during the chemical reaction is embedded into the foam. The coating is reinforced in an infrared heating field and in a subsequent reaction field. The process is schematically represented in Figure 2.34.

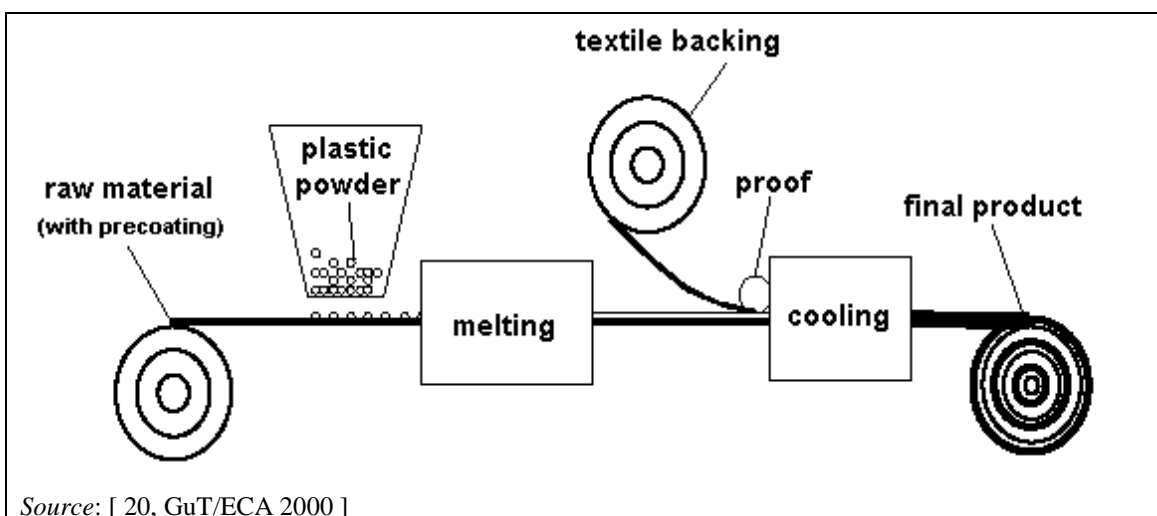


Source: [ 20, GuT/ECA 2000 ]

Figure 2.34: PU foam coating

**Textile back-coating**

Textile backing consists of the application of a textile fabric onto the pre-coated carpet (see Figure 2.35). The connection between the carpet and the textile fabric is obtained through the application of a layer of molten laminating glue.



Source: [ 20, GuT/ECA 2000 ]

Figure 2.35: Textile backing

*Laminating glue*

In this process, an x-SBR latex is applied to the carpet by sloop-padding. After the application of the textile fabric, the final reinforcement of the latex is carried out by means of heat treatment (Figure 2.36). The latex composition is similar to that used for pre-coating, with a higher share of polymer dispersion in order to allow a higher adhesive power.

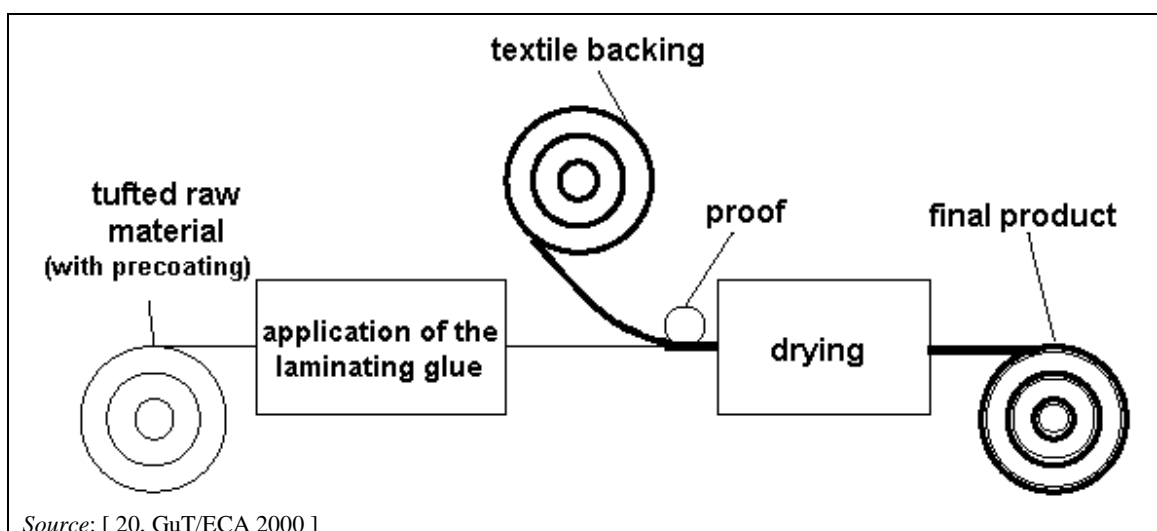


Figure 2.36: Textile backing by means of the laminating glue process

### Melting glue

This system uses thermoplastic polymers (mainly polyethylene) which are meltable by means of heat. In powder lamination (and in particular in powder scattering lamination), polyethylene powder is evenly sprinkled onto the back of the carpet. Subsequently, the polymer is melted in an infrared field. In the next stage, the fabric is pressed into the melting glue. Through subsequent cooling, the melting glue connects permanently the textile fabric to the back of the carpet. The process is represented in Figure 2.37.

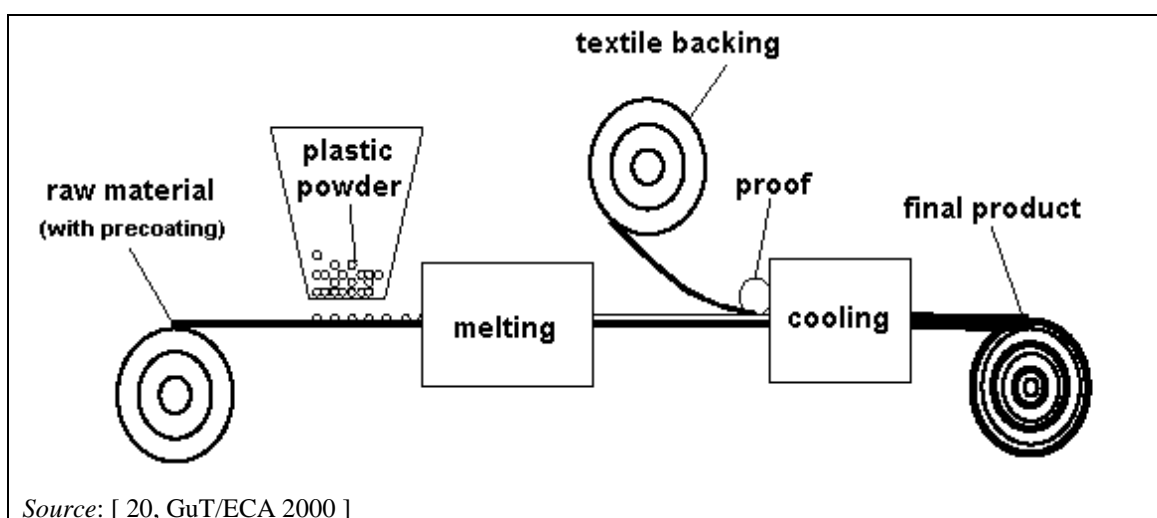
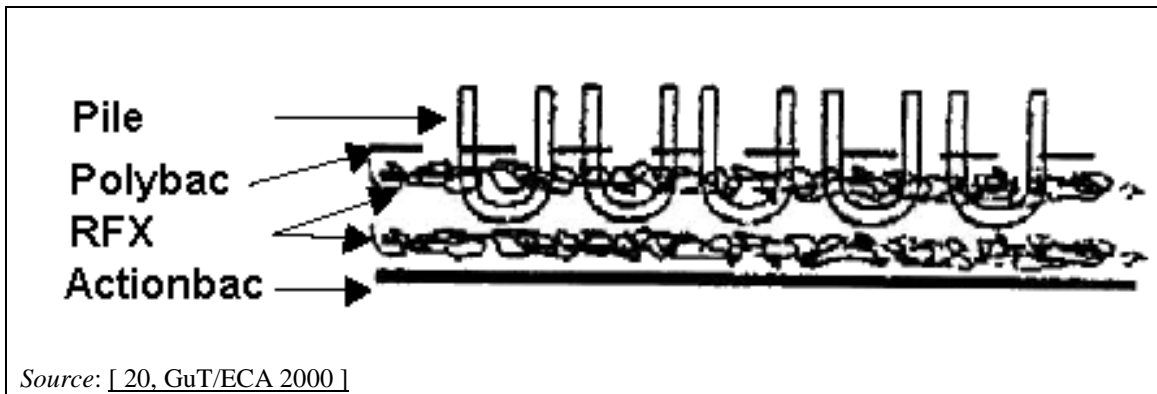


Figure 2.37: Textile backing by means of powder lamination (melting glue)

Another textile backing process by means of melting glue is the so-called AdBac process. In this case, the carpet is constructed using a primary cloth (carrier layer) with low-melting-point additives. In the next stage, the secondary cloth (also with a low melting point) is brought into contact with the back of the carpet before this enters the heating zone. The higher temperature melts the cloths, which are then forced together by nip rolls at the exit of the heating zone. The carpet is then cooled. A scheme of a carpet produced with the AdBac process is shown in Figure 2.38.



Source: [ 20, GuT/ECA 2000 ]

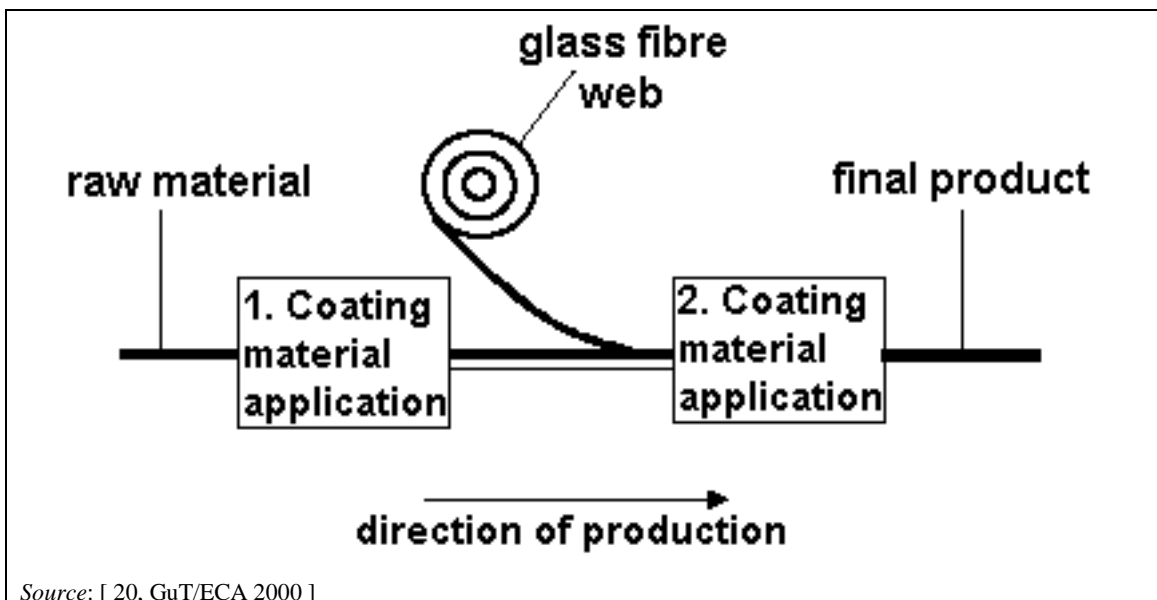
Figure 2.38: Carpet manufactured with the AdBac process

### Heavy coating

Heavy coating is mainly used for the coating of self-laying (SL) tiles. The coating process consists of the application of the coating material by means of sloop-padding or a doctor blade and subsequent reinforcement. In most cases, the coating material is applied in layers (two-coat technique). After the first layer, which may also serve as a pre-coating layer, a glass-fibre web may be added. The second coating application follows. The following coating materials are used:

- APO (atactical polyolefin);
- bitumen (enriched with inorganic and organic additives);
- PVC (polyvinylchloride);
- EVA (ethylene vinyl acetate).

The process principle is schematised in Figure 2.39.



Source: [ 20, GuT/ECA 2000 ]

Figure 2.39: Representation of the heavy coating process

### 2.10.3 Environmental issues

The main environmental concerns in coating/laminating operations relate to emissions to air arising from solvents, additives and by-products contained in the formulations of the coating

compounds. A distinction must therefore be made between the various products available (the following information is taken from [ 5, UBA 2001 ]).

### Coating powders

The emission potential of coating powders is in most cases negligible, with the exception of polyamide 6 and its copolymers (the residual monomer epsilon-caprolactam is released at standard process temperatures). In some cases, softeners (often phthalates) can be found in the emissions.

### Coating pastes

The emissions from the coating pastes result mainly from the additives (except in the case of PA 6, which is mentioned above). These are mainly:

- fatty alcohols, fatty acids, fatty amines from surfactants;
- glycols from emulsifiers;
- alkylphenols from dispersants;
- glycol, aliphatic hydrocarbons, N-methylpyrrolidone (NMP) from hydrotropic agents;
- aliphatic hydrocarbons, fatty acids/salts, ammonia from foaming agents;
- phthalates, sulphonamides/esters, e.g. softeners/plasticisers;
- acrylic acid, acrylates, ammonia, aliphatic hydrocarbons from thickeners.

(Note: NMP is a SVHC, subject to restriction #71 under Annex XVII to REACH (as of May 2020) due to potential harm to workers' health.)

### Polymer dispersions (aqueous formulations)

The emission potential of polymer dispersions is low compared to coating pastes. Components that are responsible for emissions to air are the dispersing agents, residual compounds from the polymerisation (especially t-butanol used as catalyst in radically initialised polymerisation reactions) and monomers arising from incomplete reaction during polymerisation. The latter are particularly relevant to the workplace atmosphere and odour nuisances. They include:

- acrylates such as acrylic acid, butyl acrylate, ethyl acrylate, methyl acrylate, ethylhexyl acrylate and vinyl acetate;
- carcinogenic monomers like acrylonitrile, vinyl chloride, acrylamide, 1,3-butadiene and vinylcyclohexene.

Vinylcyclohexene is not often identified in the exhaust air. However, it is always formed (2 + 2 cycloaddition product) if 1,3-butadiene is used.

Acrylamide in the exhaust air is often related to formaldehyde emissions (reaction products of methylolacrylamide).

### Melamine resins

Melamine resins are widely applied. Melamine resins are produced by the reaction of melamine and formaldehyde and subsequent etherification mostly with methanol in an aqueous medium. The products can contain considerable amounts of free formaldehyde and methanol. During their application, the cross-linking reaction of the resin with itself or with the fabric (e.g. cotton) is initiated by an acid catalyst and/or temperature, releasing stoichiometric amounts of methanol and formaldehyde.

### Polymer dispersions (organic solvent-based formulations)

Solvent coating is not very common in the textile finishing industry. When this technique is applied, exhaust air cleaning equipment based on thermal incineration or adsorption on activated carbon is normally installed.



### **Emissions to air**

Ammonia emissions are expected [ 58, EURATEX 2020 ], [ 352, Zietlow B. 2020 ] from the coating process, especially for technical textiles, either to adjust the pH value or to cross-link the auxiliaries used (film formation).

## 2.11 Washing

### 2.11.1 Washing with water

Important factors in washing are:

- water characteristics;
- choice of soaps and detergents;
- hydromechanical action;
- temperature and pH;
- rinsing stage.

Washing is normally carried out in hot water (40-100 °C) in the presence of a wetting agent and a detergent. The detergent emulsifies the mineral oils and disperses the undissolved pigments. The choice of the surfactants may also vary depending on the type of fibre. Mixtures of anionic and non-ionic surfactants are commonly used. An important factor in the selection of a surfactant is its effectiveness in strong alkaline conditions.

Washing always involves a final rinsing step to remove the emulsified impurities.

Fabric washing can be carried out in rope form or open-width, and in either discontinuous or continuous mode. The most commonly used technique is continuous mode in open-width form.

### 2.11.2 Dry cleaning

Industrial solvent washing is sometimes necessary, especially for delicate fabrics. In this case, the impurities are carried away by the solvent, which is usually perchloroethylene. In the same step, softening treatments may also be carried out. In this case, water and surfactant-based chemicals are added to the solvent.

Solvent washing may be carried out continuously in open-width (for woven or knitted fabric) or discontinuously with yarn or fabrics in rope form (generally for knitted fabric).

Solvent plants have a built-in solvent treatment and recovery system in which the solvent is purified by distillation and reused for the next washing process. Residual sludge from distillation is disposed of as hazardous waste in the event of a high concentration of solvent.

After distillation, the solvent is cooled before reuse and thus large amounts of cooling water are required. This water is never contaminated by solvent and can therefore be reused. In mills with both solvent and water washing facilities, warm water from the cooling plant may be used for water washing treatments, allowing water and energy savings. In many cases, however, this water is not reused and it is discharged together with the other effluents.

Both closed and open airflow circuits can be used for the removal of solvent from fabric.

In open-circuit machines, when the washing cycle is over, large amounts of air are taken from the external environment, warmed up with a steam heat exchanger and introduced into the machine, thus obtaining the evaporation of the organic solvent. This process goes on until the solvent is almost completely eliminated from clean fabrics. Solvent-rich air is then sent to a centralised activated charcoal filtering system. Filters require regular regeneration to ensure optimal cleaning performance. Most modern filters allow discharge into the atmosphere below 3-4 mg/Nm<sup>3</sup>.

In closed-circuit machines, the air used to carry out the drying process, instead of being filtered and released into the atmosphere, is treated internally. Such treatment consists of recovering the solvent by adsorption. When the solvent has been removed from the air and recovered, solvent-poor air is heated by a heat exchanger and then sent into the machine again. Recovered solvent is sent to a centralised plant, where it is distilled and purified. See Section 4.4.5 for more details.

Apart from the above-mentioned emissions to air in open-circuit machines, possible emissions during washing operations may result from machine losses (which can be eliminated or reduced by hermetic sealing of the machinery) and from solvent attached to the dried fabric and ultimately released into the atmosphere. Most modern machines have a built-in control system which makes it impossible to open the machine hatch if the solvent concentration in the machine is greater than values established by national regulations.

Other potential sources of emissions are represented by the solvent contained in the residual sludges and active carbon filters.

Figure 2.40, Figure 2.41 and Figure 2.42 show the solvent and the air circuits in open-loop and closed-loop solvent washing machines (the solvent circuit is always closed).

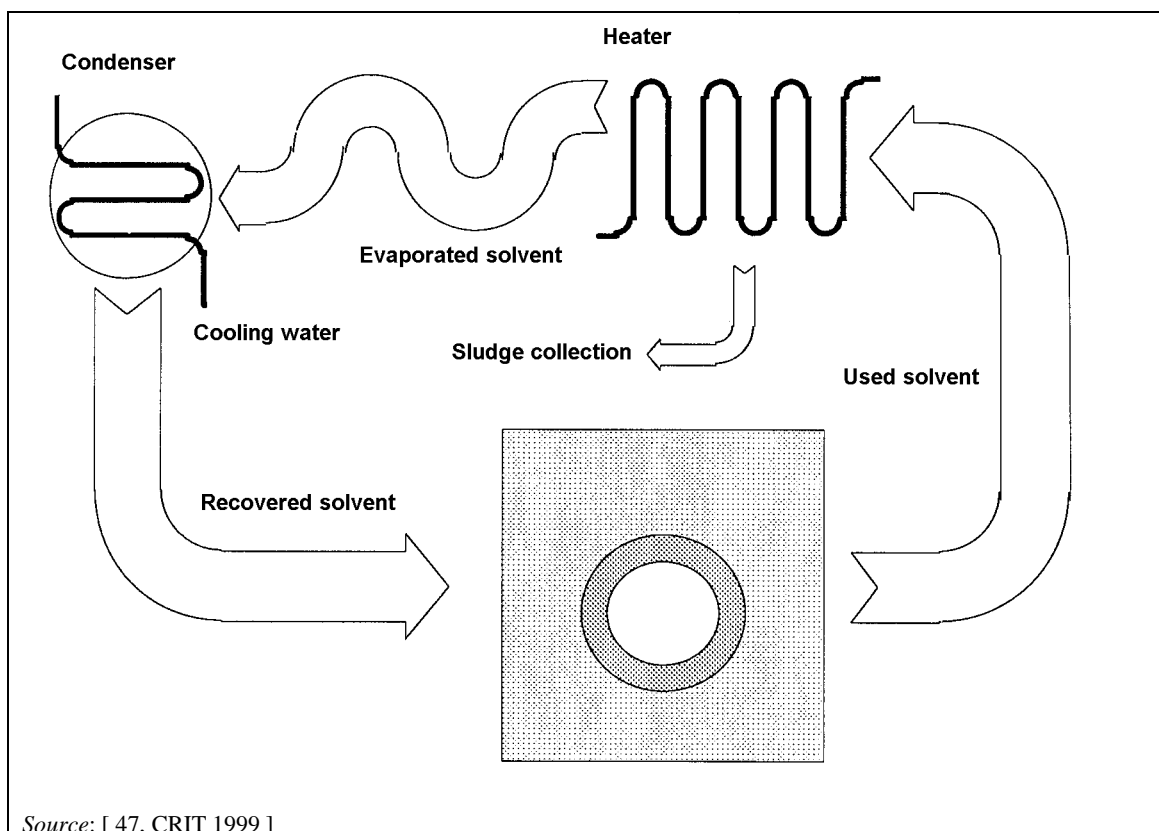


Figure 2.40: Solvent washing: representation of the solvent circuit

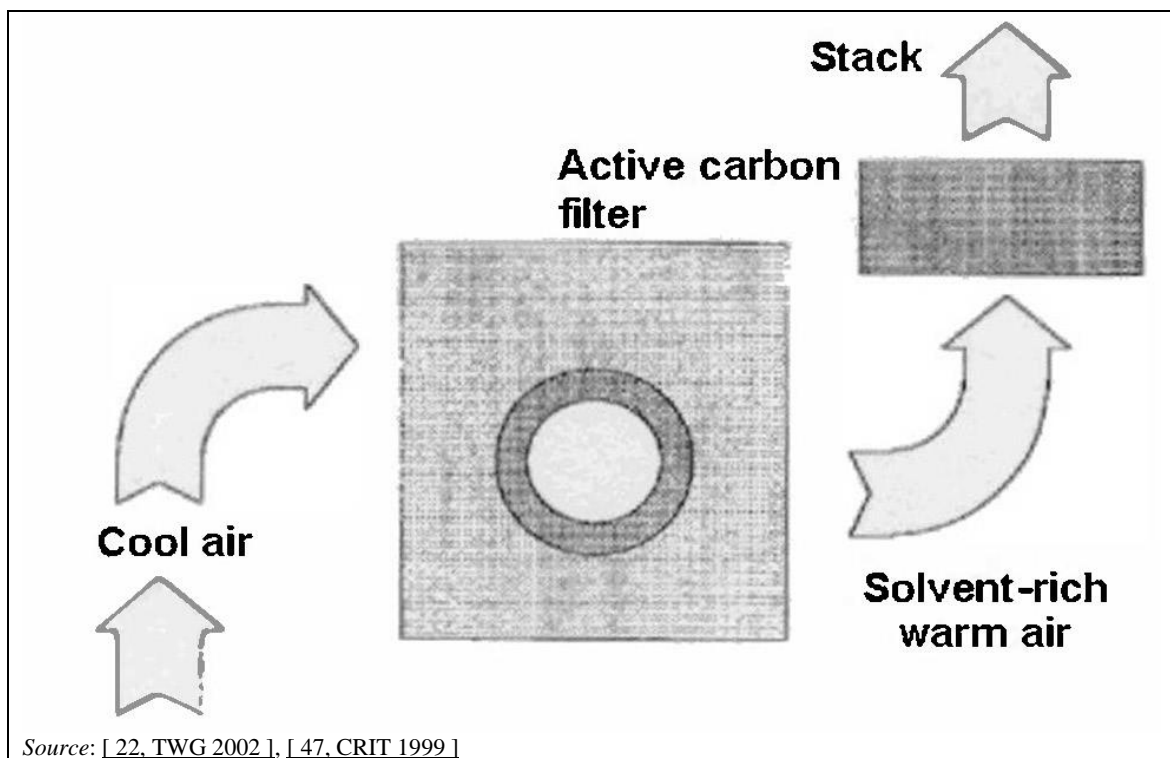


Figure 2.41: Solvent washing: representation of the air circuit in an open-loop washing machine

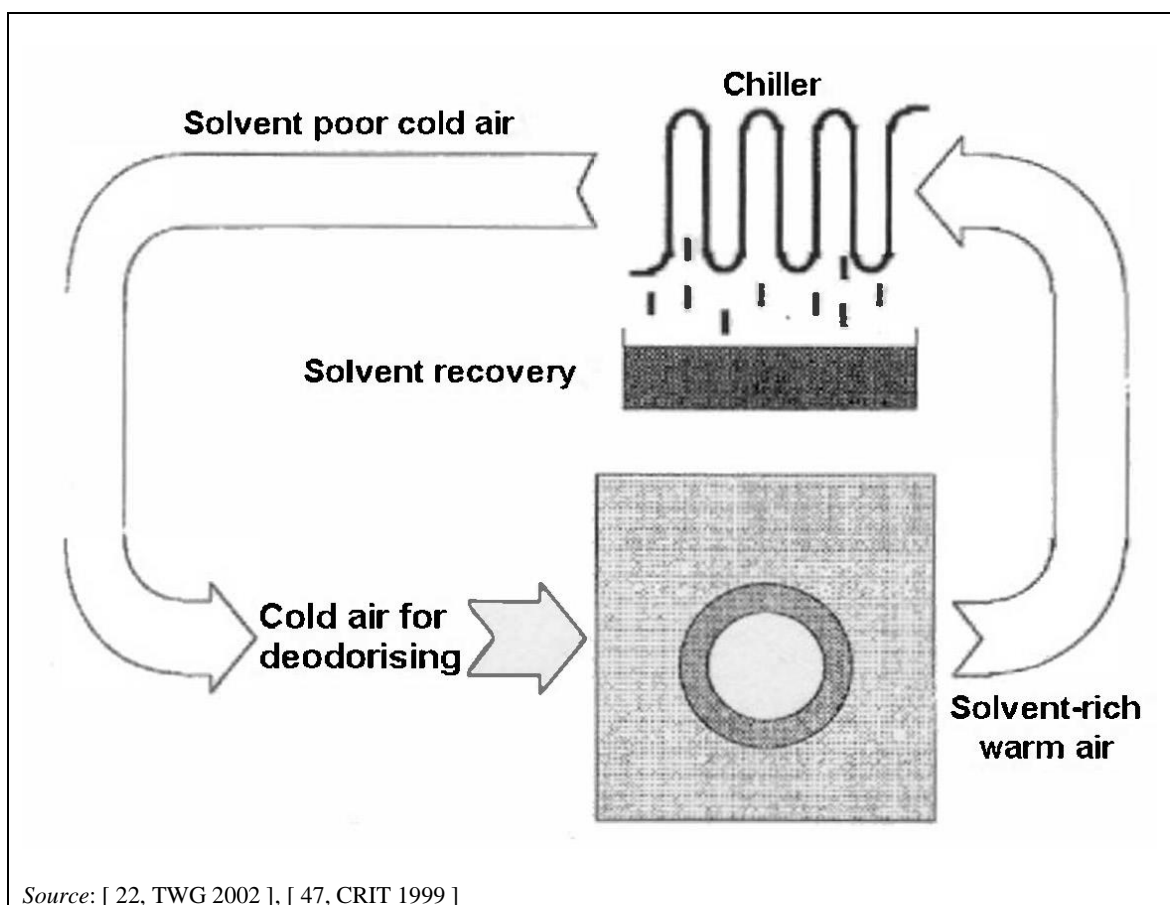


Figure 2.42: Solvent washing: representation of the air circuit in a closed-loop washing machine

## 2.12 Drying

Drying is necessary to eliminate or reduce the water content of the fibres, yarns and fabrics following wet processes. Drying, in particular by water evaporation, is a highly energy-intensive step (although overall consumption may be reduced if reuse/recycling options are adopted).

Drying techniques may be classified as mechanical or thermal. Mechanical processes are used in general to remove the water which is mechanically bound to the fibre. This is aimed at improving the efficiency of the following step. Thermal processes consist of heating the water and converting it into steam. Heat can be transferred by means of:

- convection;
- infrared radiation;
- direct contact;
- radio-frequency.

In general, drying is never carried out in a single machine; normally drying involves at least two different techniques.

### 2.12.1 Loose fibre drying

The water content of the fibre is initially reduced by either centrifugal extraction or by mangling before evaporative drying.

#### 2.12.1.1 Centrifugal extraction

Textile centrifugal extractors (hydroextractors) are essentially a more robust version of the familiar domestic spin dryer, and normally operate in batch, although machines capable of continuous operation may be used in very large installations.

When using conventional batch hydroextractors, fibre is unloaded from the dyeing machine into specially designed fabric bags which allow direct crane loading of the centrifuge. An extraction cycle of 3-5 minutes reduces the residual moisture content to approximately 1 l/kg dry fibre (in the case of wool).

#### 2.12.1.2 Mangling

Pneumatically loaded mangles may be used to reduce the water content of dyed loose fibre. Such equipment is often associated with a fibre-opening hopper which is designed to break up the dyepack and present the fibre to a continuous dryer as an even mat. Mangling is invariably less efficient than centrifugal extraction.

#### 2.12.1.3 Evaporative drying

All hot-air evaporative dryers are of essentially similar design consisting of a number of chambers through which hot air is circulated by fans. Consecutive chambers operate at different temperatures, fibre passing from the hottest into progressively cooler chambers. Fibre may be transported on a brattice or conveyer belt or may be carried through the machine on the surface of a series of 'suction drums'. High-efficiency dryers with perforated steel conveyer belts have been developed which even out the air pressure drop across the fibre mat. This design results in more even drying and lower thermal energy requirements.

While the majority of dryers are steam-heated, a number of manufacturers supply radio-frequency dryers. Fibre is conveyed on a perforated polypropylene belt through the radio-frequency field and airflow is fan-assisted. With these machines the fibre is not subjected to such high temperatures and the moisture content of the dried material can be controlled within precise limits.

Radio-frequency dryers are reported to be significantly more energy-efficient than steam-heated chamber dryers. However, the higher efficiency is not always gained if a more global analysis is made, comparing the primary energy needed for production of electric power with methane gas consumed for thermal energy production. Radio-frequency dryers are mainly used where the cost of electricity is low.

## **2.12.2 Hank drying**

### **2.12.2.1 Centrifugal extraction**

Drained hanks from the dyeing machine can contain (in the case of wool) up to 0.75 kg water per kg of dry fibre (or higher depending on the hydrophilicity of the fibre). Moisture content is normally reduced by centrifugal extraction prior to evaporative drying using equipment identical to that described for loose fibre, above. Yarn is normally unloaded from the dyeing machine into fabric bags held in round carts to facilitate direct crane loading of the centrifuge. Hydroextraction reduces the moisture content to approximately 0.4 litres/kg of dry weight.

### **2.12.2.2 Evaporative drying**

Evaporative dryers consist of a number of heated chambers with fan-assisted air circulation, through which the hanks pass suspended on hangers or poles or supported on a conveyer.

The hank sizes employed in carpet yarn processing require a slow passage through the dryer to ensure an even final moisture content, and a residence time of up to 4 hours is not uncommon. Air temperature is maintained below 120 °C to prevent yellowing (wool yellows above the boiling temperature).

All designs are capable of continuous operation. Thermal input is normally provided by a steam-heated exchanger and many designs incorporate air-to-air heat exchangers on the dryer exhaust to recover heat.

Less commonly, hanks may be dried by employing a dehumidifying chamber. Moisture is recovered by condensation, using conventional dehumidification equipment. In comparison to evaporative dryers, yarn residence time tends to be longer, but energy consumption is lower.

## **2.12.3 Yarn package drying**

The moisture content of dyed packages is initially reduced by centrifugal extraction. Specially designed centrifuges, compatible with the design of the dyeing vessel and yarn carriers, are employed.

Traditionally packages were oven-dried, very long residence times being required to ensure adequate drying of the yarn on the inside of the package. Two methods are currently used, rapid (forced) air drying and radio-frequency drying, the latter sometimes being combined with initial vacuum extraction. Forced air dryers generally operate by circulating hot air from the inside of the package to the outside at a temperature of 100 °C, followed by conditioning, in which remaining residual moisture is redistributed in a stream of air passing from the outside to the inside of the package. Radio-frequency dryers operate on the conveyer principle and are perhaps

more flexible than the types mentioned above. Lower temperatures can be used and energy efficiency is said to be high (comments made for evaporative drying of loose fibre apply in this case too).

### 2.12.4 Fabric drying

The drying process for fabric usually involves two steps: the first one is intended to remove water which is mechanically bound to fibres, while the second one is necessary to completely dry the fabric.

#### 2.12.4.1 Hydroextraction by squeezing

The fabric is squeezed by means of a padding machine through two or three rollers covered with rubber. This process cannot be applied to delicate fabric.

#### 2.12.4.2 Hydroextraction by suction

The fabric is transported flat over a 'suction drum' which is linked to a pump. The external air is sucked through the fabric and thereby removes the excess water (see the principles shown in Figure 2.43). The resulting residual humidity is still about 90 %.

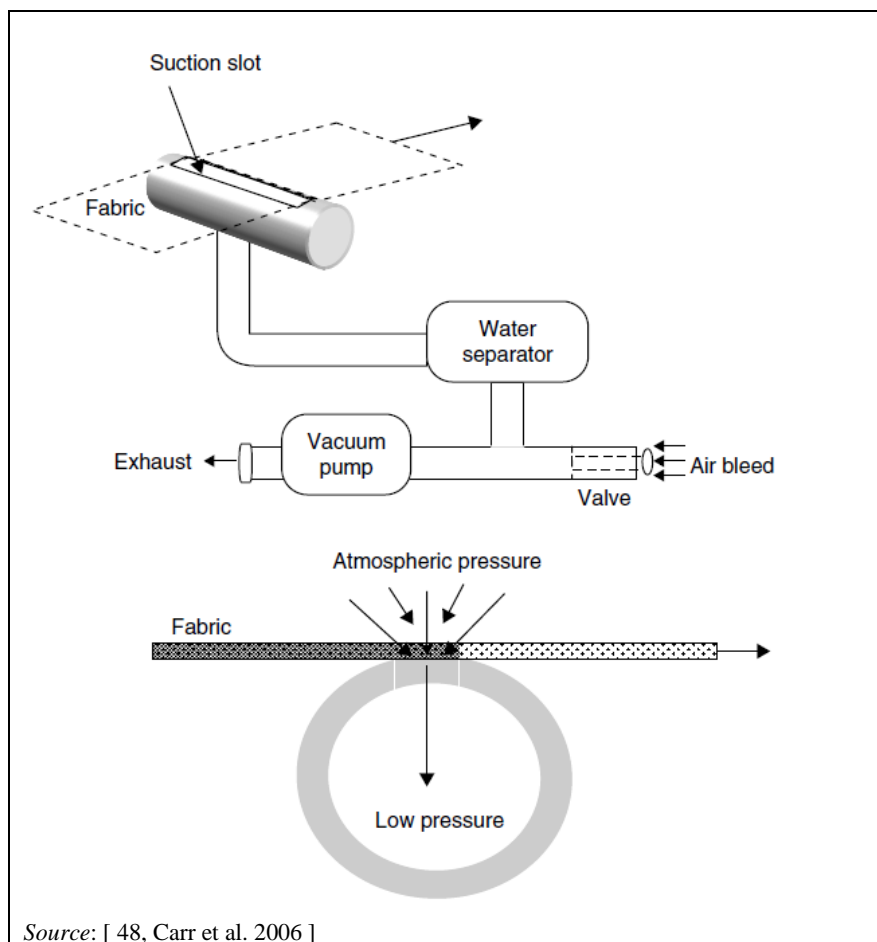


Figure 2.43: Principle of dewatering by vacuum extraction

### **2.12.4.3 Centrifugal hydroextractor**

The design of this machine is similar to the one described earlier for loose fibre and yarn hydroextraction. With heavy fabric, a horizontal axis machine may be used.

This is the most efficient method for mechanical water removal, but it cannot be applied to delicate fabrics prone to forming permanent creases.

### **2.12.4.4 Stenter**

This machine is used for full drying of the fabric. The fabric is conveyed through the machine in open-width. A hot current of air is blown across the fabric, thereby producing evaporation of the water.

The fabric is sustained and moved by two parallel chain loops. The fabric is hooked undulating and not taut to allow it to shrink during drying.

Most common stenter designs are horizontal and multi-layer, but many new designs exist. In the horizontal stenter machine, the fabric enters wet from one side and exits dried from the other. In the multi-layer type, it enters and exits from the same side. While in the first one the fabric moves horizontally without direction changes, in the second it is deviated many times, which makes this equipment unsuitable for delicate fabrics. However, horizontal stenter frames occupy more space and are less efficient (in terms of energy consumption).

For more information on stenters, see Section 8.4.

### **2.12.4.5 Hot-flue dryer**

This machine is composed of a large metallic box in which many rolls move the fabric (in full width) so that it runs a long distance (about 250 m) inside the machine. The internal air is heated by means of heat exchangers and ventilated.

### **2.12.4.6 Contact dryer (heated cylinder)**

In this type of machinery, the fabric is dried by direct contact with a hot surface. The fabric is longitudinally stretched on the surface of a set of metallic cylinders. The cylinders are heated internally by means of steam or a direct flame.

### **2.12.4.7 Conveyor fabric dryer**

The fabric is transported within two blankets through a set of drying modules. Inside each module the fabric is dried by means of a hot airflow.

This equipment is normally used for combined finishing operations on knitted and woven fabrics when, along with drying, a shrinking effect is also required in order to give the fabric a soft handle and good dimensional stability.

### **2.12.4.8 Dryers integrated with wet treatments**

These machines have integrated washing, softening and drying operations for woven and knitted fabrics in rope form.



During the drying phase, the fabric in rope form is recirculated in the machine by means of a highly turbulent airflow. Water is thus partly mechanically extracted and partly evaporated.

Thanks to the particular design of these machines, it is possible to carry out wet treatments such as washing in the same machine. In this case, the bottom of the machine is filled up with water and the required chemicals and the fabric is continuously soaked and squeezed.

The capacity of these machines is determined by the number of channels (from two to four).

## 2.13 Types of textile mills

Up to this point, this chapter has described the fundamental processes in the textiles industry that are within the scope of this document. The information given has been structured by fibre type, which has made it possible to explain those issues that are determined by the physico-chemical behaviour of the fibre. From a practical point of view, however, a subdivision of the textile industry activities into subsectors based on the type of fibre is of little benefit.

In practice, there are established patterns of activity, with finishing mills tending to concentrate on particular kinds of make-up or end-product (e.g. yarn, woven fabric, carpet), because this is defined by the specialist machinery used. This degree of specialisation does not apply to the same extent to the fibre. Although in the past the predominance of natural fibres made it possible to identify separate sectors based on the fibre (mainly cotton and wool), nowadays the proliferation of man-made fibres means that finishers almost always process a wide variety of fibres, even if one type is dominant within a particular mill (e.g. wool, cotton).

As an aid to the use of this BREF, therefore, the rest of this chapter gives examples of the main configurations (i.e. combinations of processes and fibre types) that may be found at actual mills and which are summarised in Table 2.23 below.

**Table 2.23: Main types of textile mills**

Main types of mill	Main fibre types and/or activities
Wool scouring mills	WO
Mills finishing yarn and/or floc	Mainly CV, PES, PAC and/or CO floc material
	Mainly WO floc/tops/yarn
	Mainly CO yarn
	Mainly PES yarn
Mills finishing knitted fabric	Mainly WO, PAC and/or CV yarn
	Mainly CO
	Mainly CO with a significant proportion of printing
	Mainly synthetic fibres
Mills finishing woven fabric	Mainly WO
	Mainly CO and/or CV
	Mainly CO and/or CV with a significant proportion of printing
	Mainly WO
Carpet manufacturing mills	Mainly PA
	Wool and wool-blend carpet yarn / loose fibre dyehouses
	Piece carpet dyeing and printing mills
	Integrated carpet manufacturing companies

Carpet manufacturing mills are kept in a separate group from the other finishing mills because the peculiarity of carpet as an end-product involves such specific requirements that companies tend to specialise in the processing of products that are suitable only for the carpet sector.

### 2.13.1 Wool scouring mills

Wool processed in Europe is mostly imported. Most of the wool produced in Europe is in fact coarse wool which is suitable for the manufacturing of carpets, but not for use in apparel. Merino wool (fine wool) is therefore imported mainly from Australia, New Zealand, South Africa, Argentina, Uruguay and Brazil.

The organisation of the scouring sector reflects the two main systems used to process wool: the woollen and the worsted system. Scourers tend to specialise in one or the other. Woollen system

scourers normally only scour the wool (sometimes they may blend it before dispatching it to the customer). Worsted system scourers usually scour, card and comb the wool, thus producing a sliver of parallel fibres which is called tops. Because of this difference, worsted system scourers are usually referred to as combers.

Within Europe, significant quantities of wool are also obtained from skins of slaughtered animals by a process called fellmongering in which the skins are treated chemically or biochemically to loosen the wool roots so that the wool can be easily separated from the skins.

The scouring process is usually the only wet process carried out in scouring mills and it has been described in detail in Section 2.3.1.1.

### 2.13.2 Mills finishing yarn and/or floc

A common feature of floc and yarn finishing is that all process steps are normally carried out in the same equipment. The basic process sequence is:

- pretreatment (scouring/bleaching);
- dyeing;
- finishing (mainly softening by addition of softening agents in the last rinsing bath, but also flame-retardant or mothproofing treatments for carpet wool fibre).

Pretreatment can be carried out as a separate step, especially in the case of natural fibres, or together with dyeing by adding additional specific auxiliaries in the dye bath. The second option is common when the amount of impurities on the fibre is not significant and they are easy to remove, or when auxiliaries (e.g. preparation agents, spinning lubricants) are specially chosen not to interfere with the dyeing process.

Bleaching is normally not applied for synthetic fibres. With natural fibres, bleaching is commonly omitted for dark shades, whereas for light shades it is often combined with scouring. After washing, the material is dyed in the same machine and then submitted to final washing and rinsing.

For dyeing, it is common practice, in the case of floc and tops material, to achieve the desired final shade by thorough mixing of individual dyes. With yarn, on the other hand, the required shade has to be achieved with only one dye since, unlike floc and tops, the shade cannot be corrected by compensation. For this reason, a higher standard of accuracy is required in the development of the dye recipe in the laboratory.

As explained in other parts of this document, the dyes and auxiliaries applied vary with the fibres processed.

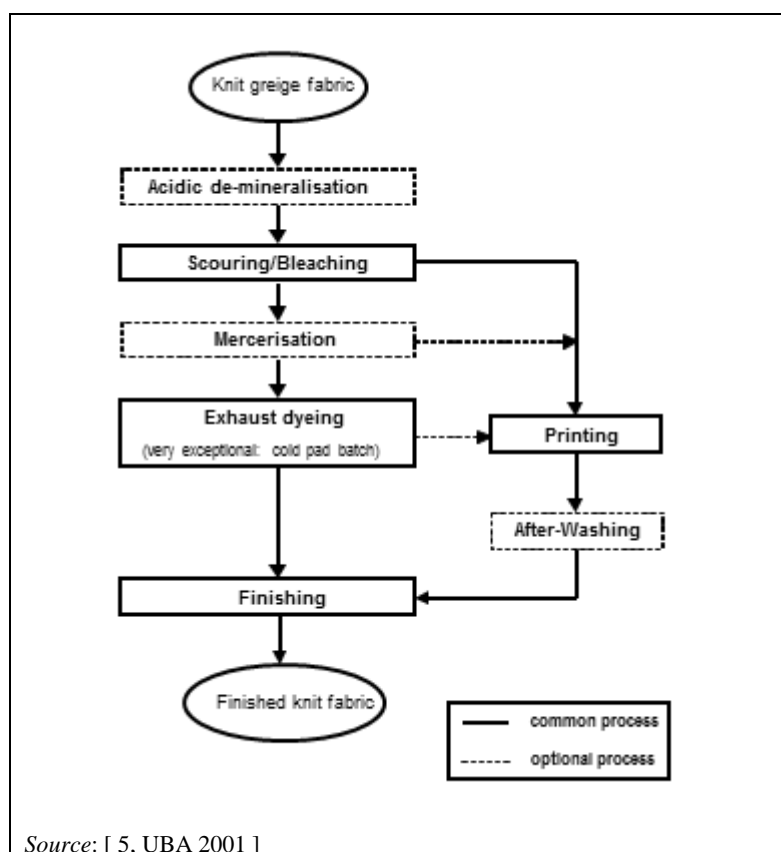
Mercerising treatment may be desired for cotton. If so, the material is processed in hank form. Mercerisation is carried out in a separate machine and is normally the first treatment applied.

Anti-felt treatment is another optional operation; it is applied only on wool and mainly on tops.

### 2.13.3 Mills finishing knitted fabric

#### **Mills finishing knitted fabric consisting mainly of cotton**

The typical process sequence for finishing knitted fabric consisting mainly of cotton is shown in Figure 2.44 (only the wet processes are reported). The dotted lines indicate processes that are not obligatory or are not common practice. Acidic demineralisation, for example, is applied only in a few mills. Mercerisation is also indicated with a dotted line because this additional treatment is only required for certain articles.



**Figure 2.44:** Typical process sequence for the finishing of knitted fabric consisting mainly of cotton

Scouring is generally a batch operation, but large installations often do it in continuous mode. Hydrogen peroxide is the most commonly applied bleaching agent in cotton mills today.

Cotton knitted fabric can be dyed with different classes of dyestuffs such as reactive, direct, sulphur and vat dyestuffs. Reactive dyestuffs are the most commonly used. Direct dyestuffs may be used for lighter shades and sulphur dyestuffs for dark shades. Vat dyestuffs may be used for very high lightfastness requirements.

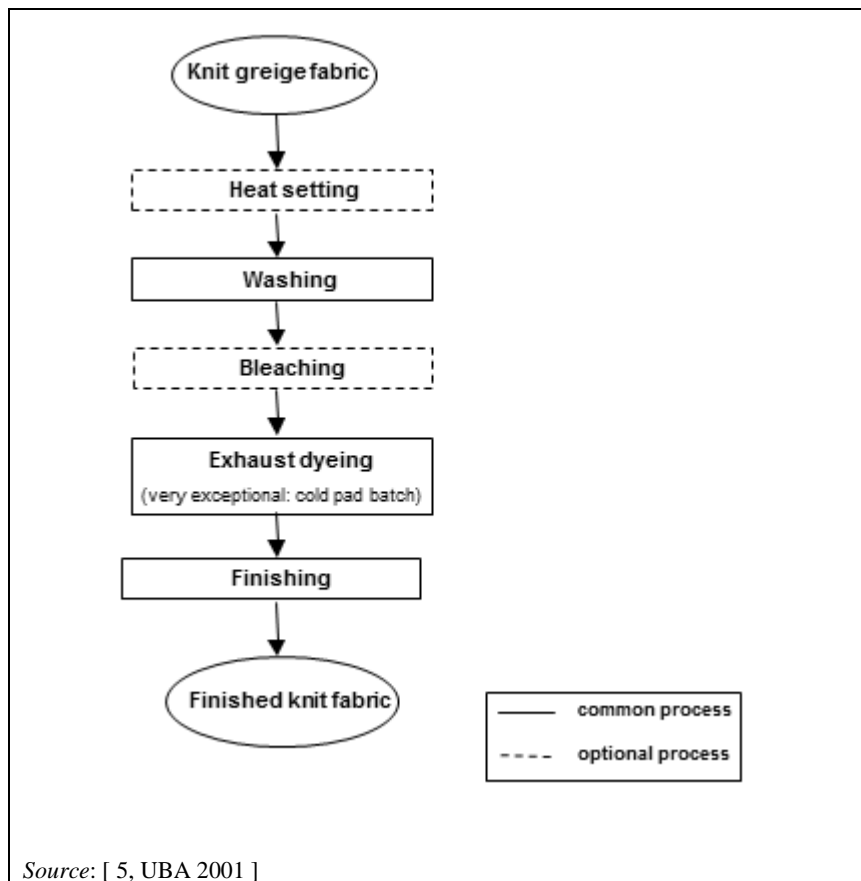
In printing, two further subclasses can be identified:

- mills finishing cotton knitted fabric without a printing section; and
- mills finishing cotton knitted fabric with a printing section.

Pigment printing is widely applied for knitted fabric and does not need the after-washing step required when printing with reactive, disperse and vat dyes (also relatively common techniques in this sector).

#### **Mills finishing knitted fabric consisting mainly of synthetic fibres or wool**

The typical process sequence for finishing knitted fabric consisting mainly of man-made fibres or wool is shown in Figure 2.45 (only the wet processes are indicated). Optional operations are indicated with dotted lines.



**Figure 2.45: Typical process sequence for the finishing of knitted fabric consisting mainly of man-made fibres or wool**

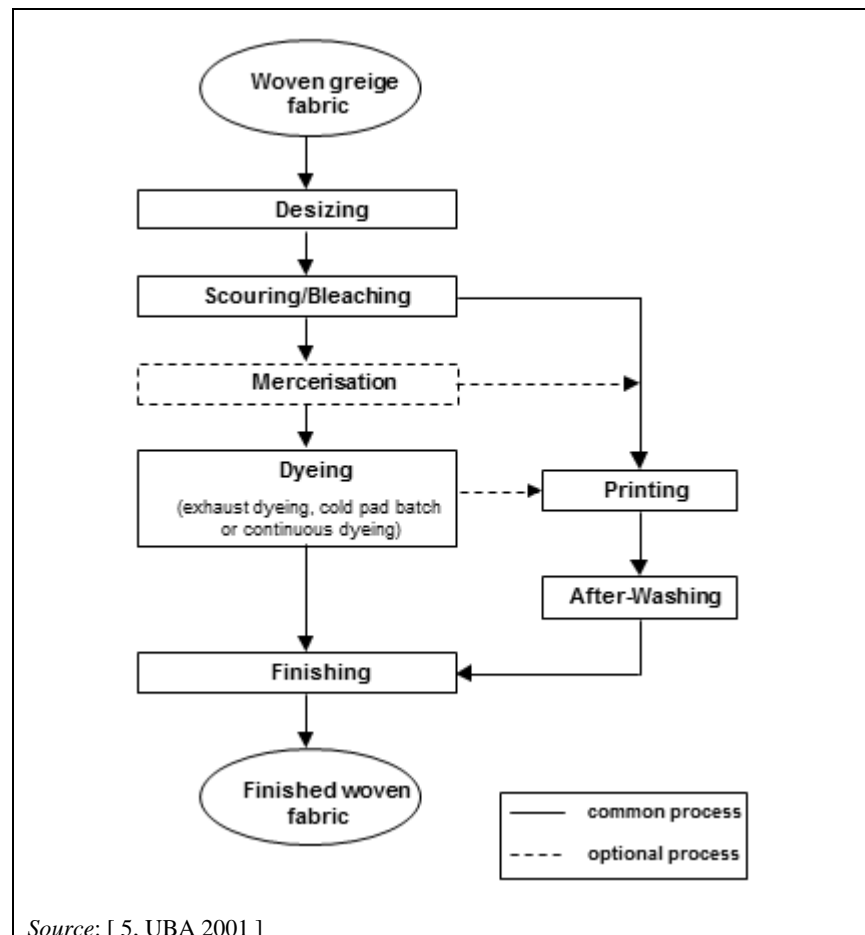
Before dyeing, the fabric is normally rinsed in order to remove preparation agents and impurities. Heat-setting is not always needed, but when carried out this operation can take place either before washing (on the raw fabric) or after the washing step.

Depending on the required degree of whiteness, bleaching may be needed.

#### 2.13.4 Mills finishing woven fabric

##### Mills finishing woven fabric consisting mainly of cotton and/or cotton blends

The typical process sequence for the finishing of woven fabric consisting mainly of cotton or cotton blends is shown in Figure 2.46. Optional operations are indicated with dotted lines.



**Figure 2.46: Typical process sequence for the finishing of woven fabric consisting mainly of cotton or cotton blends**

Woven fabric consisting mainly of cotton or cotton blends is finished on semi-continuous/continuous lines or in discontinuous mode, mainly depending on the size of the lot.

Pretreatment operations such as desizing, scouring and bleaching are very often combined in one single step in continuous lines. Pretreatment of viscose usually requires alkali treatment and washing only, provided that the sizing agents are water-soluble, which is normally the case.

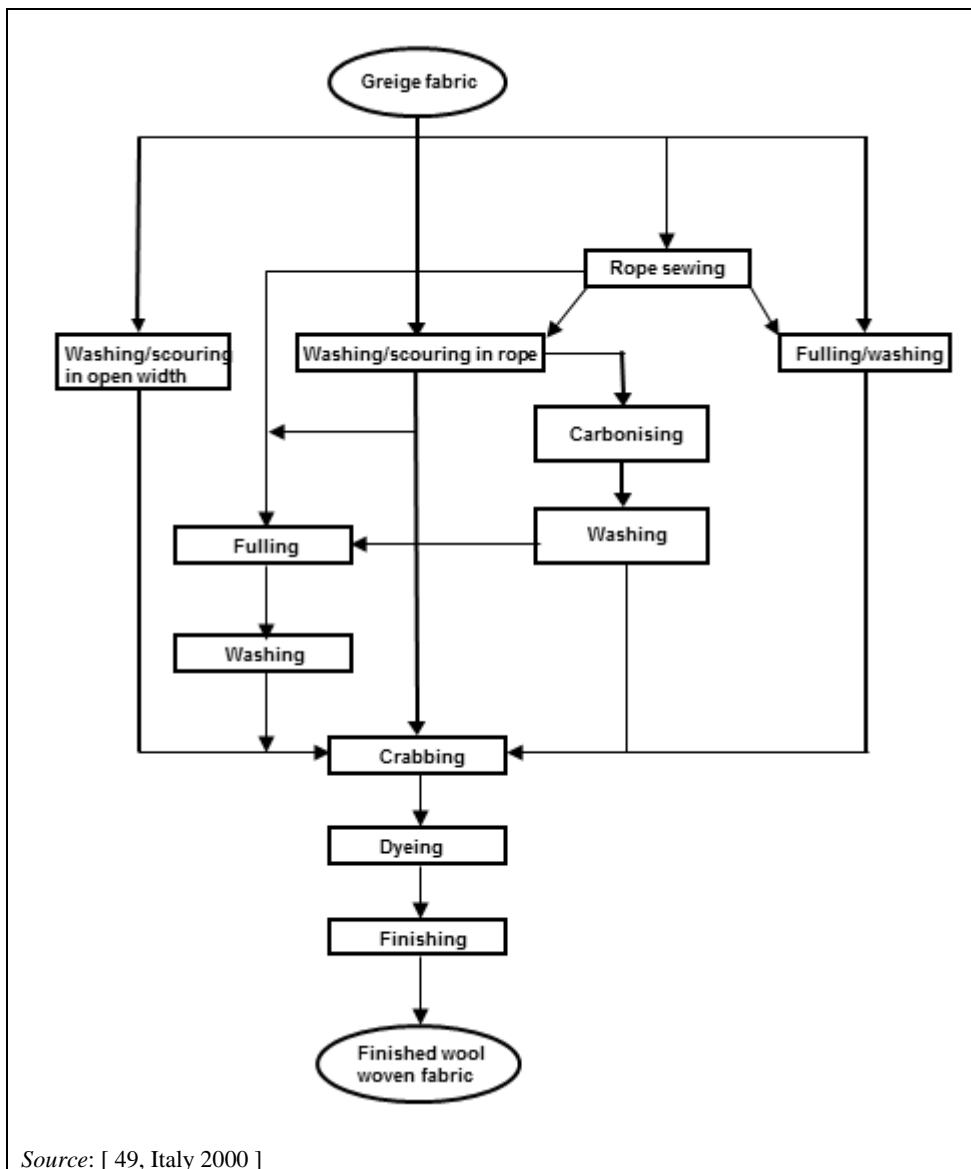
In addition to the processes mentioned in Figure 2.46, further treatments may exceptionally be applied, such as pretreatment with liquid ammonia (carried out at very few sites in Europe only).

For printing, two further subclasses can be identified:

- mills finishing cotton woven fabric without a printing section; and
- mills finishing cotton woven fabric with a printing section.

#### **Mills finishing woven fabric consisting mainly of wool**

The typical process sequence for the finishing of woven fabric consisting mainly of wool (woollen and worsted wool) is shown in Figure 2.47.



**Figure 2.47: Typical process sequence for the finishing of woven fabric consisting mainly of wool**

Both water washing and solvent washing (dry cleaning) are common in the wool sector. Washing in an aqueous medium is carried out either in rope form (in batch) or in open-width (mostly in continuous mode, but also in batch). Heavy fabrics (woollen wool) are preferably treated in rope form, whereas washing in open-width is preferred for fine worsted fabric.

Carbonising and fulling are optional treatments in the basic process sequence. Carbonising is applied only on woollen wool fabric, which is also the most common form of fabric for fulling treatments.

Crabbing can be carried out before or after dyeing, depending on the desired effect. Crabbing on raw fabric is done in order to set the dimensions of the fabric, so that they will not change during use or during the subsequent processes.

#### **Mills finishing woven fabric consisting mainly of synthetic fibres**

The process sequence for the finishing of woven fabric consisting mainly of man-made fibres is similar to the one illustrated in Figure 2.45 for knitted fabric. However, here the washing/desizing step is more important because all sizing agents need to be removed. Synthetic sizing agents are normally used, which are easily removed with water, often in continuous washing machines.

In fabric with a certain percentage of elastane, silicones are also present. The complete removal of these substances can be very difficult. In some cases, solvent cleaning is applied; totally closed systems are mainly used for this purpose, which severely limits losses of solvent.

Dyeing is carried out in continuous or in batch dyeing machines. The use of disperse dyes is predominant.

### **2.13.5 Carpet manufacturing mills**

#### **2.13.5.1 Wool and wool-blend carpet yarn dyehouse**

The production of spun-dyed yarn can be regarded as a specific sector within the carpet manufacturing industry. Mills can be identified as dyehouses processing mainly wool and wool-blend fibres. Different treatments are carried out in order to convert white loose fibre into dyed carpet yarn. Wet processes essentially consist of dyeing and other ancillary operations carried out either in loose fibre or yarn form. Dry processes consist, in turn, of blending, carding, spinning, etc. These processes will not be considered here, since they have already been described in previous sections. Depending on when colouration takes place, raw fibre flows through some or all of these processes. As can be seen in Figure 2.48, three basic process sequences are possible.



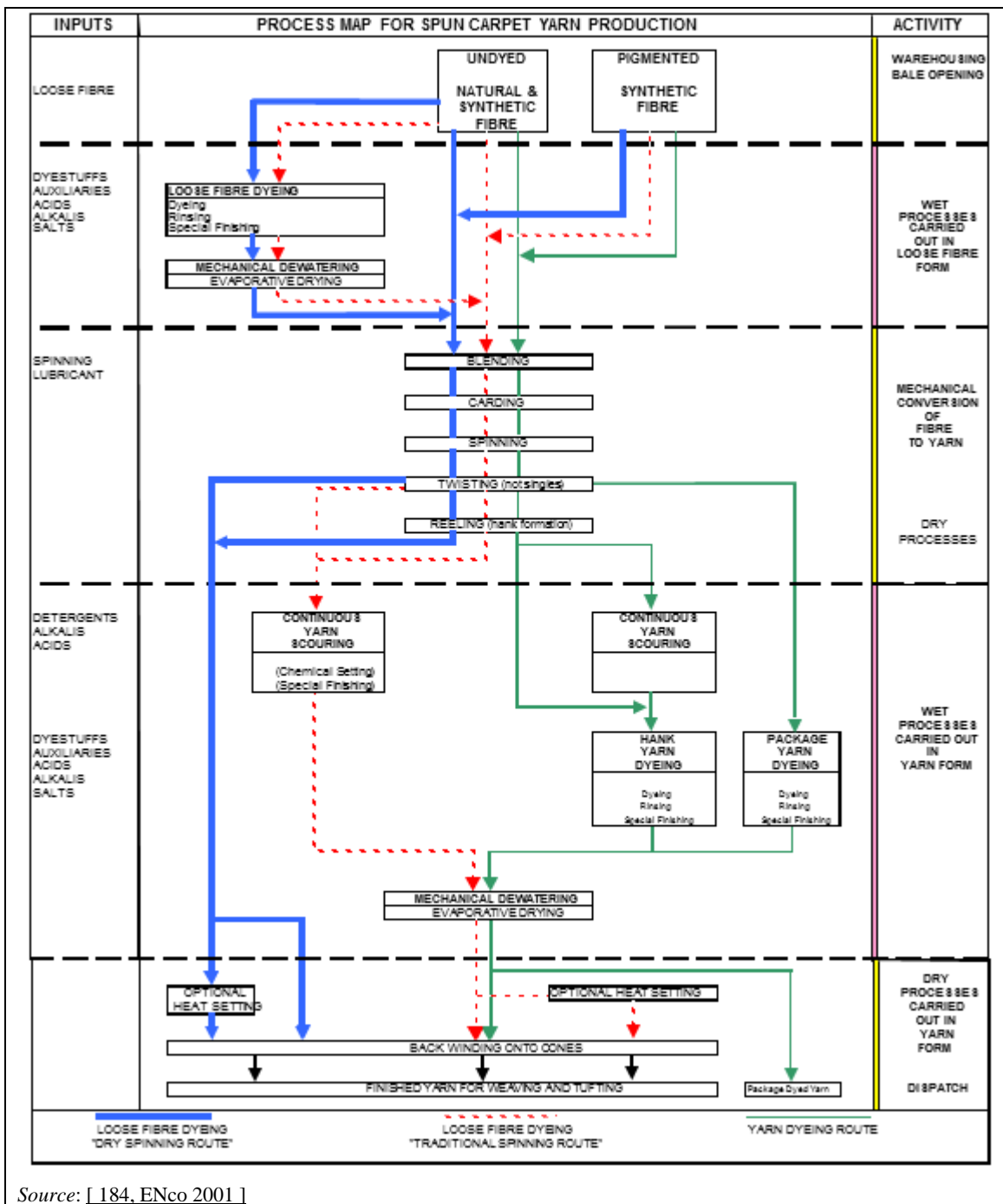


Figure 2.48: General process flow diagram for wool and wool-blend carpet yarn production

The **dry spinning route**, so called because there is no wet processing after yarn formation, begins with colouration at the loose fibre stage. This is followed by yarn formation and finally twist setting. This process sequence is of relatively recent origin and requires the consistent use of wool with a low lanolin content and specialised spinning lubricants which can be left on the yarn without causing subsequent soiling of the carpet. The process is particularly useful in the production of yarn for large-volume plain-shade carpets and for effect yarns, obtained by blending together fibre dyed to different shades. While this production sequence is the most economical in terms of resource consumption, the selection of clean raw materials and the ongoing maintenance of the mill in a clean condition are essential.

The **traditional loose stock dyeing route** was originally used to produce large batches of yarn to the same shade for plain carpets. Loose fibre is first dyed and then converted to yarn using what is still sometimes referred to as the ‘oil spinning’ process; this terminology arose from the

practice of using spinning lubricants based on emulsions of mineral oil. Even small traces of residual mineral oil would lead to a marked propensity for the carpet to soil in service, and so yarns prepared by this route were thoroughly cleaned by scouring (washing) in hank form (see below). While the use of mineral-oil-based lubricants has been largely replaced with water-soluble synthetic products, the practice of scouring the yarn is still judged to be essential by many processors in order to avoid potential claims arising from soiling. Unlike the dry spinning process, this route allows greater flexibility in the purchase of raw materials, so that wool with a higher lanolin content can be used. See Section 4.7.7.4 for more details.

In the **yarn dyeing route**, clean fibre is first converted into yarn before dyeing. This process is particularly suitable for the production of the small coloured lots required for patterned carpet weaving or the bespoke trade, where white yarn can be held in stock and dyed as required to fill orders. The process is, however, by no means restricted to small batches, and dyeing machines with capacities of up to four tonnes are used to produce plain shades for both tufting and weaving. See Section 4.7.7.5 for more details.

In the case of integrated yarn manufacturers, it is common to find two or more of these process streams operating side by side and sharing common wet processing equipment. Since the dyeing and finishing techniques used apply equally to all three sequences, they are discussed in the following sections without further considering the different routes mentioned. Variants are described where they occur, and the relevance of any dry process segments is discussed where they have a significant impact on environmental performance or emissions.

### 2.13.5.2 Integrated carpet manufacturing mills

Fully integrated carpet manufacturers carry out all the mechanical processes, wet processes (pretreatment, dyeing, printing and finishing operations) required to convert natural and synthetic fibres into finished carpet. Such companies may also produce their own synthetic fibres from raw polymer feedstock. Regarding the natural fibres processed, they can in some cases select and purchase natural fibres and operate the whole chain of processes from wool scouring to dyeing, yarn spinning and carpet weaving/tufting. However, usually not all of these operations are carried out at the same site.

The conversion of the fibre into finished carpet can follow different routes depending on the style of the carpet to be produced.

#### Tufted carpet

Yarn can be manufactured from:

- staple fibres, from both synthetic (PA, PP, PES, PAC) and natural (wool and cotton) fibres;
- continuous filaments, exclusively from synthetic fibres (mainly PA, PP and PES).

The carrier materials (primary backing) usually consist of:

- PP woven fabrics or webs;
- PES woven fabrics or webs;
- jute fabrics.

Finishing of tufted carpets involves:

- dyeing and/or printing;
- coating;
- mechanical finishing;
- chemical finishing.

Dyeing and chemical finishing can be applied on loose fibre, yarn or pieces, while the other operations are carried out on the final carpet.

### **Needle-felt carpet**

Almost all fibres may be used for the production of needle-felts (PP, PA, PES, PAC, wool, cotton jute/sisal, coconut fibre and viscose). However, mostly, man-made fibres are used.

Needle-felt finishing involves:

- dyeing (rarely done);
- coating;
- mechanical finishing (rare);
- chemical finishing.

### **Woven carpet**

Both natural and synthetic fibres are used in woven carpet production.

Carpets are woven using dyed yarns (so piece dyeing is not applied in woven carpet production). The final carpet is then subjected to mechanical and chemical finishing treatments.

## 3 EMISSION AND CONSUMPTION LEVELS

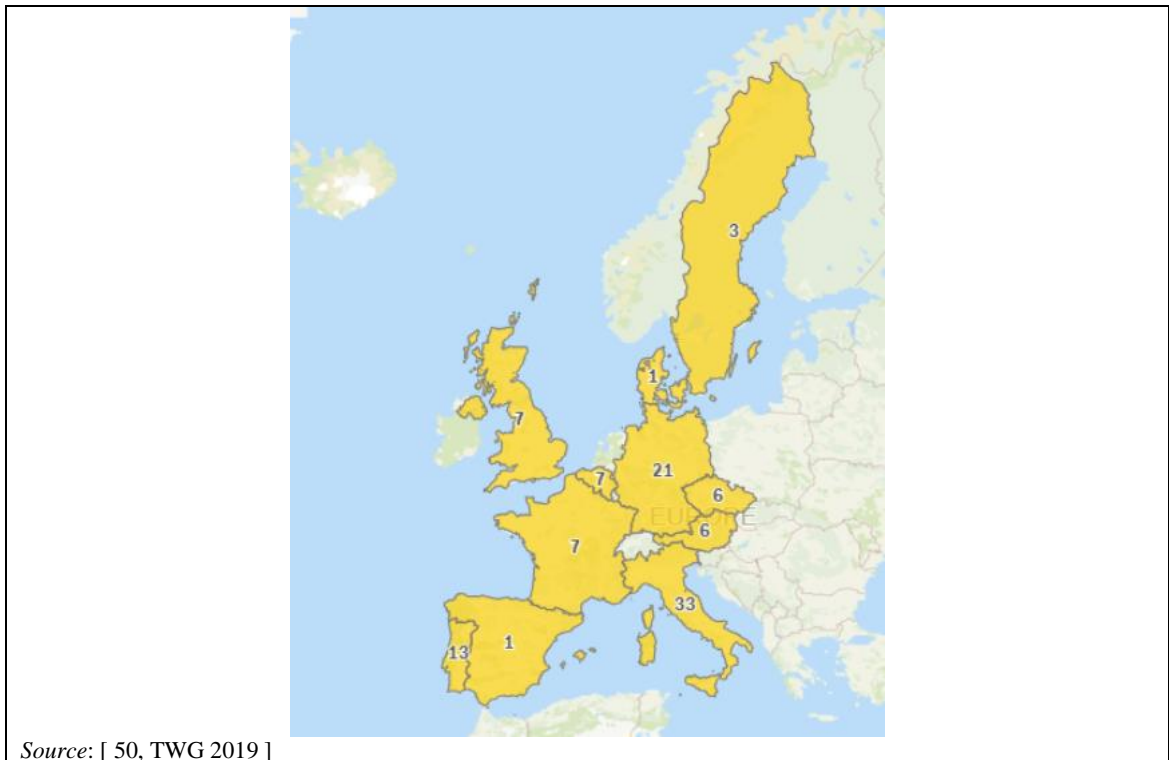
### 3.1 Introduction

The main environmental issues relevant for the textile industry have been dealt with in detail, process by process, in Chapter 2.

The textiles industry has always been regarded as a water-intensive sector. The main environmental concern is therefore about the amount of water consumed and discharged and the chemical load in the waste water. Other important issues are energy consumption, emissions to air and solid wastes and odours, which can be a significant nuisance in certain treatments.

The emission and consumption levels presented in this chapter are based on data collected from 106 plants across the EU (see geographical distribution in Figure 3.1 below) over a reference period covering the years 2016, 2017 and 2018. The data was collected via 108 questionnaires (as some plants provided more than one questionnaire).

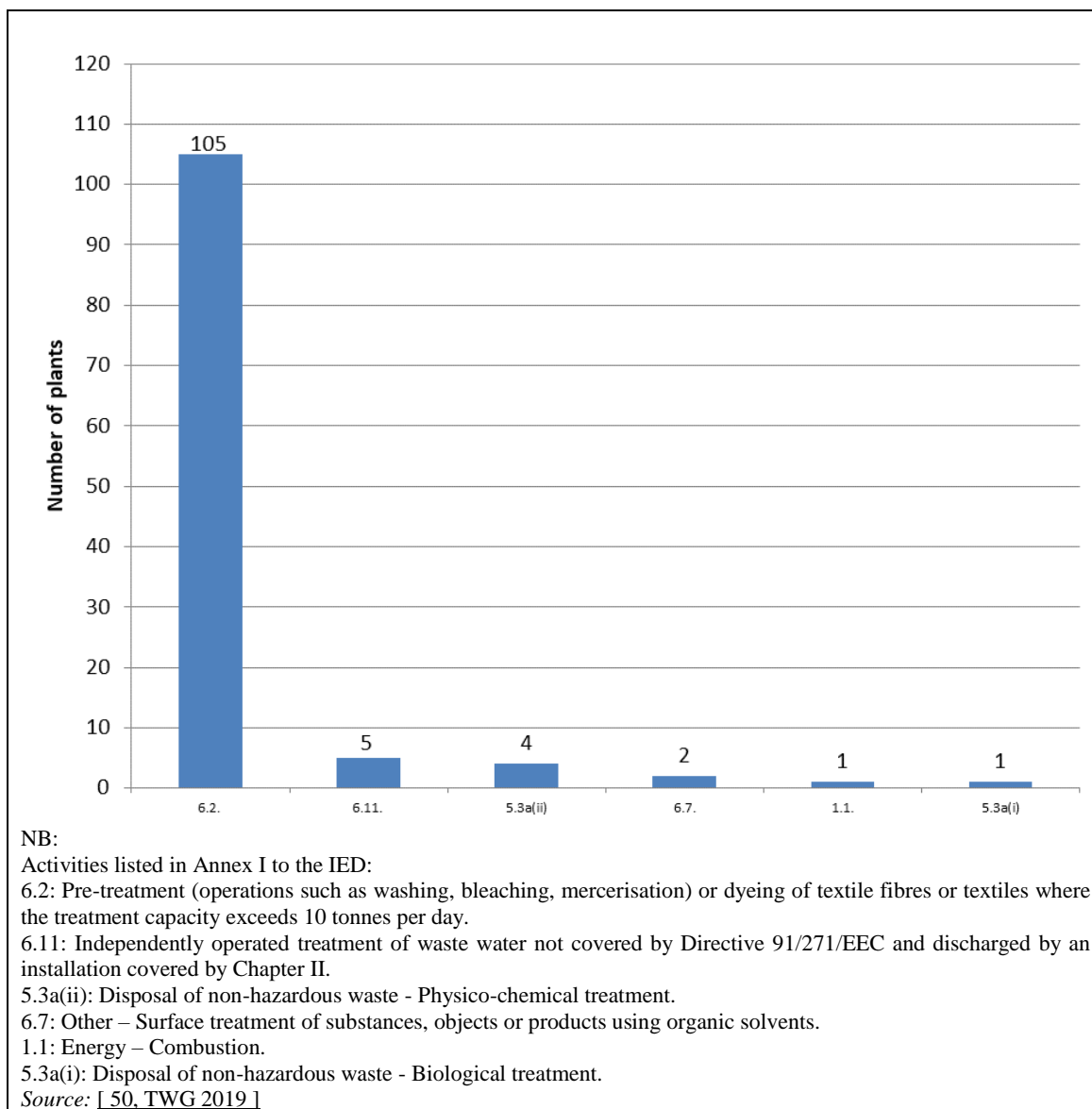
The plants from the data collection are listed in Section 8.7.



**Figure 3.1: Geographical distribution of the plants that participated in the data collection**

## 3.2 Processes

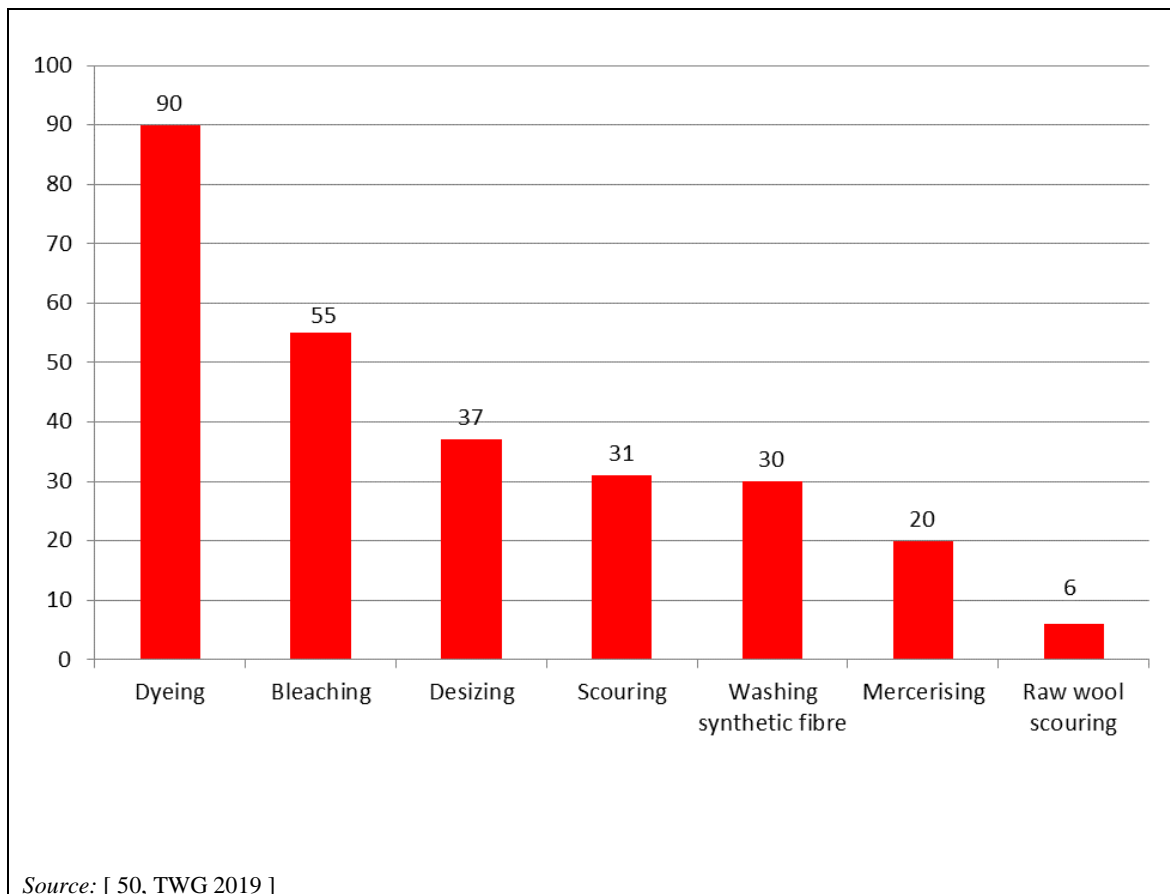
Figure 3.2 below shows the IED activities carried out by the plants that participated in the data collection.



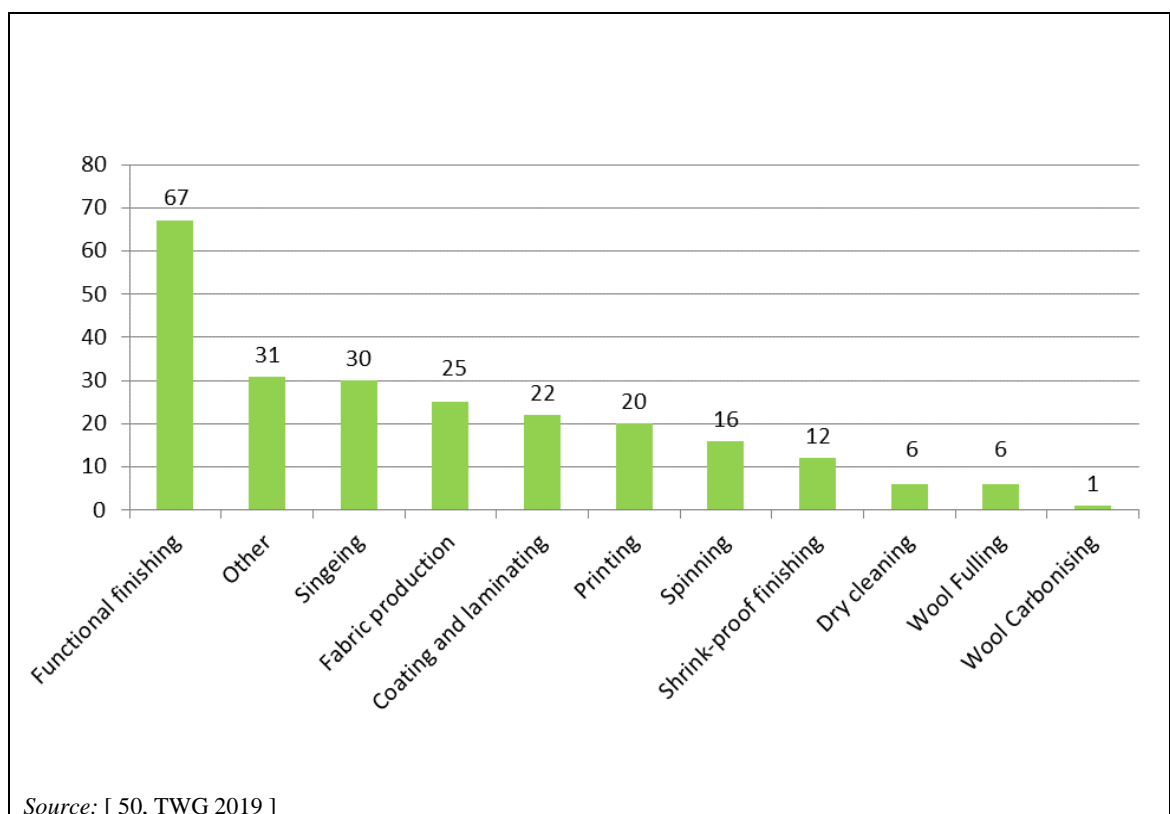
**Figure 3.2: IED activities carried out at the plants of the data collection**

All plants of the data collection carry out activities listed in point 6.2 of IED Annex I.

The processes carried out at the plants are shown in Figure 3.3 and Figure 3.4 below for activities covered by point 6.2 of IED Annex I and for the directly associated activities (DAAs), respectively.



**Figure 3.3: Number of plants performing 6.2 activities**



**Figure 3.4: Number of plants performing directly associated activities**

No plants reported silk weighting as a directly associated activity.

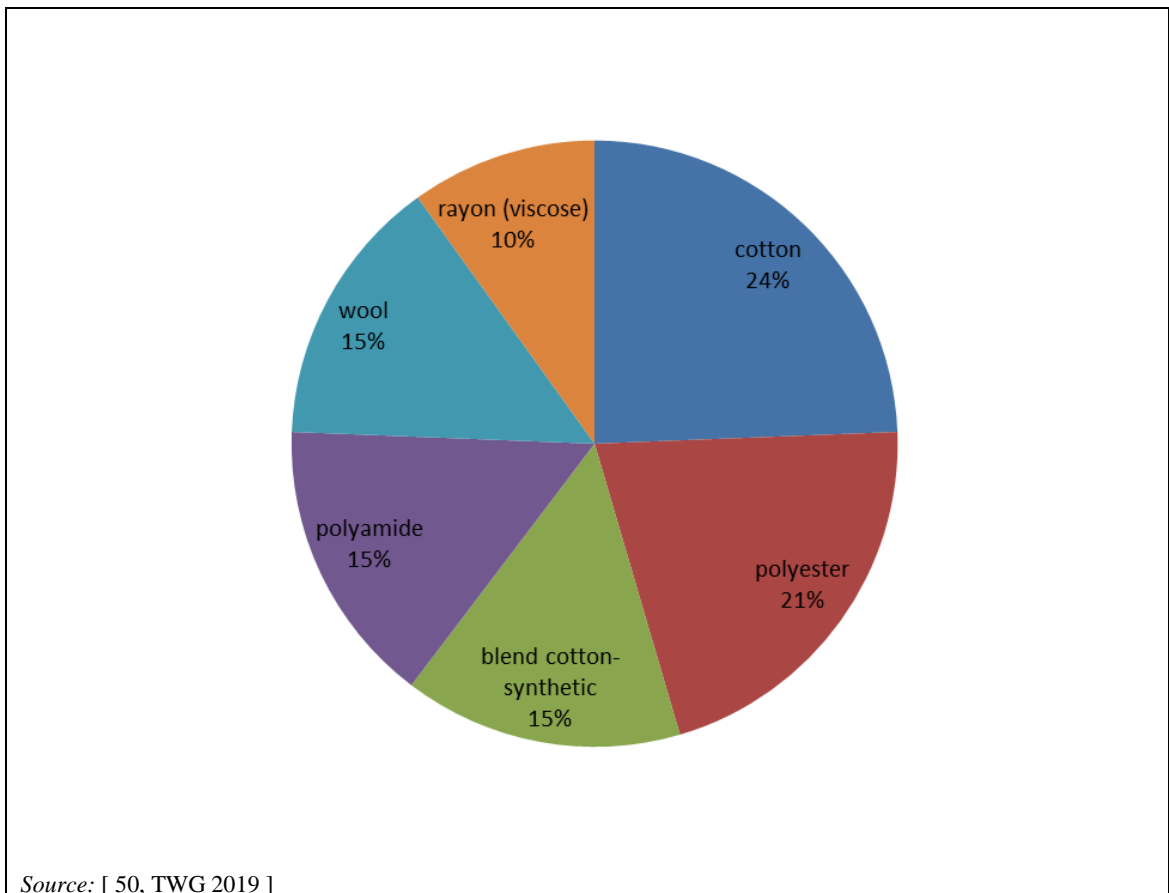
In more detail, concerning fabric production, 5 plants carry out knitting, 12 sizing, 4 tufting, 14 warping, 3 waxing and 19 weaving. No plant reported carrying out needle-felting or production of non-woven fabric.

Out of the 89 plants performing dyeing, 39 carry out continuous dyeing and 68 batch dyeing.

Out of the 66 plants performing functional finishing, 56 carry out continuous finishing and 23 batch finishing.

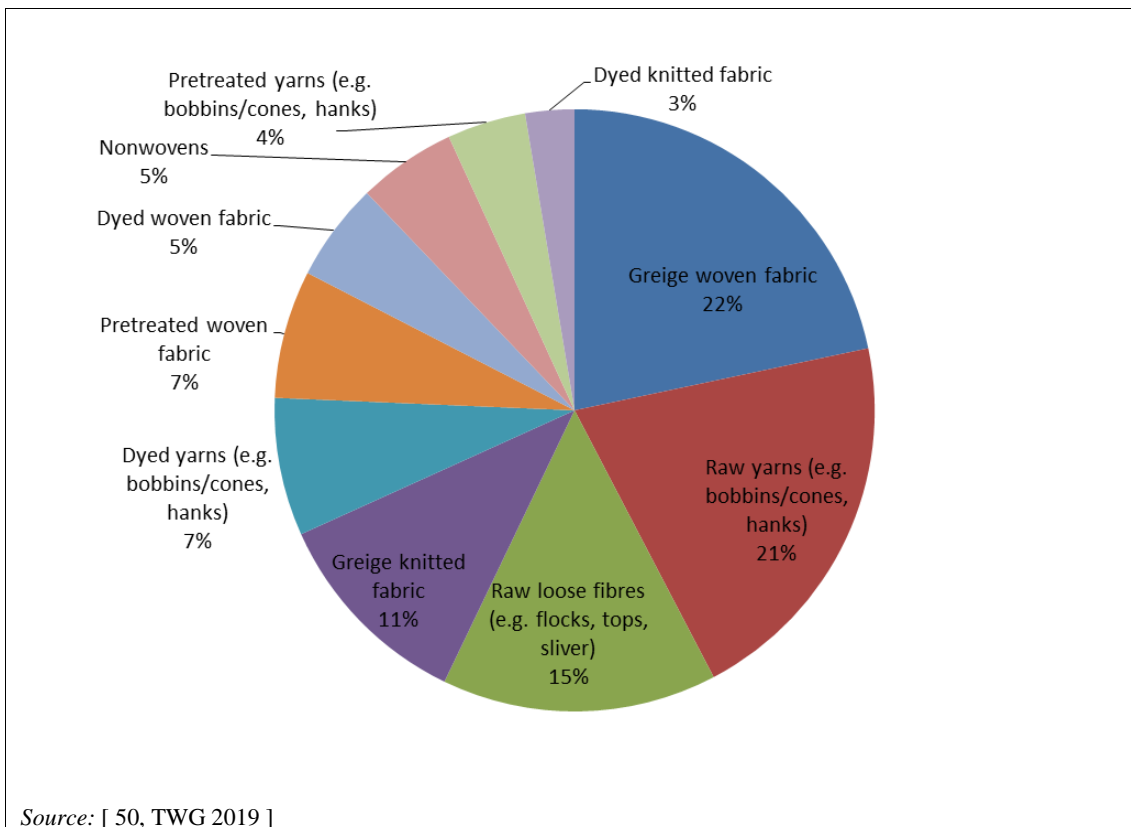
### 3.3 Raw material and products

The composition and form of the main raw materials treated by the plants in the data collection are given in Figure 3.5 and Figure 3.6 respectively.



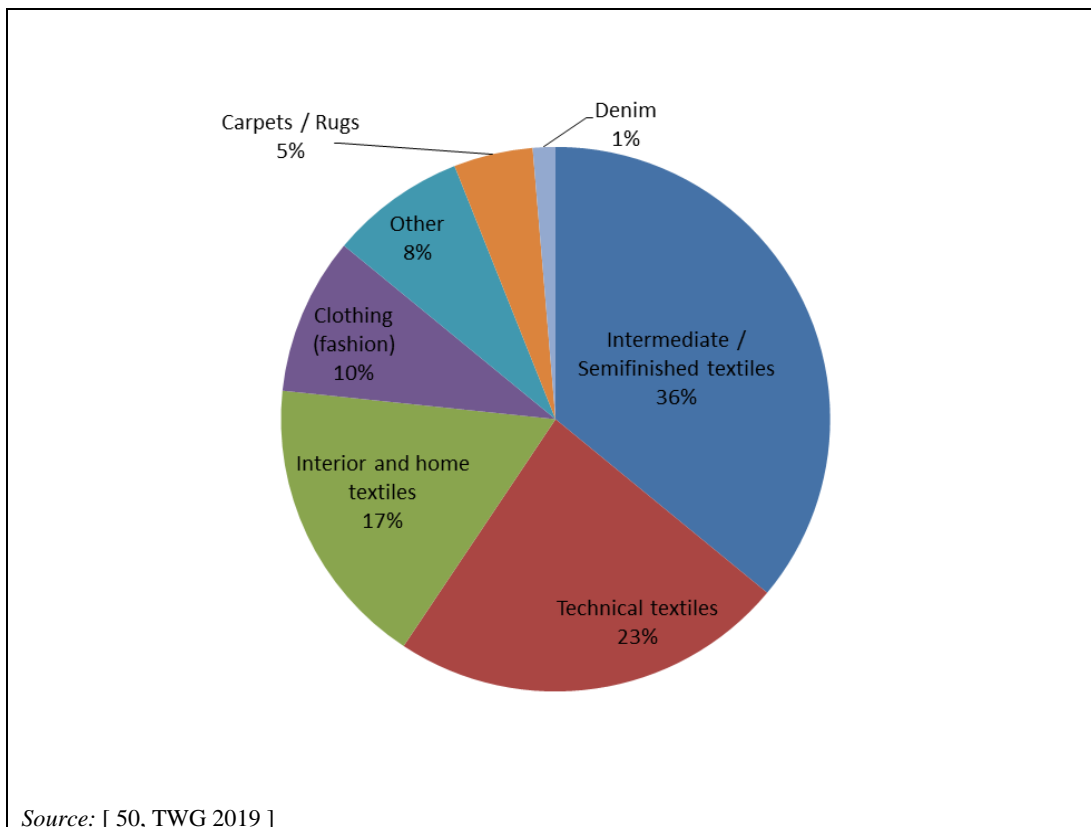
**Figure 3.5: Composition of the main raw materials treated**





**Figure 3.6: Form of the main raw materials treated**

The main products of the plants of the data collection are shown in Figure 3.7.



**Figure 3.7: Main products of the plants of the data collection**

## 3.4 Emissions to water

### 3.4.1 Overview

The 108 questionnaires from 106 plants present a total of 115 monitored points of emissions to water. A total of 103 plants reported one monitored emission point, 11 plants reported two monitored emission points and 1 plant reported three monitored emission points.

In total, 3 plants reported no points of emissions to water (DK054, FR130 and FR133). In the case of DK054, no information was provided in the questionnaire to explain why there are not emission points to water. FR130 did not report points of release to water, as the plant uses evapo-condensation for water reuse (85 %) and subcontracts a residue treatment for the waste water. Similarly, FR133 reported a proportion of recycled/reused water above 95 % as a rationale for reporting no emission points to water.

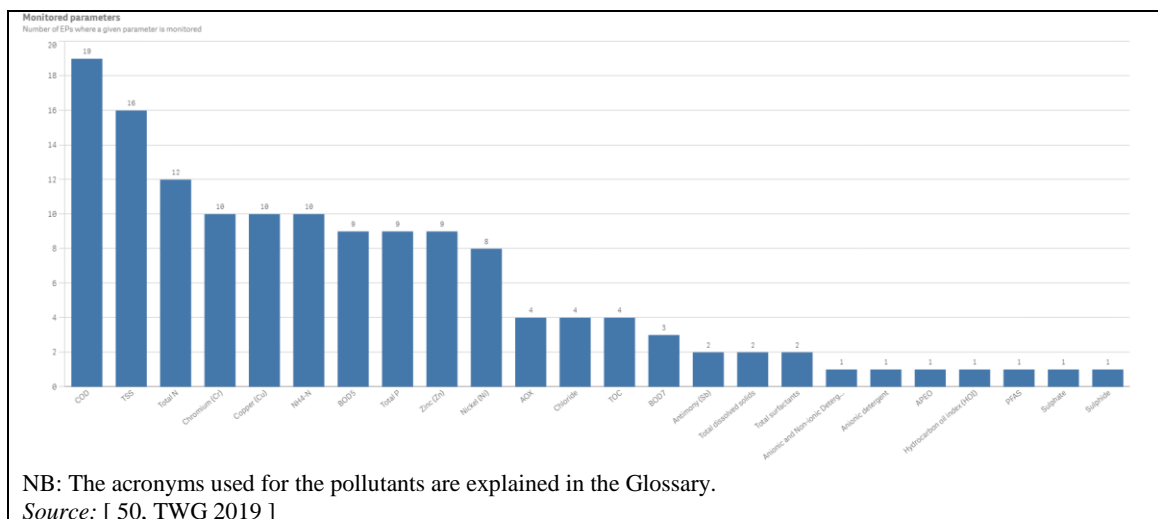
The 108 questionnaires present a total of 1 212 data sets related to emissions of pollutants to water. These data sets correspond either to a combination of individual measurements, when the parameter is measured up to 12 times a year (periodic monitoring), or to a combination of minimum/average/maximum/97<sup>th</sup> percentile, when the parameter is measured more than 12 times a year (frequent monitoring).

The distribution of data sets according to the type of monitoring is as follows:

- periodic monitoring: 1 053;
- frequent monitoring: 140.

#### Frequent monitoring

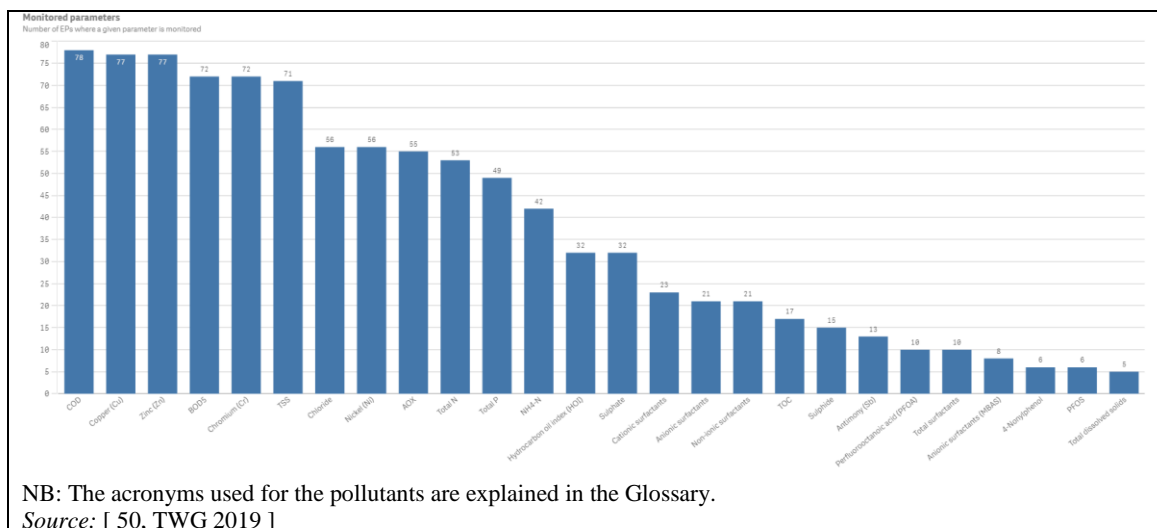
The distribution of the monitoring frequencies of the 140 data sets that were reported as frequent measurements can be seen in Figure 3.8.



**Figure 3.8: Distribution of the reported monitoring frequencies (number of data sets concerned) for the frequent measurements**

#### Periodic monitoring

The distribution of the monitoring frequencies of the 1 053 data sets that were reported as periodic measurements can be seen in Figure 3.9.



**Figure 3.9: Distribution of the reported monitoring frequencies (number of data sets concerned) for the periodic measurements**

Concerning the alkylphenols and alkylphenol ethoxylates, the perfluorocarbons, the pesticides, the brominated flame retardants and the surfactants, information about the individual substances or groups of substances measured is given in Sections 3.4.13 to 3.4.17.

#### Type of discharge

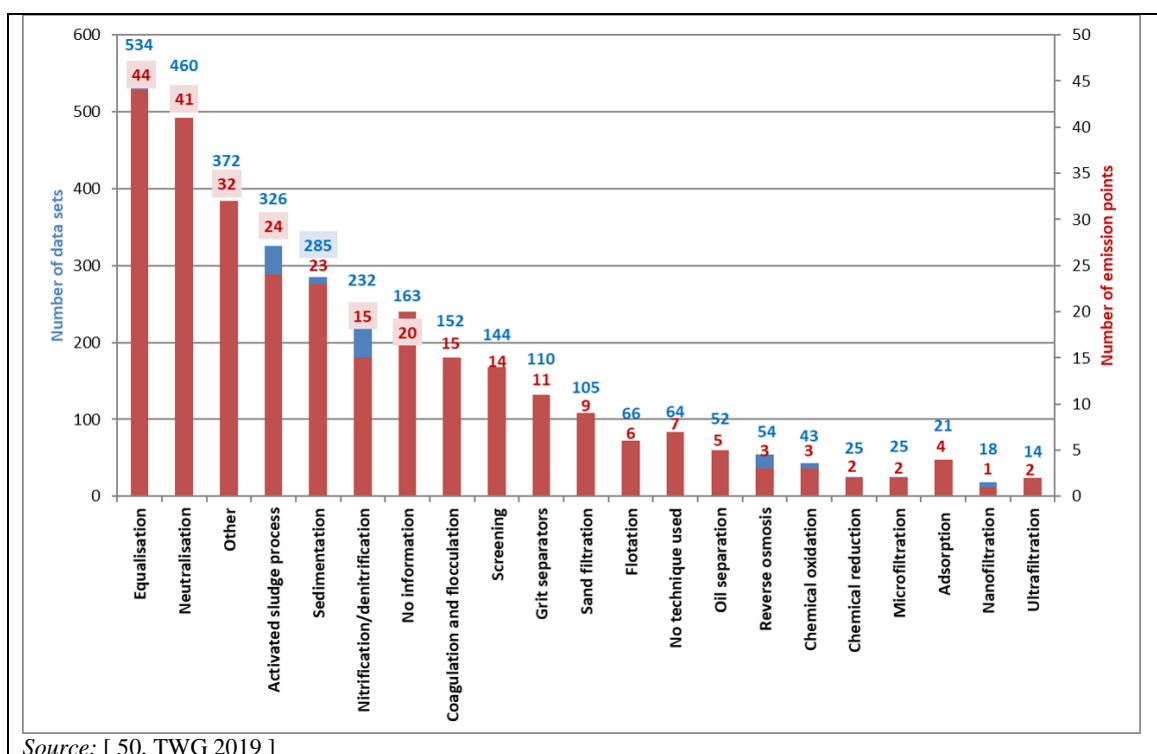
Out of 115 emission points, 25 correspond to direct discharge to the environment and 90 to indirect discharge.

Some particular cases are to be noted concerning the type of discharge:

- Plant CZ016: the waste water is not discharged but taken by truck to an external waste water treatment plant. It represents a small amount of about 1.5 m<sup>3</sup>/t of textiles treated.
- A number of plants located in the Prato district, Italy, discharge waste water to the same centralised industrial waste water treatment plant (Plants IT059, IT061, IT064, IT065, IT068, IT069, IT070, IT070, IT071, IT074, IT078, IT079, IT088, IT090 and IT094). Some of the treated water is reused by these plants.

#### Abatement techniques

Out of 115 emission points that reported 1 212 data sets of emission measurements, Figure 3.10 shows the number of emission points and data sets related to each of the waste water treatment techniques.



**Figure 3.10: Number of emission points (red) and data sets (blue) related to a given waste water treatment technique**

‘No information’ was reported for 20 emission points and 163 data sets and for 7 emission points and 64 data sets it was reported that ‘No techniques’ were used. When no information was reported, it was assumed that no technique is used.

The pollutant removal efficiency of these techniques was reported for only 16 out of 1 212 data sets. The data reported about removal efficiency is shown in Table 3.1.

Additionally, EURATEX and France provided data on removal efficiencies for the parameter COD. These data was collected in addition to the questionnaires, and are grouped in Table 3.2. For example, 1 out of 8 emission points (i.e. FR131\_w{1}) reported a specific waste water discharge below 25 m<sup>3</sup>/t, reporting a COD abatement efficiency  $\geq 95$  % as a rolling yearly average and COD daily emission values around 150 mg/l (minimum 67mg/l, median 140 mg/l and maximum 373 mg/l).

Sweden provided information about the COD removal efficiency achieved in the waste water treatment plant called Skene. This plant received the waste water discharge from four textile-dyeing installations. The COD removal efficiency reported is in the range of 90-95 % [ 51, Hansson. S 2020 ].

A COD reduction of 90 % can be assumed for biological treatment (e.g. activated sludge treatment). When using a biological membrane reactor with optimum performance and a high percentage of easily biodegradable compounds, especially starch, a removal efficiency of up to 96 % can be achieved [ 52, Schönberger H. 2018 ].

Table 3.1: Removal efficiency data reported in the data collection

Point of discharge	Substance	Type of discharge	Minimum concentration over 3 years (mg/l)	Average concentration over 3 years (mg/l)	Maximum concentration over 3 years (mg/l)	Maximum mass flow over 3 years (g/day)	Removal efficiency (%)	Abatement techniques
CZ020_w {1}	COD	DIR	21.0	34.4	65.	NI	95.3 – 96.3	Sedimentation - Nitrification/ denitrification - Neutralisation - Coagulation and flocculation - Activated sludge process
PT117_w {1}	COD	IND	213.0	539.8	736.0	59 468	4.4 – 4.7	Neutralisation
UK129_w {1}	COD	IND	6 790	10 766	17 200	6 037	95.1 – 95.6	Grit separators - Screening - Oil separation - Coagulation and flocculation - Ultrafiltration - Flotation
UK128_w {1}	COD	IND	9 530	17 957	29 200	8 826	77.5 – 78.5	Coagulation and flocculation - Neutralisation - Sedimentation
CZ020_w {1}	TSS	DIR	2.0	7.0	28.0	NI	94.5 – 98.2	Sedimentation - Nitrification/ denitrification - Neutralisation - Coagulation and flocculation - Activated sludge process
PT117_w {1}	TSS	IND	34.0	90.5	169	10 672	9.0 – 9.2	Neutralisation
UK128_w {1}	TSS	IND	1.0	1 200	8 370	2 368	96.0 – 98.8	Coagulation and flocculation - Neutralisation - Sedimentation

CZ020_w {1}	BOD <sub>5</sub>	DIR	1.8	3.4	9.8	NI	98.2 – 99.1	Sedimentation - Nitrification/ denitrification - Neutralisation - Coagulation and flocculation - Activated sludge process
PT117_w {1}	BOD <sub>5</sub>	IND	90.0	167.1	260	14 741	3.1 – 3.5	Neutralisation
CZ020_w {1}	AOX	DIR	0.00003	0.00014	0.00095	NI	52.4 – 83.8	Sedimentation - Nitrification/ denitrification - Neutralisation - Coagulation and flocculation - Activated sludge process
CZ020_w {1}	NH <sub>4</sub> -N	DIR	0.03	1.8	19	NI	94.8 – 96.8	
CZ020_w {1}	Total N	DIR	2.5	6.2	24	NI	88.3 – 92.5	
CZ020_w {1}	Total P	DIR	0.08	0.2	0.7	NI	96.2 – 96.9	
UK129_w {1}	Organochlorine pesticides	DIR	0.00004	0.001	0.004	NI	99.0	Grit separators - Screening - Oil separation - Coagulation and flocculation - Ultrafiltration - Flotation
UK129_w {1}	Organo- phosphorus pesticides	DIR	0.0002	0.02	0.09	NI	99.0	
UK129_w {1}	Synthetic pyrethroid pesticides	DIR	0.0002	0.008	0.08	NI	95.0	

Source: [ 50, TWG 2019 ]

Table 3.2: Additional data about removal efficiency for COD

Plant	Type of discharge	COD influent range (mg/l)	COD effluent range (mg/l)	Removal efficiency (%)	Higest COD concentration reported for a removal efficiency above 90 %	Abatement techniques
BE009	DIR	393-1870	50-353	55-96	124	Equalisation, Activated sludge process, Sand filtration, Coagulation and flocculation, Flotation, Chemical oxidation (incl. Advanced oxidation), Sand filtration, Chemical reduction, Microfiltration, Reverse osmosis
BE010	DIR	351-1 600	31-128	79-96	110	Equalisation, Activated sludge system, Nitrification/denitrification
FR131	DIR	3 811	150	97	NI	Buffer basin, Decantation to collect the sludges, Chemical discoloration

*Source:* [ 53, EURATEX 2020 ] [ 54, Viers S. 2021 ]

### 3.4.2 Amount of waste water discharged

A total of 95 out of 115 emission points reported data related to the specific amount of waste water discharged.

The data about specific waste water discharged are shown in Figure 3.11 and Figure 3.12.

There is a great variability in the range of reported data, from 0.01 m<sup>3</sup>/t of textiles treated to 696 m<sup>3</sup>/t of textiles treated (median: 45.6 m<sup>3</sup>/t of textiles treated, average: 79.6 m<sup>3</sup>/t of textiles treated, 80<sup>th</sup> percentile: 115.4 m<sup>3</sup>/t of textiles treated).

### 3.4.3 Presentation of data

In the following sections, each graph or table presents the minimum, average and maximum emission concentrations over the 3-year reference period as well as the Emission Limit Value (ELV), the maximum emission mass flow over the 3-year reference period, the type of discharge (direct or indirect), the type of monitoring (periodic or frequent), the associated processes and the abatement techniques applied at the emission points.

In the case of frequent monitoring, the minimum emission concentration corresponds to the maximum of the three minima reported. Likewise, the average and maximum concentrations correspond to the maximum of the three averages and three maxima reported, respectively. The maximum emission mass flow corresponds to the maximum emission concentration multiplied by the average water flow.

The graphs and tables have been sorted in ascending order of the maximum emission concentration of all reported values (minimum, average and maximum).

### 3.4.4 Chemical oxygen demand (COD) and total organic carbon (TOC)

#### 3.4.4.1 Direct discharge to the environment

The direct discharges of COD to water are shown in Figure 3.13.

The COD concentrations from 24 emission points range from 39 mg/l to 776 mg/l.

It should be noted that, out of the 24 emission points concerned, 22 are equipped with activated sludge treatment, 18 with equalisation, 15 with neutralisation, 13 with nitrification/denitrification, 8 with coagulation/flocculation, 7 with sand filtration, 5 with screening and 3 with grit separators. Some are also equipped with nano-filtration, chemical oxidation and/or reduction. The combination of these techniques effectively removes COD from the effluent.

Regarding the textile activities (activity 6.2 from Annex I to the IED), 21 plants carried out dyeing, 8 bleaching, 6 washing of synthetic fibres and 5 desizing. Regarding the activities directly associated with activity 6.2 from Annex I to the IED, 11 plants carried out functional finishing and 7 printing.

The higher concentration values are correlated to the treatment of synthetic fibres like washing and dyeing of synthetic fibres (FR134, FR131, UK124, DE025 and BE009).

Out of the 24 emission points, the majority (18) are in plants processing fibre in the form of loose fibre, yarns or floc for example (of these, 5 produce wool fibre, 5 cotton fibre, 4 synthetic fibre, 2 cotton-synthetic blends and 4 all types of fibres).



The waste water discharge of these 24 emission points ranges from 0.05 m<sup>3</sup>/t to 494.2 m<sup>3</sup>/t of textiles treated, with a median value of 58.7 m<sup>3</sup>/t of textiles treated, average value of 101.8 m<sup>3</sup>/t of textiles treated and 80<sup>th</sup> percentile value of 224 m<sup>3</sup>/t of textiles treated. It is interesting to note that the majority of the plants with the highest COD concentrations typically discharge less than 25 m<sup>3</sup>/t of textiles treated, and the plants with the lowest COD concentrations more than 55 m<sup>3</sup>/t of textiles treated.

TOC emissions to water are shown in Figure 3.14. They are monitored at only 9 emission points of the data collection and range from 10.4 mg/l to 44 mg/l. All 9 emission points are equipped with activated sludge treatment. A total of 7 plants also reported COD concentrations with average COD/TOC ratios from 1.9 (IT092\_w{1}) to 6.0 (IT097\_w{1}) (see Figure 3.15).

### 3.4.4.2 Indirect discharge to the environment

Indirect discharges of COD to water were reported for 97 emission points and are shown in Figure 3.16 and Figure 3.17. The COD concentration ranges from 54 mg/l to 29 200 mg/l.

The waste water discharge of these 71 emission points ranges from 0.01 m<sup>3</sup>/t to 695.8 m<sup>3</sup>/t of textiles treated, with a median value of 43.1 m<sup>3</sup>/t of textiles treated, average value of 67.49 m<sup>3</sup>/t of textiles treated and 80<sup>th</sup> percentile value of 103 m<sup>3</sup>/t of textiles treated.

A total of 12 data sets are available for indirect discharges of TOC emissions to water (see Figure 3.18). The emissions range from 51 mg/l to 1 600 mg/l. For emission points from Plants ES058 and DE031, no waste water treatment techniques were reported. Other plants report using primary treatments like neutralisation, equalisation, grit/oil separators and screening. Some plants also reported COD and in these cases the average COD/TOC ratios range from 4.2 (PT115\_w{1}) to 11.1 (CZ015\_w{1}) (see Figure 3.19)

## 3.4.5 Biological oxygen demand (BOD)

### 3.4.5.1 Direct discharge to the environment

BOD concentrations in direct emissions to water expressed as BOD<sub>5</sub> were reported for 24 emission points. They are shown in Figure 3.20 and range from 3 mg/l to 77 mg/l. In total, 22 emission points are equipped with the activated sludge process and 13 with nitrification/denitrification.

A total of 22 out of 24 emission points that reported COD concentrations for direct discharge also reported BOD<sub>5</sub> concentrations. The average BOD<sub>5</sub>/COD ratios range from 0.05 to 0.4. See Figure 3.21.

### 3.4.5.2 Indirect discharge to the environment

BOD concentrations in indirect emissions to water expressed as BOD<sub>5</sub> were reported for 57 emission points. They are shown in Figure 3.22 and Figure 3.23. The BOD<sub>5</sub> concentration ranges from 0.55 mg/l to 8 150 mg/l. Plants reporting the highest emissions (UK127, DE024 and CZ016) and the plant reporting the lowest emissions (IT061) do not have an appropriate waste water treatment to remove BOD (e.g. only equalisation and neutralisation). Of the plants using appropriate waste water treatment techniques, it is worth noting that Plant IT084 is at the lower end of the spectrum with a maximum BOD<sub>5</sub> concentration of 25 mg/l, and Plant PT114 at the upper end of the spectrum with a maximum BOD<sub>5</sub> concentration of 460 mg/l.

It should be noted that emissions of BOD expressed as BOD<sub>7</sub> were also reported in three instances.

All the emission points that reported COD concentrations for indirect discharge also reported BOD<sub>5</sub> concentrations (except emission point ES058\_w {1}, which did not report information about COD values). The average BOD<sub>5</sub>/COD ratios range from 0.01 to 0.6. See Figure 3.24.

### **3.4.6 Total suspended solids (TSS)**

#### **3.4.6.1 Direct discharge to the environment**

TSS concentrations in direct emissions to water were reported for 22 emission points. They are shown in Figure 3.25 and range from 1 mg/l to 107 mg/l. The plants apply various combinations of waste water treatment techniques: 20 are equipped with the activated sludge process, 14 with sedimentation, 7 with coagulation/flocculation, 6 with various forms of filtration (ultra-, micro- and nano-filtration) and 5 with screening. The plants at the upper end of the spectrum report low waste water discharges (e.g. BE009 and DE025 less than 25 m<sup>3</sup>/t of treated textiles, and IT067 less than 44 m<sup>3</sup>/t of treated textiles), while the plants at the lower end of the spectrum report higher waste water discharges (e.g. BE011 and IT096 up to 65 m<sup>3</sup>/t of treated textiles, and IT097 up to 260 m<sup>3</sup>/t of treated textiles).

It should be noted that emissions of total dissolved solids were also reported in three instances.

#### **3.4.6.2 Indirect discharge to the environment**

Indirect discharges of TSS to water were reported for 65 emission points and are shown in Figure 3.26 and Figure 3.27. The TSS concentration ranges from 0.21 mg/l to 54 000 mg/l.

It should be noted that emissions of total dissolved solids were also reported in four instances.

### **3.4.7 Nitrogen (expressed as Total N or ammonium)**

#### **3.4.7.1 Direct discharge to the environment**

Direct emissions of nitrogen to water expressed as Total N were reported for 18 emission points. They are shown in Figure 3.28 and range from 2.2 mg/l to 47 mg/l. The plant with the highest emission level (FR131) reported that the high concentration of nitrogen in the effluent may be due to the urea which is added in the WWTP for the operation of the biological treatment.

It should also be noted that Plant BE014 uses ammonium sulphamate for flame-retardance finishing, which could explain the high level of nitrogen emissions (up to 29 mg/l) in spite of a nitrification/denitrification treatment.

Plant IT067 carries out printing with reactive dyes, which may explain the high emission levels in the event that urea is used.

Out of the 18 plants, 10 report using nitrification/denitrification.

A total of 13 data sets are also available for direct emissions of ammonium to water. They are shown in Figure 3.29 and range from 0.1 mg/l to 27.2 mg/l. In total, 11 of the emission points monitoring ammonium are equipped with nitrification/denitrification, with the maximum concentration up to 19 mg/l.

### 3.4.7.2 Indirect discharge to the environment

Indirect emissions of nitrogen to water expressed as Total N were reported from 47 emission points with the concentration ranging from 5.5 mg/l to 2 790 mg/l (see Figure 3.30). No plant uses nitrification/denitrification.

In total, 39 data sets are also available for indirect emissions of ammonium to water. They are shown in Figure 3.31 and range from 0.1 mg/l to 115 mg/l. The average value of SE120 seems to be a mistake in reporting (e.g. the maximum reported is 25 mg/l). Meanwhile, 2 plants report using the nitrification/denitrification technique (IT076 and IT075).

### 3.4.8 Phosphorus (expressed as Total P)

#### 3.4.8.1 Direct discharge to the environment

Direct emissions of phosphorus to water expressed as Total P were reported from 21 emission points. They are shown in Figure 3.32 and range from 0.35 mg/l to 52 mg/l. In total, 7 emission points are equipped with coagulation/flocculation and in that case the maximum concentration is up to 15 mg/l (and the majority of the concentrations are below 1.7 mg/l). One plant (BE010) reported using precipitation (with FeCl<sub>3</sub>) to remove phosphorus, with a maximum concentration of 0.91 mg/l. One plant (DE025) reported using organophosphorus compounds as flame retardants (with a reported concentration of 0.41 mg/l) and two plants (FR131 and FR134) reported using phosphorus-based complexing agents (ATMP/NTMP and DTPMP) (with relatively high concentrations of 26 mg/l and 52 mg/l, respectively).

#### 3.4.8.2 Indirect discharge to the environment

Indirect emissions of phosphorus to water expressed as Total P were reported from 37 emission points with the concentration ranging from 0.24 mg/l to 77 mg/l (see Figure 3.33). Only 3 plants are using coagulation/flocculation treatment prior to discharge. Effluent from these plants is discharged in a downstream waste water treatment plant (WWTP) – often an urban WWTP. These WWTPs should take care that this effluent does not jeopardise the compliance of the WWTP of the phosphorus discharge limits, and does not pose issues for the safe valorisation of the sewage sludge (see also cross-media effects in Section 4.7.4.1).

### 3.4.9 Metals

#### 3.4.9.1 Antimony (Sb)

Emissions of antimony to water are generally associated with the presence of residues in polyester fibres because antimony oxide is used as catalyst for the production of these fibres. (See also Section 2.1.1.1.) During pretreatment or dyeing of polyester, antimony is washed out into the waste water [55, Patwary S.M. 2017].

The presence of antimony in the waste water may also be due to the use of antimony trioxide as a synergist with halogen-containing compounds in flame-retardance finishing.

Antimony concentrations in direct and indirect emissions to water are shown in Figure 3.34 and range from 0.5 µg/l to 1.1 mg/l.

Emission values of 1.1 mg/l and 1.3 mg/l (in 2019) were reported for Plant DE042, with indirect discharge, originating mainly from processing PES fibres (pretreatment, dyeing) [56, EURATEX 2021], [57, UBA 2020].

#### 3.4.9.2 Copper (Cu)

The presence of copper in waste water may be connected to the use of reactive dyes but also possibly to the degradation over time of copper-containing equipment at the plant.

Direct emissions to water of copper were reported for 18 emission points. They are shown in Figure 3.35 and range from 0.01 mg/l to 0.32 mg/l.

Indirect emissions to water of copper were reported for 71 emission points. They are shown in Figure 3.36 and Figure 3.37, and range from 0.008 mg/l to 1.7 mg/l.

#### 3.4.9.3 Chromium (Cr)

The presence of chromium in waste water may be connected to the use of dyes containing chromium such as chrome dyes for wool dyeing or polyamide or silk dyeing with metal-complex dyes. Plant DE022 is using metal-complex dyes for dyeing polyamide and wool fibres, and reported a maximum emission value of 0.16 mg/l in 2021 [ 56, EURATEX 2021 ].

Direct emissions to water of chromium were reported for 15 emission points. They are shown in Figure 3.38 and range from 0.008 mg/l to 0.5 mg/l.

Indirect emissions to water of chromium were reported for 69 emission points. They are shown in Figure 3.39 and in Figure 3.40, and range from 0.005 mg/l to 15.8 mg/l.

#### 3.4.9.4 Nickel (Ni)

As with copper, the presence of nickel in waste water may be connected to the use of reactive dyes.

Direct emissions to water of nickel were reported for 16 emission points. They are shown in Figure 3.41 and range from 0.003 mg/l to 1.0 mg/l.

Indirect emissions to water of nickel were reported for 49 emission points. They are shown in Figure 3.42 and range from 0.004 mg/l to 2.0 mg/l.

Plant IT092 is using metal-complex dyes for batch dyeing and reports a maximum emission value of 1 mg/l [ 50, TWG 2019 ]. Some metal-complex dyes may contain nickel (see Section 8.2.5).

#### 3.4.9.5 Zinc (Zn)

Emissions of zinc to water are generally linked to the use of cationic dyes (or pre-dyed yarns), bleaching with zinc dithionite, and the treatment of cellulose fibres like regenerated cellulose fibres to which zinc oxide powder is added (e.g. for skin-protective hygienic and antibacterial effects). In addition, zinc salts may be used in the production process of cellulose (felling baths with zinc sulphate), and the residues may remain on the fibre (lyocell, viscose, etc.) [ 58, EURATEX 2020 ].

Plant DE051 is dyeing with cationic dyes, has indirect discharge, applies some waste water treatment techniques and reports a maximum emission value of 0.84 mg/l [ 59, Zietlow B. 2020 ].

Direct emissions to water of zinc were reported for 17 emission points. They are shown in Figure 3.43 and range from 0.04 mg/l to 0.5 mg/l.

Indirect emissions to water of zinc were reported for 70 emission points. They are shown in Figure 3.44 and in Figure 3.45, and range from 0.06 mg/l to 29.9 mg/l.

### 3.4.10 Adsorbable organically bound halogens (AOX)

AOX concentrations in direct and indirect emissions to water are shown in Figure 3.46 and Figure 3.47, and range from 0.01 mg/l to 0.86 mg/l for direct discharges and from 0.002 mg/l to 530 mg/l for indirect discharges. The highest emission concentrations correspond to Plant CZ016 and may be a mistake.

Plant IT063 carries out solvent scouring and reported AOX emissions between 0.01 mg/l and 1.64 mg/l. In this case, the amount of waste water released is small (8.5 m<sup>3</sup>/day) and AOX emissions are treated by adsorption.

Four plants performing chlorine-based bleaching (DE022, DE051, FR131 and FR132) reported AOX emissions to water with concentrations ranging between 0.4 mg/l and 0.7 mg/l.

A total of 34 plants using dyes which are more likely to contain halogens in their molecules (vat, disperse and reactive dyes) reported AOX emissions to water, with concentrations ranging from 0.05 mg/l to 7.4 mg/l.

### 3.4.11 Hydrocarbon oil index (HOI)

HOI concentrations in direct and indirect emissions to water are shown in Figure 3.48, and range from 0.03 mg/l to 147.5 mg/l.

Oil in waste water may originate from residual knitting oil in knitted fabric, which is washed out during the treatment of the fabrics. In the case of plants treating knitted fabrics, the HOI concentrations range between 4 mg/l and 73.5 mg/l, and some of the plants concerned (such as IT059, IT064, IT068, IT070 and IT074 ) are amongst the plants with the highest emissions reported but do not apply waste water treatment.

Four plants treating knitted fabrics and applying abatement techniques show emission values of 4 mg/l (Plant PT108 applying sand filtration), 7 mg/l (Plant PT104 applying ultrafiltration) and 18 mg/l (Plant DE022 applying evaporation and oil separation).

### 3.4.12 Sulphide

Sulphide concentrations in direct and indirect emissions to water are shown in Figure 3.49, and range from 0.02 mg/l to 23.2 mg/l.

Emissions of sulphide to water are mostly relevant for plants using sulphur dyes, which is the case for 15 out of the 19 plants monitoring sulphide. Most of the reported values are below 1 mg/l, except for Plants AT005, IT065, PT102 and IT070, which are not equipped with waste water treatment.

### 3.4.13 Alkylphenols and alkylphenol ethoxylates

A total of 37 data sets were provided in relation to emissions to water of alkylphenols and alkylphenol ethoxylates but they do not necessarily all correspond to the same substance or group of substances. The monitored substances, type of discharge, minimum, average and maximum values reported over the 3 years, maximum mass flow over the 3 years, ELV, techniques and associated monitoring standards reported are shown in Table 3.5.

#### 3.4.14 Perfluorocarbons

In total, 34 data sets were reported in relation to emissions to water of perfluorocarbons but they do not necessarily all correspond to the same substance or group of substances. The monitored substances, type of discharge, minimum, average and maximum values reported over the 3 years, maximum mass flow over the 3 years, ELV, techniques and associated monitoring standards reported are shown in Table 3.6.

Various monitoring standards were reported to measure perfluorocarbons. At the moment of publishing the revised TXT BREF (2022), no EN standard for perfluorocarbon measurements in waste water emissions were available. Nevertheless, there are two ISO standards: ISO 21675 for the determination of perfluoroalkyl and polyfluoroalkyl substances (PFAS) using solid phase extraction and liquid chromatography-tandem mass spectrometry (LC-MS/MS) and ISO 25101 for the determination of perfluorooctanesulphonate (PFOS) and perfluorooctanoate (PFOA) using solid phase extraction and liquid chromatography/mass spectrometry.

#### 3.4.15 Pesticides

A total of 15 data sets were reported in relation to emissions to water of pesticides but they do not necessarily all correspond to the same substance or group of substances. The monitored substances, type of discharge, minimum, average and maximum values reported over the 3 years, maximum mass flow over the 3 years, ELV, techniques and associated monitoring standards reported are shown in Table 3.7.

#### 3.4.16 Brominated flame retardants

In total, 10 data sets were reported in relation to emissions to water of brominated flame retardants but they do not necessarily all correspond to the same substance or group of substances. The monitored substances, type of discharge, minimum, average and maximum values reported over the 3 years, maximum mass flow over the 3 years, ELV, techniques and associated monitoring standards reported are shown in Table 3.8.

#### 3.4.17 Surfactants

A total of 99 data sets were reported in relation to emissions to water of surfactants but they do not necessarily all correspond to the same substance or group of substances. The monitored substances, type of discharge, minimum, average and maximum values reported over the 3 years, maximum mass flow over the 3 years, ELV, techniques and associated monitoring standards reported are shown in Table 3.9.

#### 3.4.18 Toxicity

In total, 23 data sets (from 14 plants) were reported for toxicity; of these, 6 were obtained by toxicity tests based on daphnia magna, 4 by toxicity tests based on *Vibrio fischeri* (bacteria), 4 by inhibition tests on microorganisms from active sludge, 3 on algae, 2 on fish, 1 on fish eggs and 1 by bacteria/daphnia magna/algae toxicity tests. For 2 data sets, it was not clear to which toxicity test (standard monitoring method) they refer. The available data sets are shown in Table 3.10.

Results of the acute toxicity screening campaign in four well performing textile plants from Belgium were reported [60, Hoebeke L. 2019]. Algae, water flea, fish embryo and Microtox® tests were conducted. The results show that, if the COD levels are higher or fluctuating, the risk for high/relevant acute toxicity increase.

### 3.4.19 Microplastics

Microplastics is a generic term for very small fragments of plastics with an approximate length of 1 nm to 5 mm or for fibres 3 nm to 15 mm long, with a length to diameter ratio  $> 3$  [ 61, ECHA 2019 ].

A number of studies were made available for the review of the BREF regarding the presence of microplastics in water bodies (e.g. [ 62, Austrian EPA 2015 ]) or in waste water (e.g. [ 63, Danish EPA 2017 ]). One of these studies ([ 64, Danish EPA 2015 ]) points to synthetic textiles as a source of secondary microplastics, i.e. microplastics resulting from the fragmentation, weathering or maintenance of larger items. For instance, the study considers the following pathways for releases of synthetic fibres: laundering, synthetic cloth used for wet cleaning, synthetic fibres removed by vacuum cleaning or washing of floors and furniture surfaces, fibres released outdoors from clothing and outdoor textiles. This corresponds however to the use phase of the textiles and not to the production phase, which is outside the scope of this BREF.

No information was provided on the emissions of microplastics to water from the production of textiles via the data collection (see Section 3.1) but a study carried out by Swerea IVF [ 65, SVEREA IVF 2018 ] shows that microplastics were found in the effluents of five textiles plants in Sweden. Emissions of microplastics therefore seem relevant for the textiles sector, as they may be for other industrial or non-industrial activities, but the significance of these emissions has not been established. As an indication, 60 % of the microplastics can be found in the first rinse water of textiles [ 324, TWG 2020 ]. According to the study ‘Swedish sources and pathways for microplastics to the marine environment’ [ 66, IVL 2016 ], the main sources of microplastics are road wear and abrasion of tyres, artificial turfs, laundry, industrial production and handling of plastic pellets, and protective and decorative coatings on buildings, although the study underlines that more reliable data are needed.

In conclusion, at the time of drafting this document, there was little information available as to the emissions of microplastics to water from textile production facilities, in terms of emissions actually monitored and therefore in terms of the significance of these emissions [ 67, Jönsson et al. 2018 ].

It should be noted nevertheless that even though microplastics emissions are not monitored directly, some microplastics would be covered by the parameter TSS, as the glass fibre filters used for monitoring TSS typically show pore sizes around 1  $\mu\text{m}$  [ 68, STERLITECH 2019 ]. The parameter TSS is addressed in Section 3.4.6.

### 3.4.20 Colour

In total, 18 data sets were reported with information about colour of the effluents. The type of discharge, measurements for the years 2016, 2017 and 2018, ELV, techniques and associated monitoring standards reported are shown in Table 3.11. A total of 8 out of 18 data sets did not report the unit in which the measurements reported are expressed.

### 3.4.21 Bioeliminability/biodegradability

Data sets from 3 emission points were reported from Sweden with information about bioeliminability/biodegradability. The available data sets are shown in Table 3.3.

**Table 3.3: Data sets with information about bioeliminability/biodegradability**

Point of discharge	Type of discharge	Unit	Reported values	Monitoring standard	Combination of techniques
SE118_w{1}	IND	% DOC	70 in 10 days, 85 after 28 days	OECD 301 A = SS-EN ISO 7827:2012	Sedimentation- Equalisation- Neutralisation
SE119_w{1}	IND	% DOC	61 in 10 days	OECD 301A = SS-EN ISO 7827:2012	No techniques used
SE120_w{1}	IND	% DOC	52 after 14 days	OECD 301 A = SS-EN ISO 7827:2012	Sedimentation- Equalisation- Neutralisation- Oil separation

*Source: [ 50, TWG 2019 ]*

Additionally, AT003\_w{1} provided information about bioeliminability measurements for the years 2018, 2019 and 2020. Table 3.4 shows the additional data provided from Plant AT003.

**Table 3.4: AT003\_w{1} data sets with information about bioeliminability/biodegradability**

Zahn-Wellens-Test for	Type of discharge	Reported measurements (M) (% of biodegradability)		
		2018	2019	2020
7 days	IND	M1=84.9	M1=51.4	M1=56.1
		M2=90.6	M2=63.7	M2=66.3
		M3=87.6	M3=67.5	M3=63.5
		M4=85.7	M4=71.4	M4=66.4
14 days	IND	M1=66.9	M1=52.9	M1=51.5
		M2=69.9	M2=63.9	M2=66.3
		M3=71.3	M3=68.0	M3=70.5
		M4=74.3	M4=66.7	M4=70.5
21 days	IND	M1=63.8	M1=66.0	M1=68.9
		M2=71.4	M2=71.1	M2=81.1
		M3=73.4	M3=75.2	M3=84.2
		M4=74.3	M4=74.7	M4=83.3
28 days	IND	M1=69.9	M1=57.0	M1=69.2
		M2=71.1	M2=67.3	M2=69.9
		M3=72.9	M3=68.9	M3=71.2
		M4=72.9	M4=701.9	M4=70.9

*Source: [ 69, Moser, G 2021 ]*

### 3.4.22 Figures and tables with water emission levels

In the following figures, the average concentration is represented by a blue diamond and the minimum and maximum concentration by error bars. In the box below the graph with the concentration values, the following contextual information is given: labels (identifier) of the emission point, the monitoring frequency, the total number of measurements reported over the 3 reporting years, an indication as to whether the monitoring standard is reported, and for some parameters contextual information about the type of dye or fibre used.

Regarding the number of measurements, when the type of sampling is frequent, it has been identified as frequent (Freq) instead of giving the total number of measurements.



The meanings of the acronyms used in the graphs of this section are as follows.

<b>Monitoring frequency</b>	<b>Abbreviation</b>
Daily	D
Weekly	W
Monthly	12/y
4 times per year	4/y
Twice per year	2/y
Yearly	1/y
Once every 3 years	1/3y
Other	Ot
No information	NA

<b>Type of dyeing</b>	<b>Abbreviation</b>
Dyeing with reactive dyes	R
Dyeing with vat dyes	V
Dyeing with 1:1 metal-complex dyes	M
Dyeing with 1:2 metal-complex dyes	M
Dyeing with acid dyes	A
Dyeing with cationic dyes	C

<b>Type of fibre</b>	<b>Abbreviation</b>
Rayon (viscose)	r
Acrylic	a
Polyacrylonitrile	a

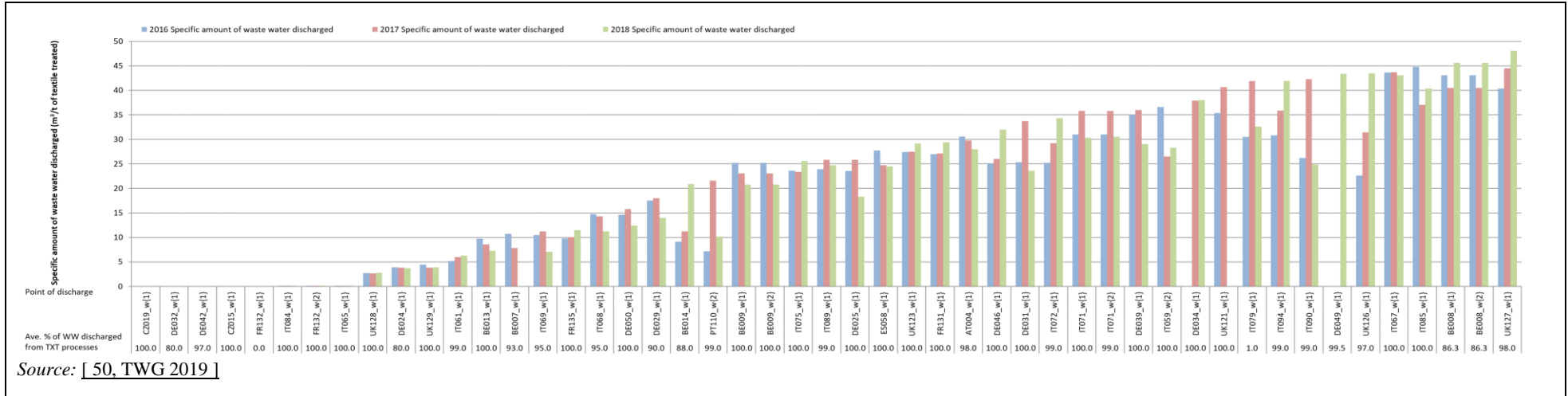


Figure 3.11: Specific amount of waste water discharged (Part 1 of 2)

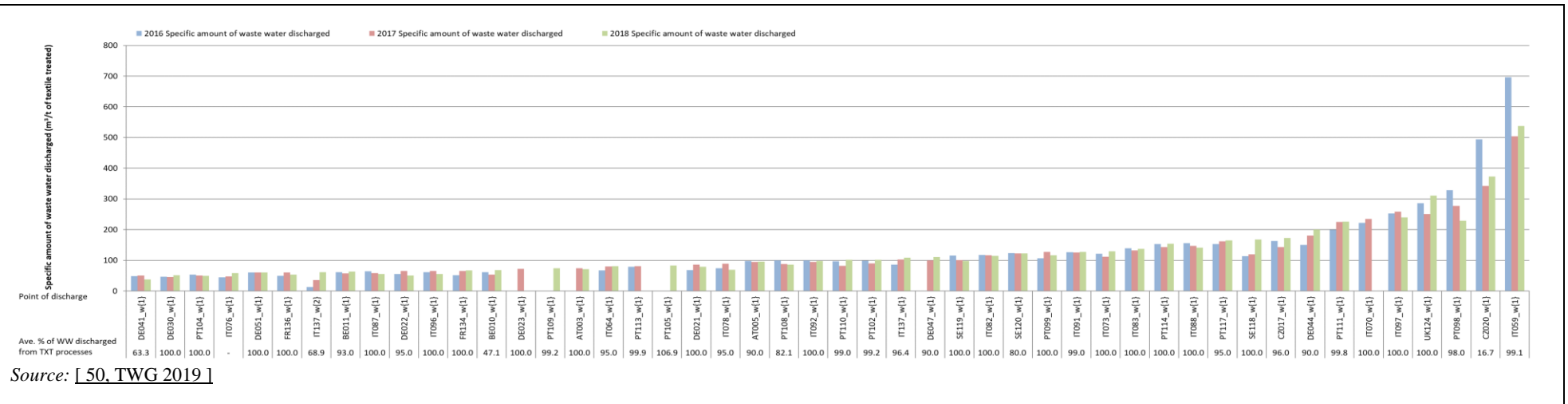
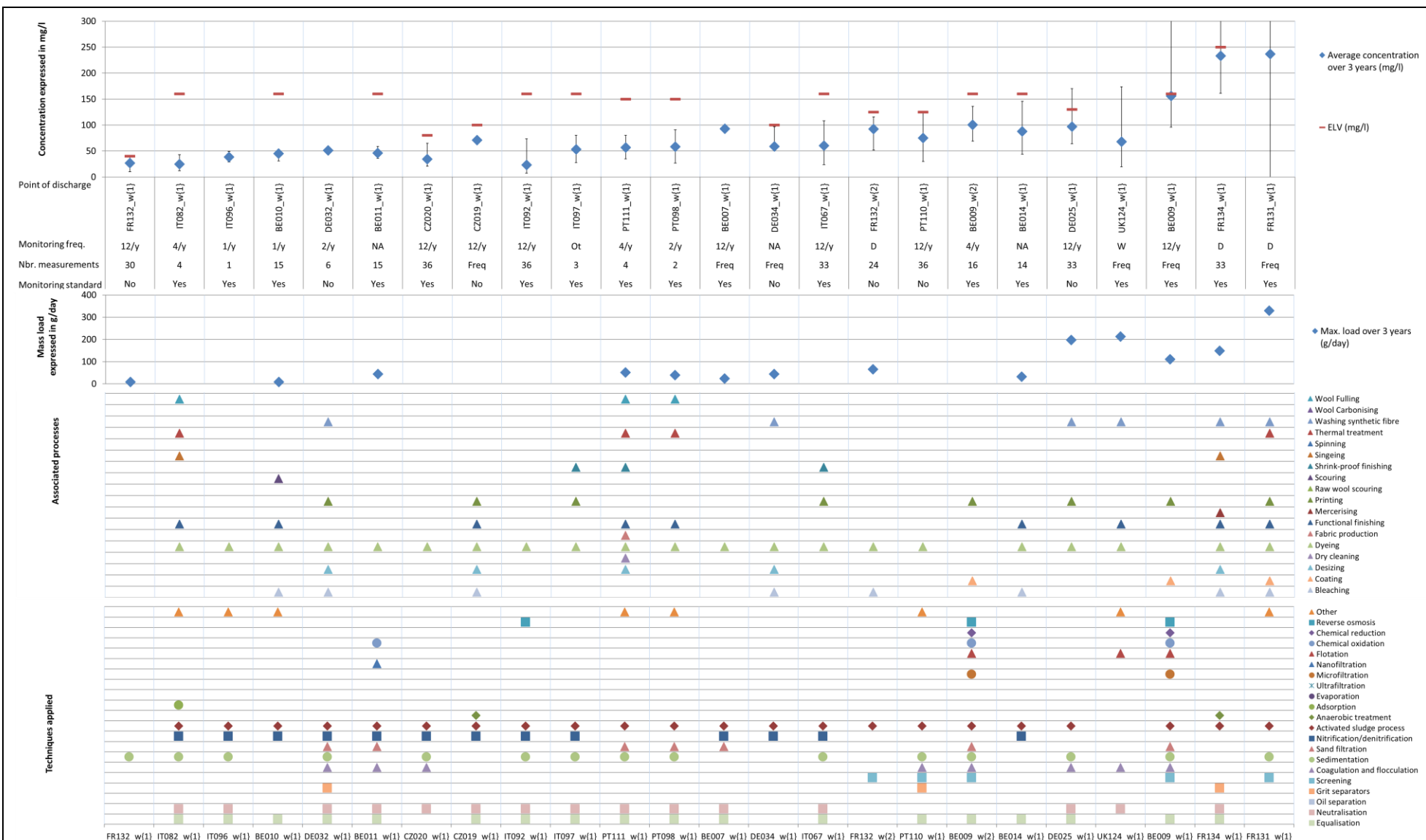


Figure 3.12: Specific amount of waste water discharged (Part 2 of 2)



NB: For better visualisation, the ELV (500 mg/l) reported by IT096\_w{1}, the maximum value (470 mg/l) reported by BE009\_w{1}, the maximum value (470 mg/l) reported by FR134\_w{1} and the maximum value (776 mg/l) reported by FR131\_w{1} are not shown in the figure.

Source: [ 50, TWG 2019 ]

Figure 3.13: COD emissions to water for direct discharges



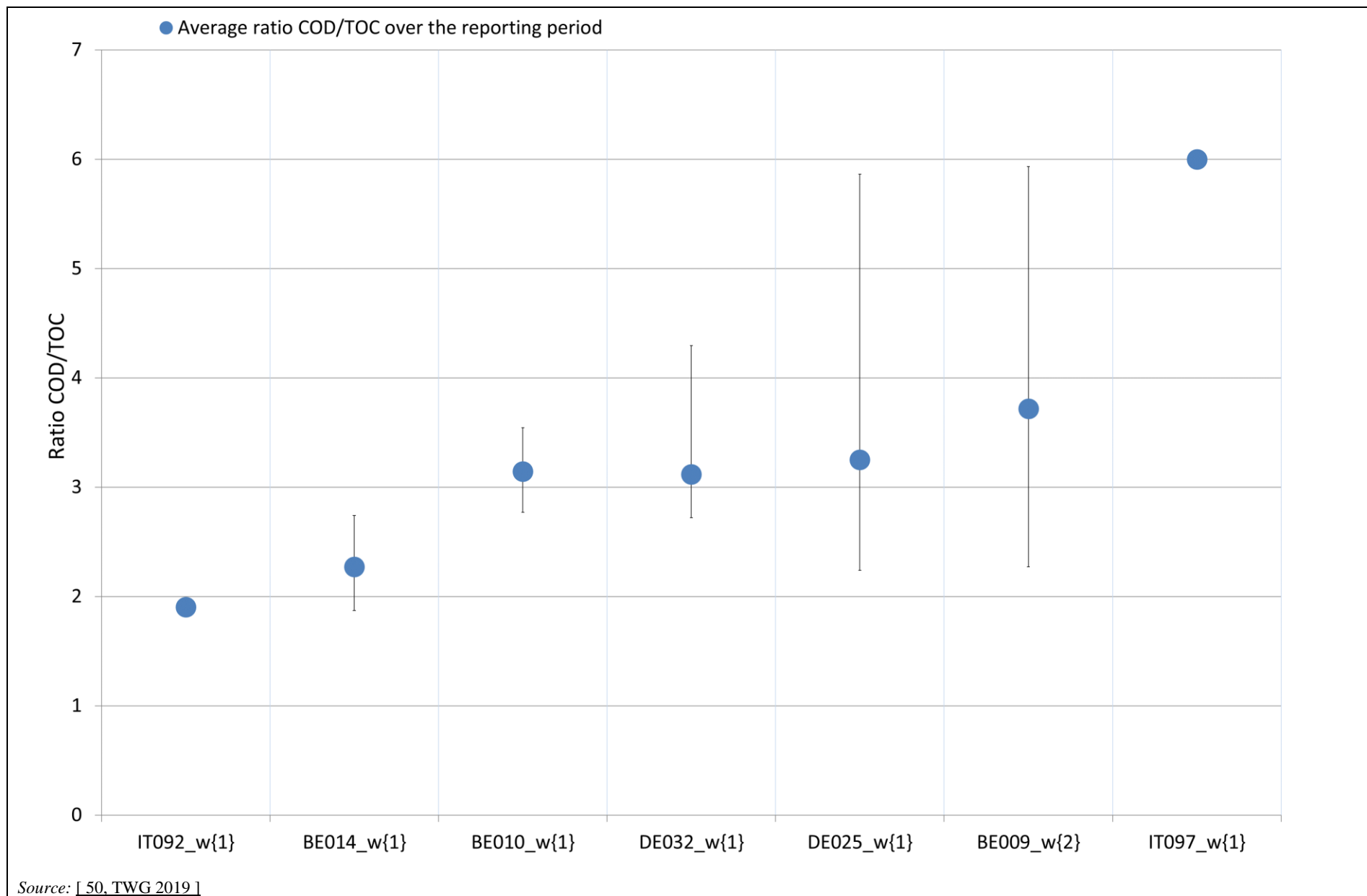


Figure 3.15: COD/TOC ratio in emissions to water for direct discharges

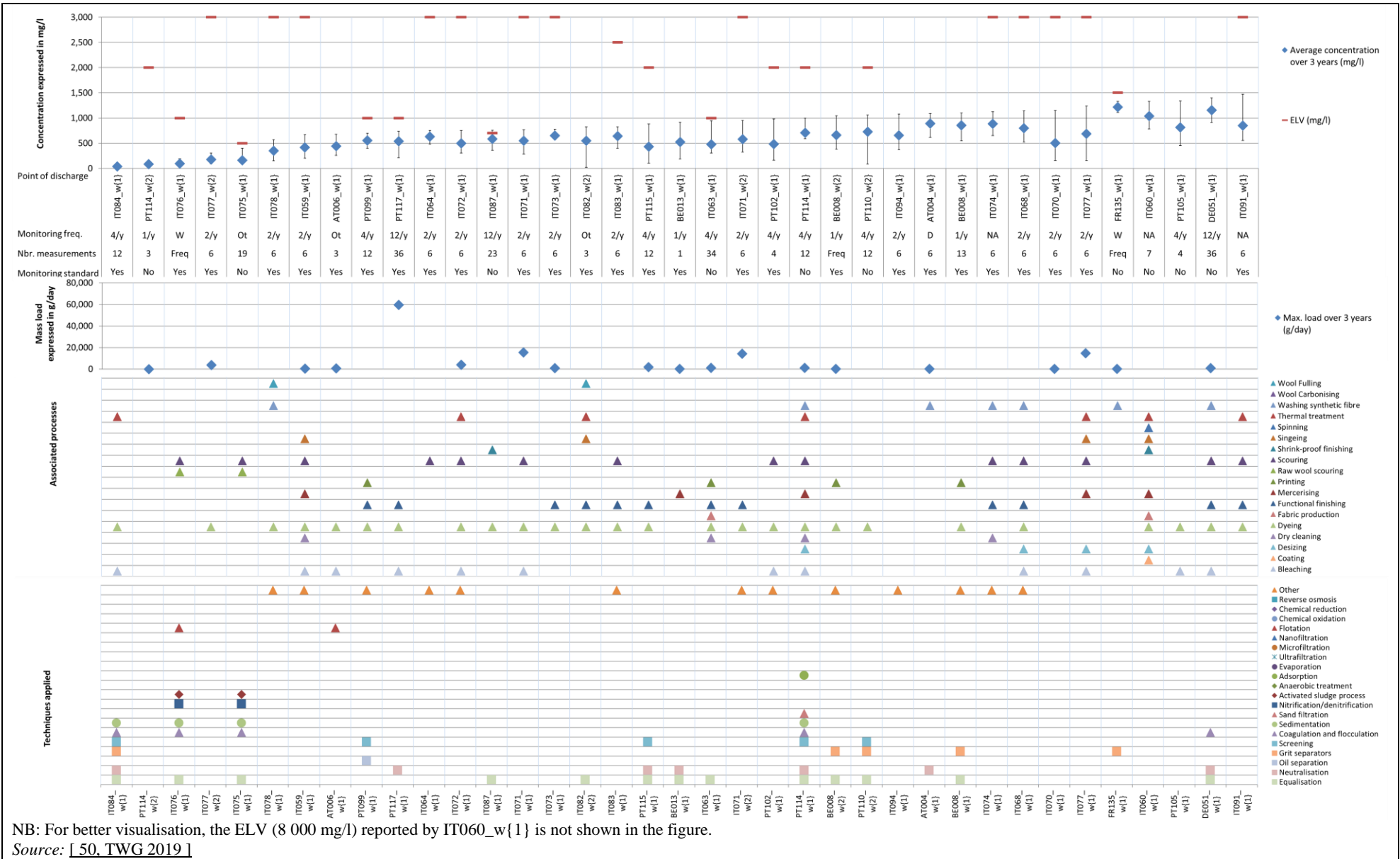


Figure 3.16: COD emissions to water for indirect discharges (Part 1 of 2)

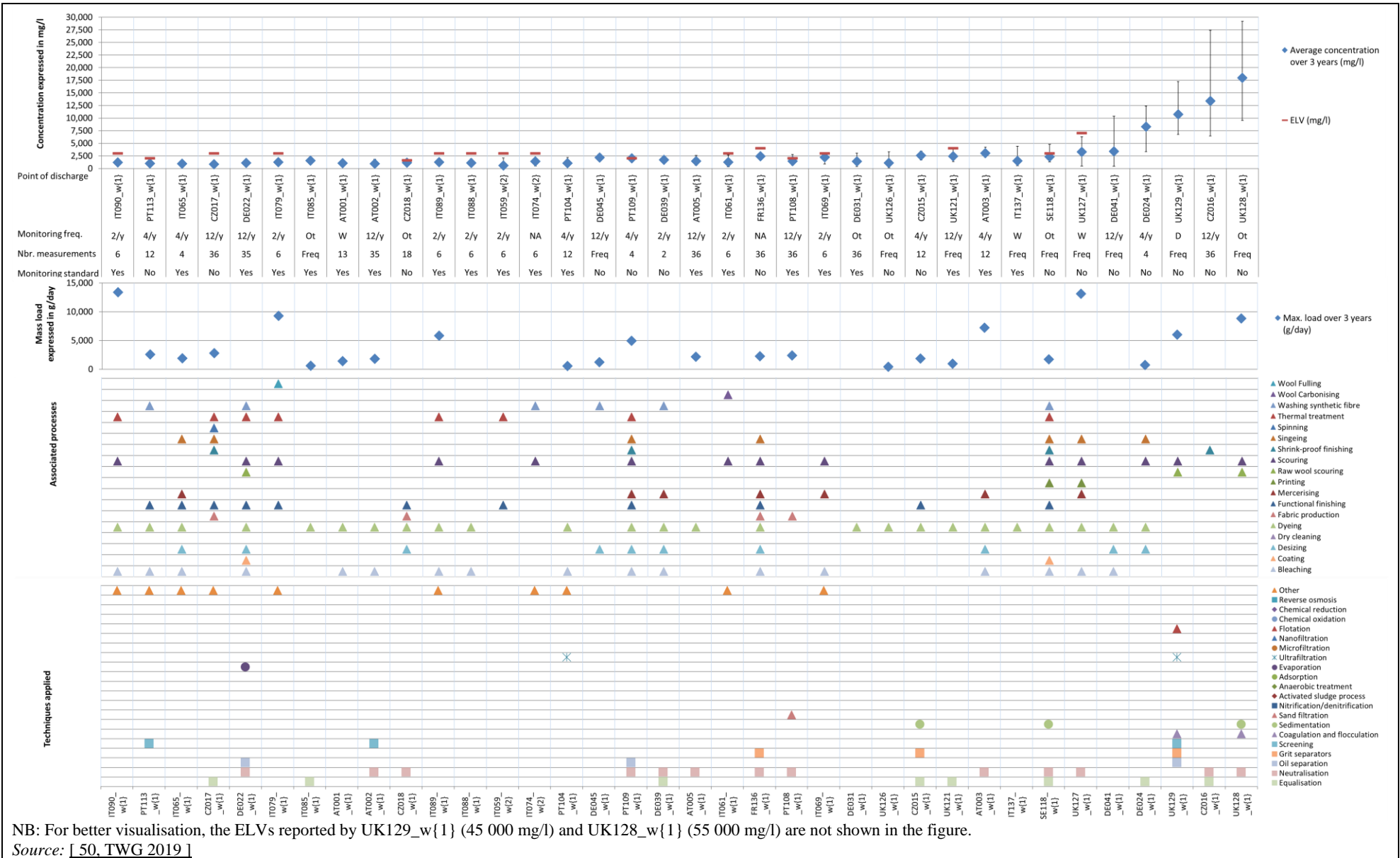
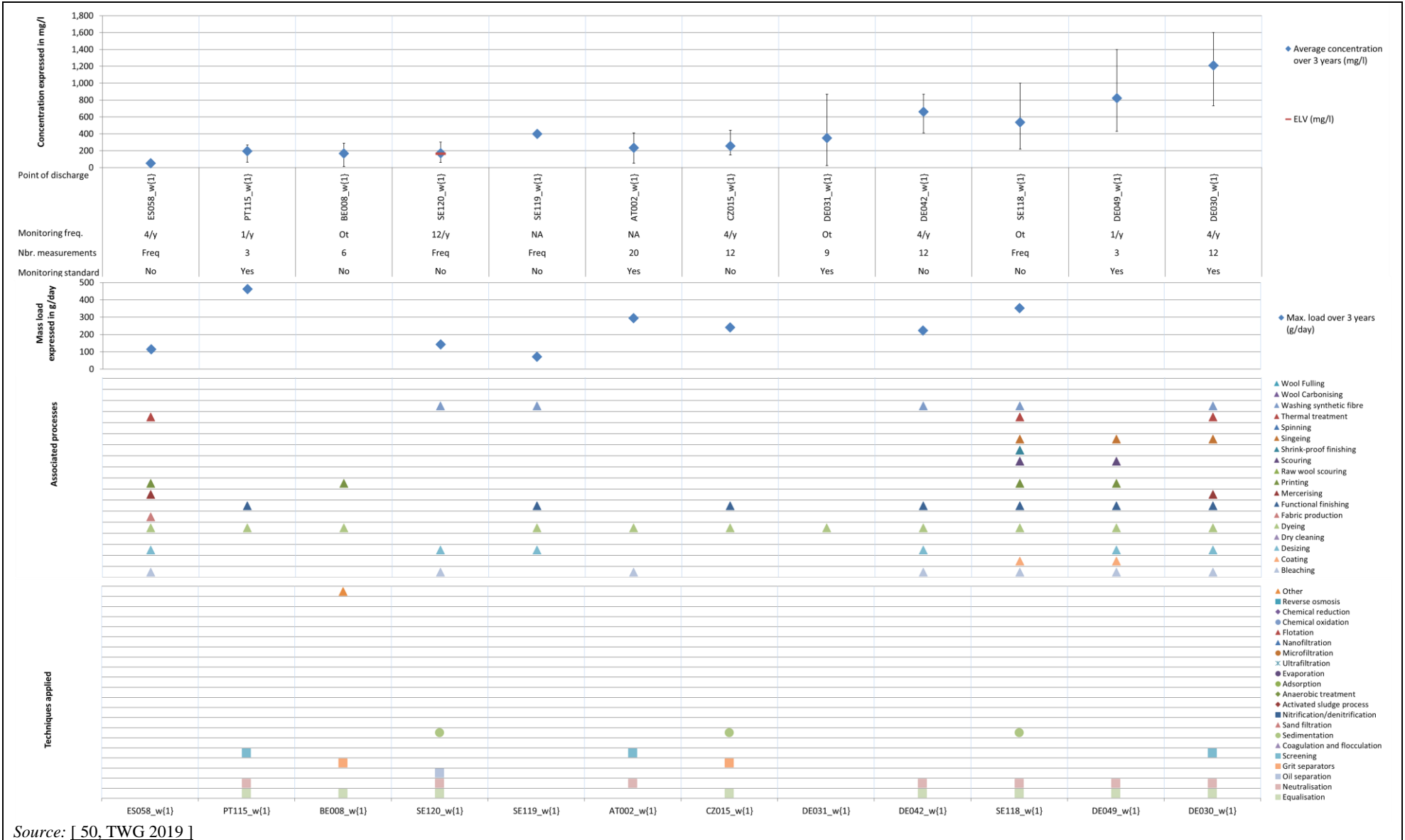


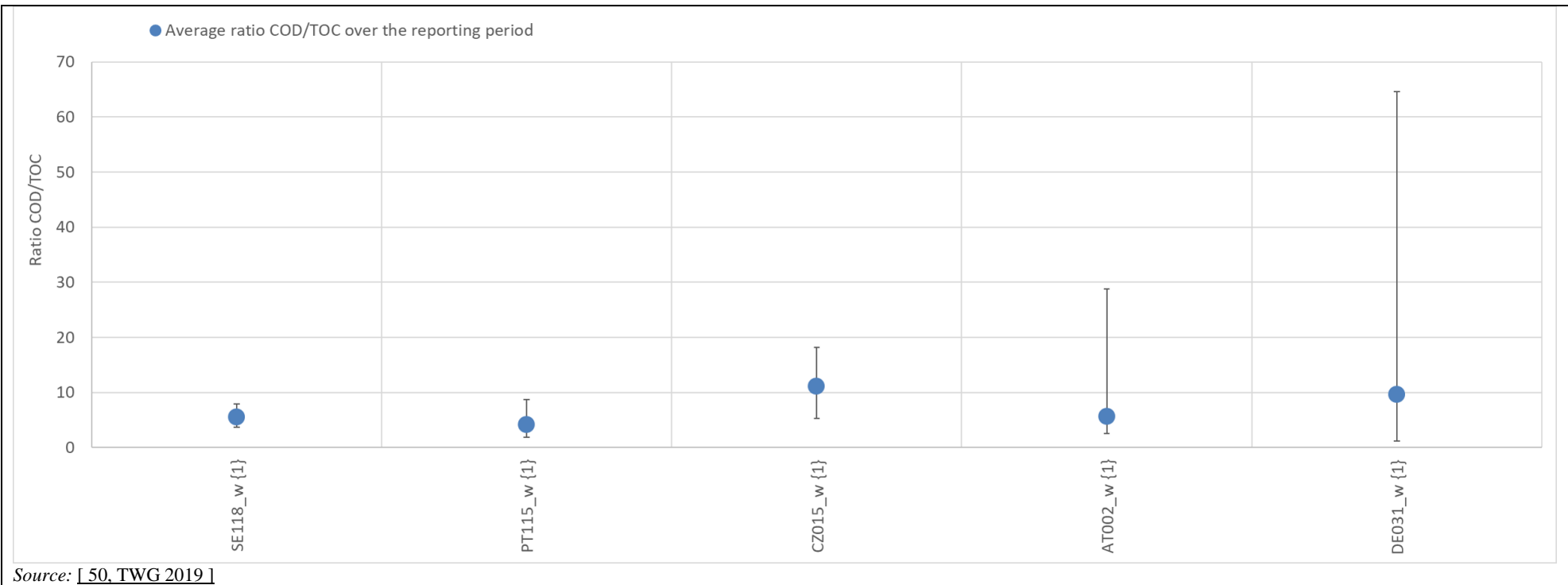
Figure 3.17: COD emissions for water for indirect discharges (Part 2 of 2)



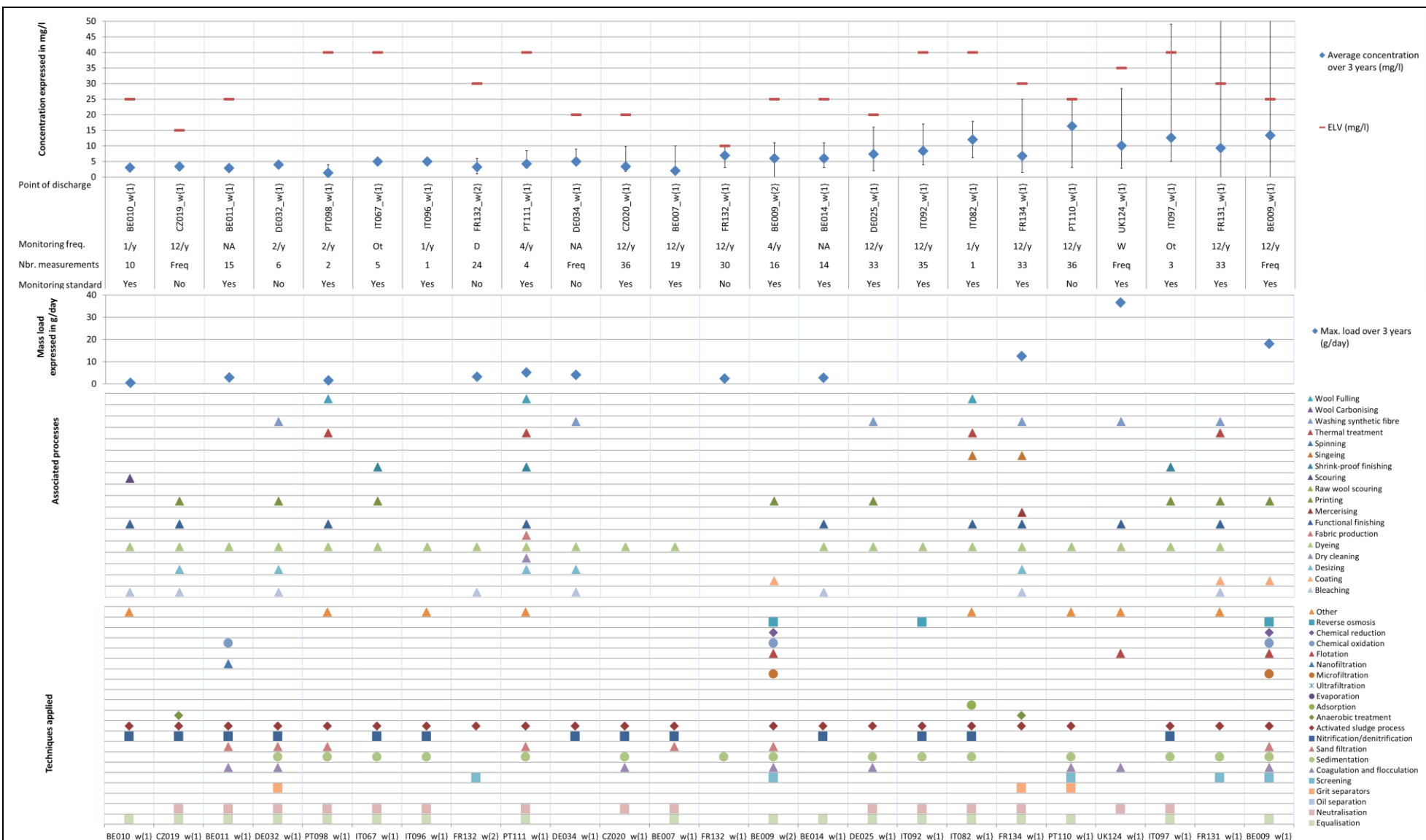
Source: [ 50, TWG 2019 ]

Figure 3.18: TOC emissions to water for indirect discharges





**Figure 3.19: COD/TOC ratio in emissions to water for indirect discharges**



N.B. For better visualisation, the ELV reported by IT096\_w{1}(250 mg/l) is not shown in the figure.

For better visualisation, the maximum values reported by FR131\_w{1} (51 mg/l) and by BE009\_w{1} (77 mg/l) are not shown in the figure.

Source: [ 50, TWG 2019 ]

Figure 3.20: BOD<sub>5</sub> emissions to water for direct discharges

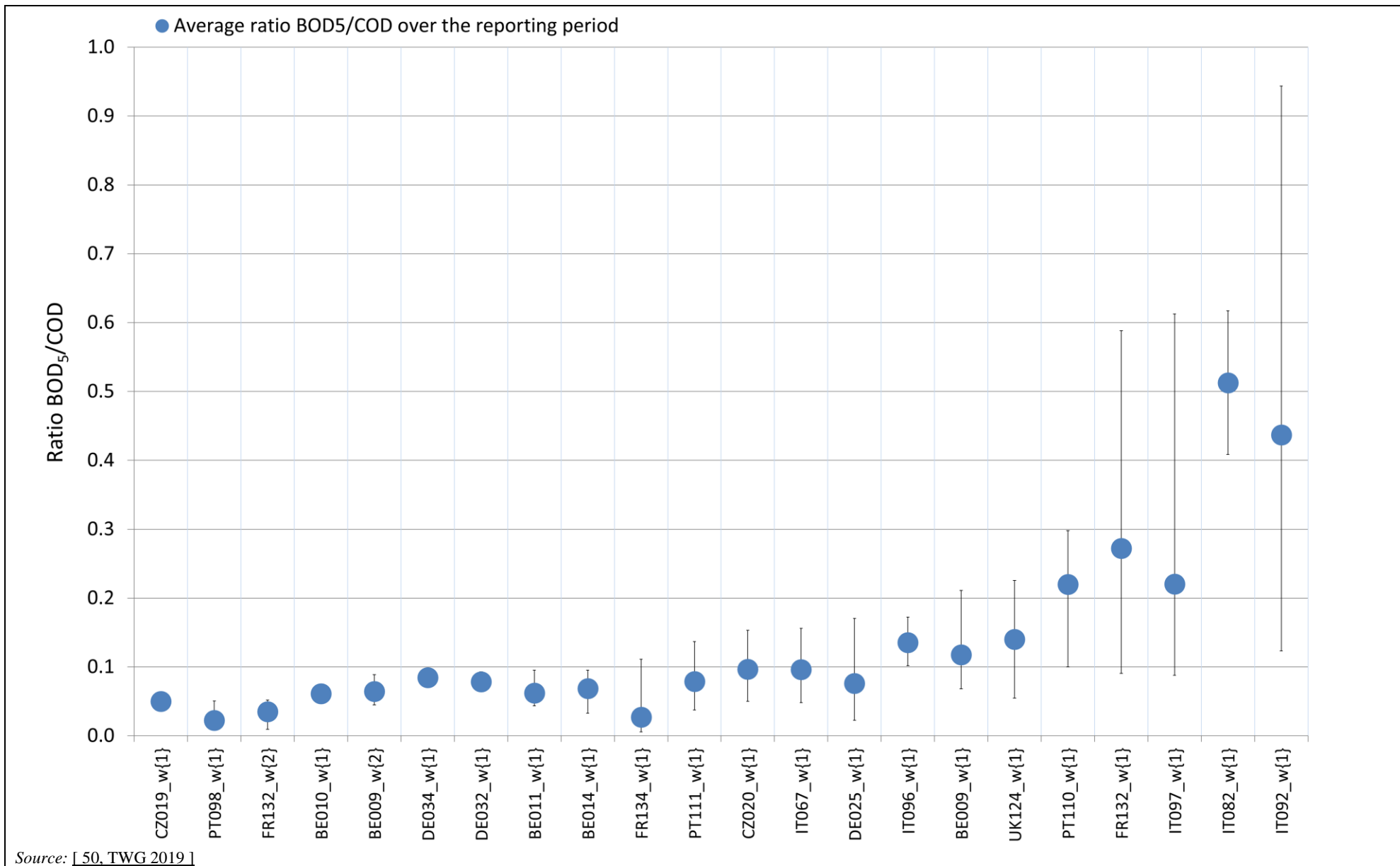


Figure 3.21: BOD<sub>5</sub>/COD ratio in emissions to water for direct discharges

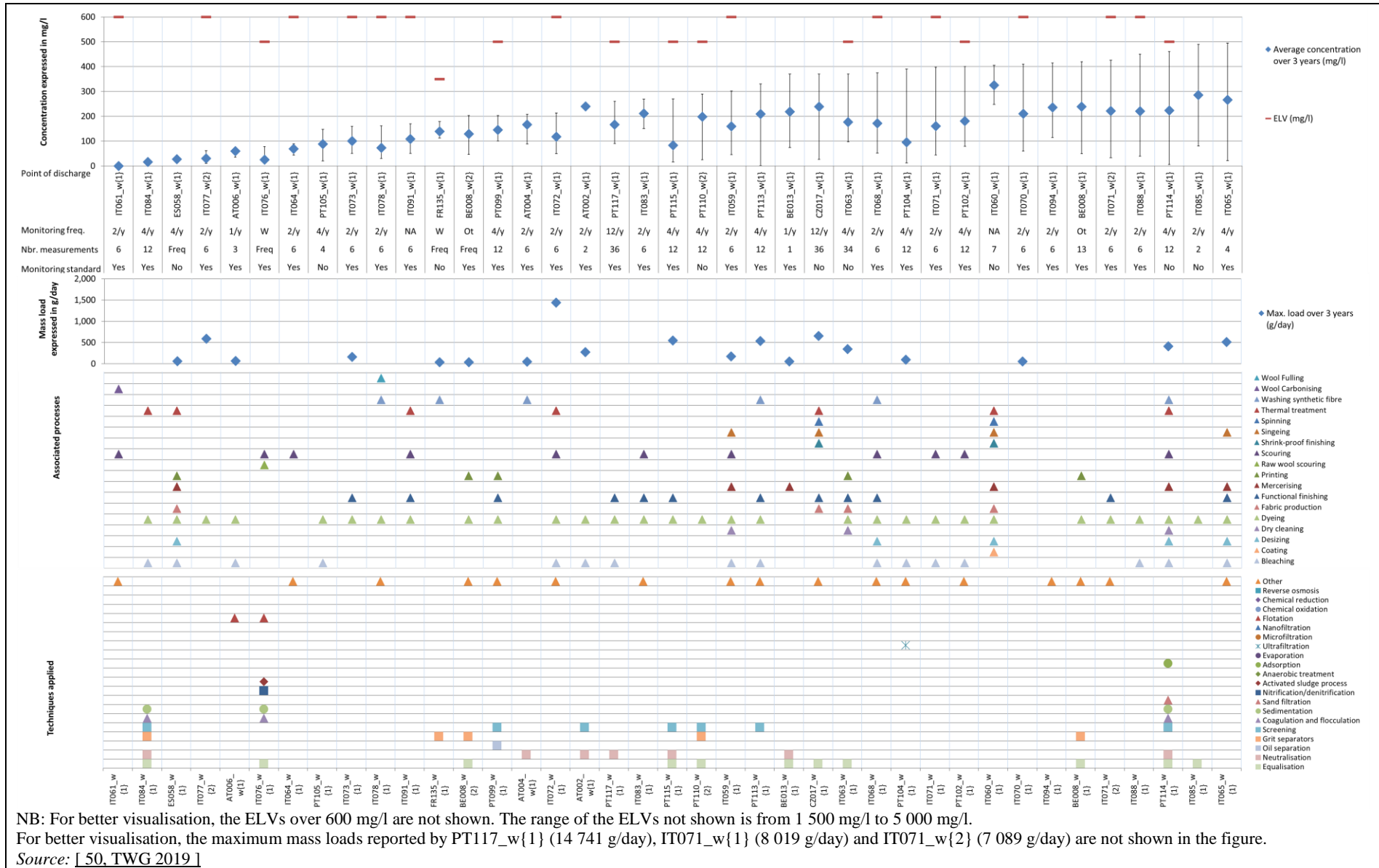


Figure 3.22: BOD<sub>5</sub> emissions to water for indirect discharges (Part 1 of 2)

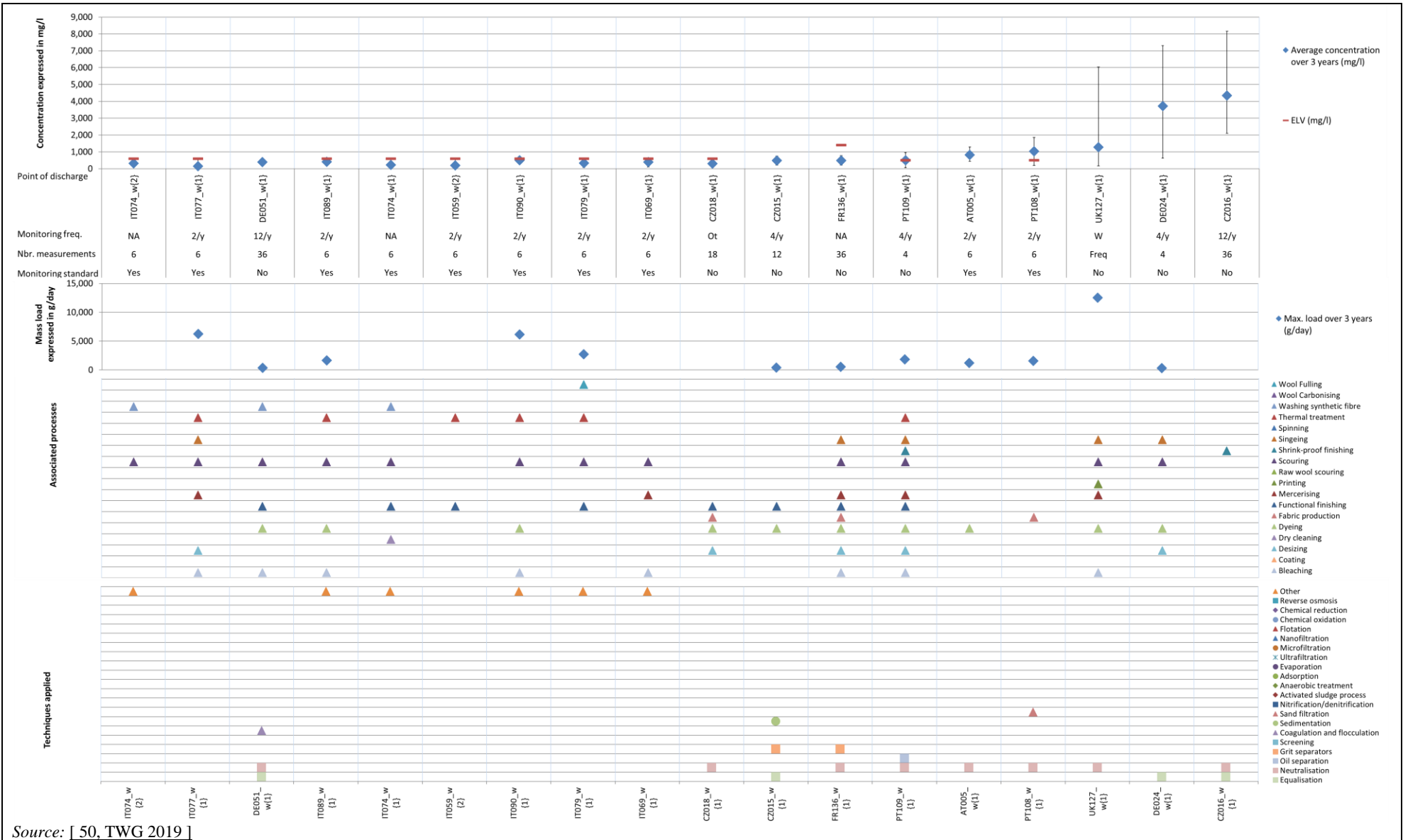
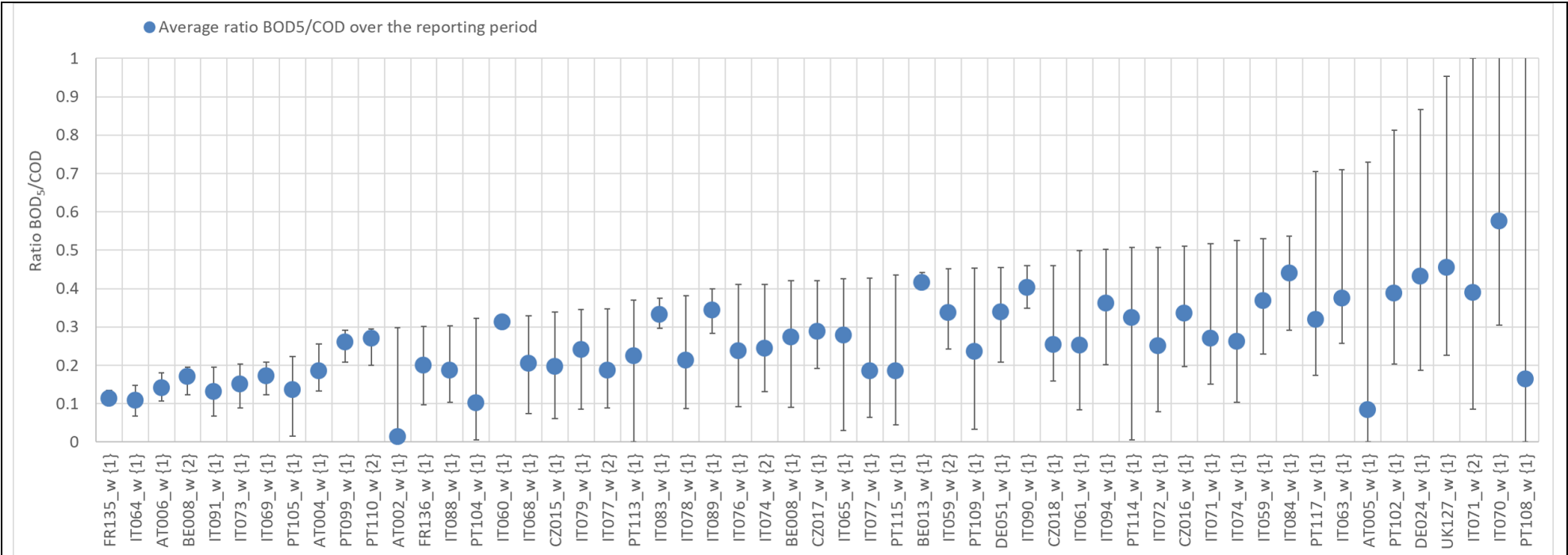


Figure 3.23: BOD<sub>5</sub> emissions to water for indirect discharges (Part 2 of 2)

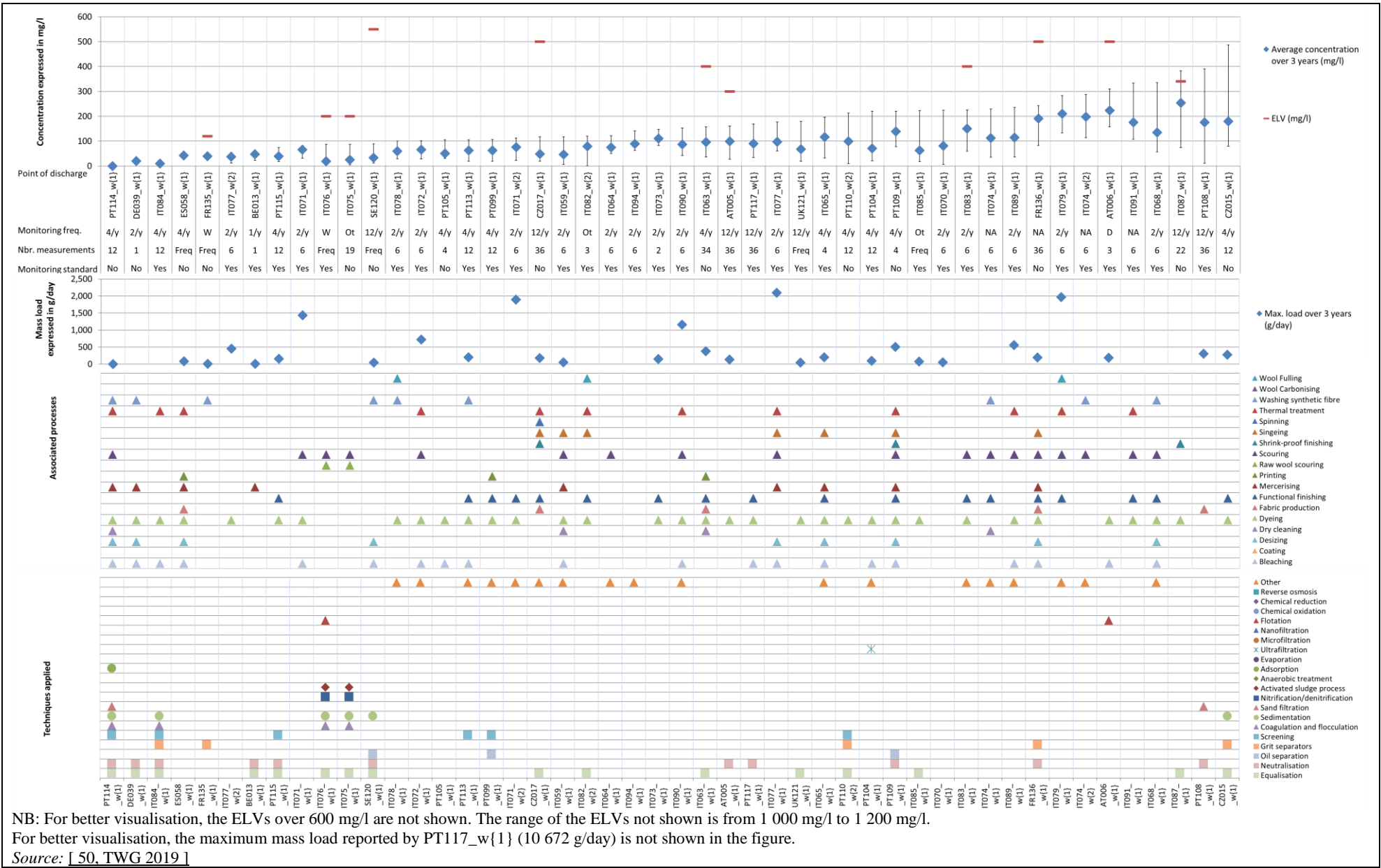


NB: For better visualisation, the maximum BOD<sub>5</sub>/COD ratios obtained for the points of discharge IT070\_w{1} (1.32) and PT108\_w{1} (2.24) are not shown in the figure.

Source: [ 50. TWG 2019 ]

**Figure 3.24: BOD<sub>5</sub>/COD ratio in emissions to water for indirect discharges**





NB: For better visualisation, the ELVs over 600 mg/l are not shown. The range of the ELVs not shown is from 1 000 mg/l to 1 200 mg/l.  
 For better visualisation, the maximum mass load reported by PT117\_w{1} (10 672 g/day) is not shown in the figure.

Source: [ 50, TWG 2019 ]

Figure 3.26: TSS emissions to water for indirect discharges (Part 1 of 2)



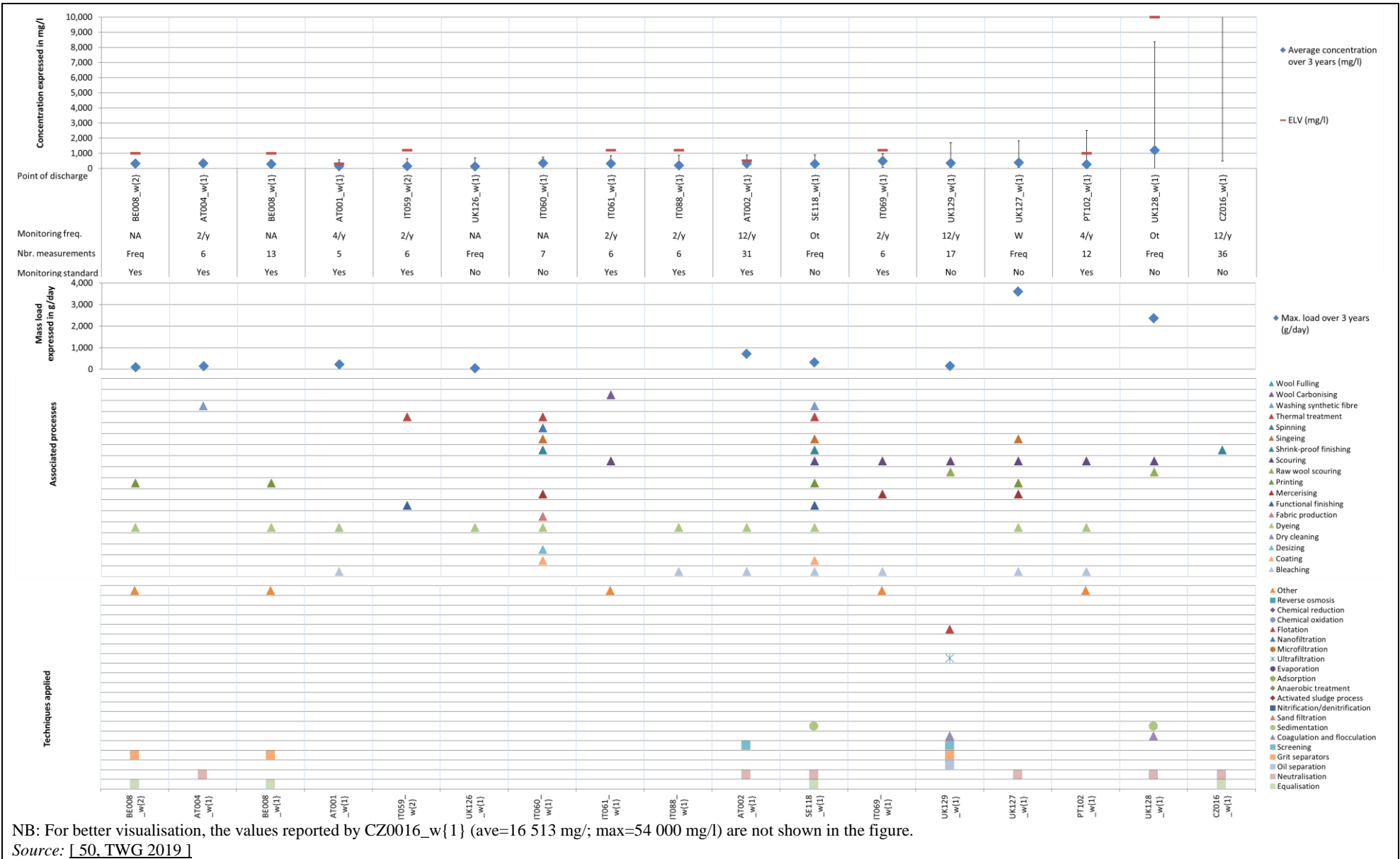


Figure 3.27: TSS emissions to water for indirect discharges (Part 2 of 2)

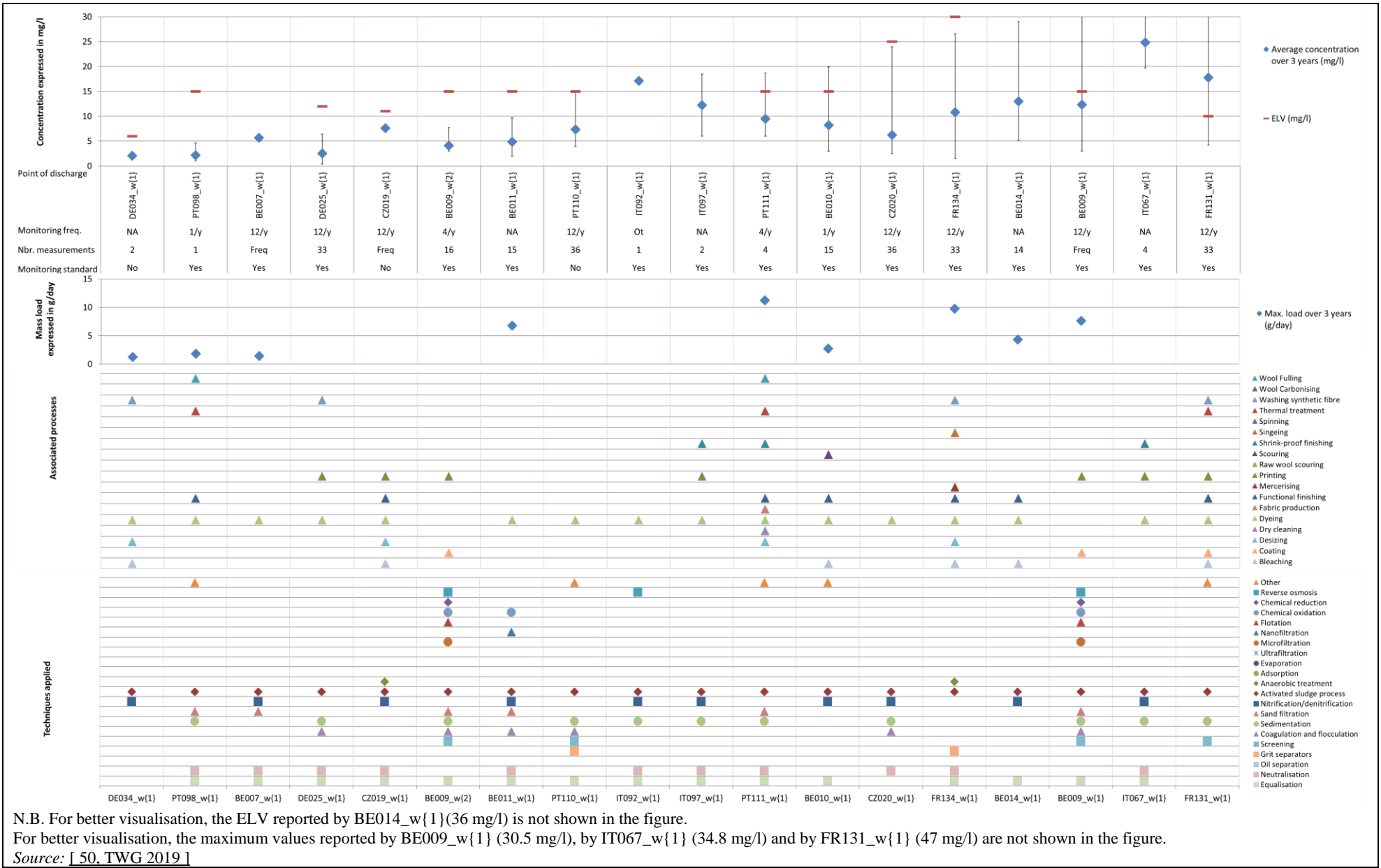


Figure 3.28: Total N emissions to water for direct discharges

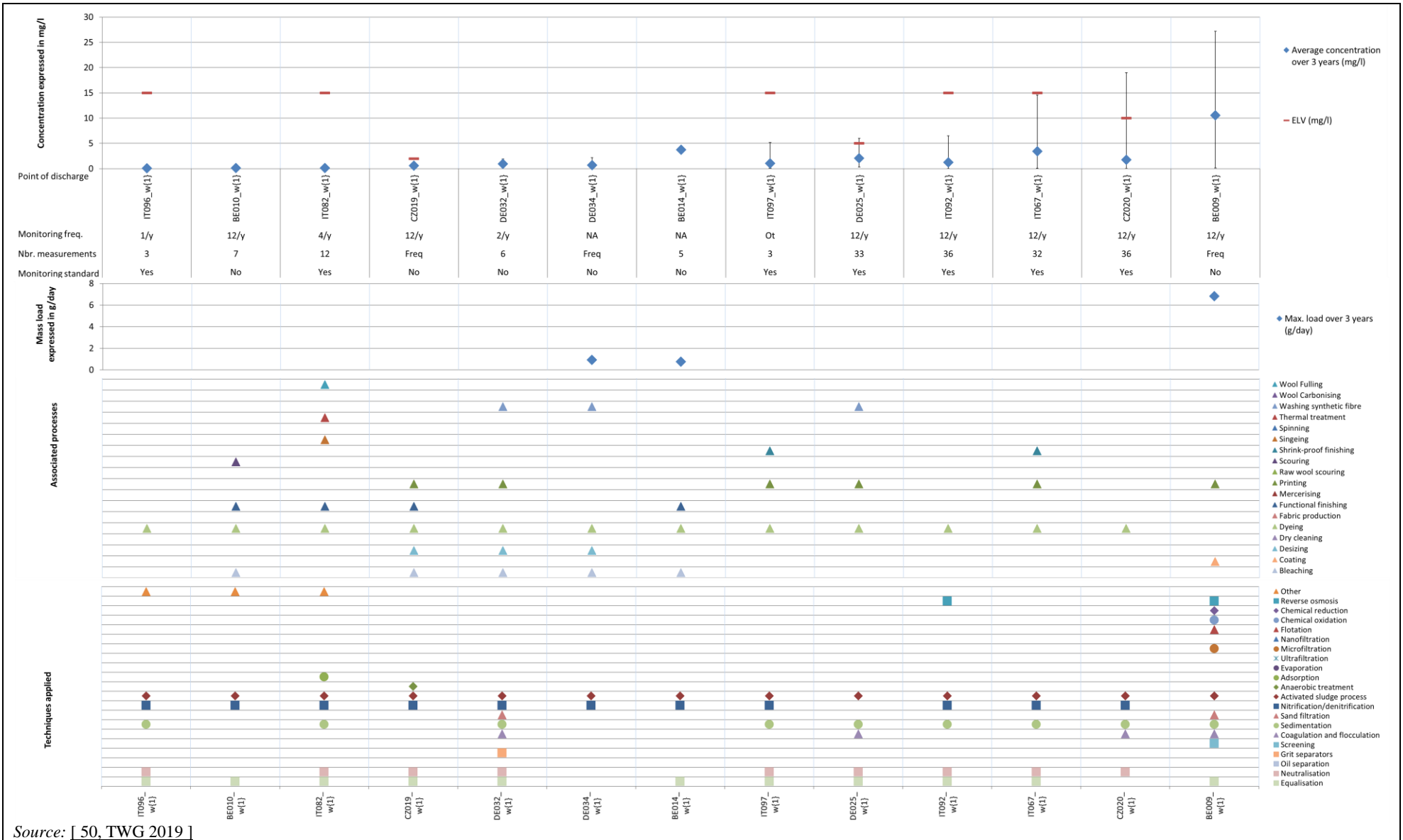


Figure 3.29: Ammonium emissions to water for direct discharges

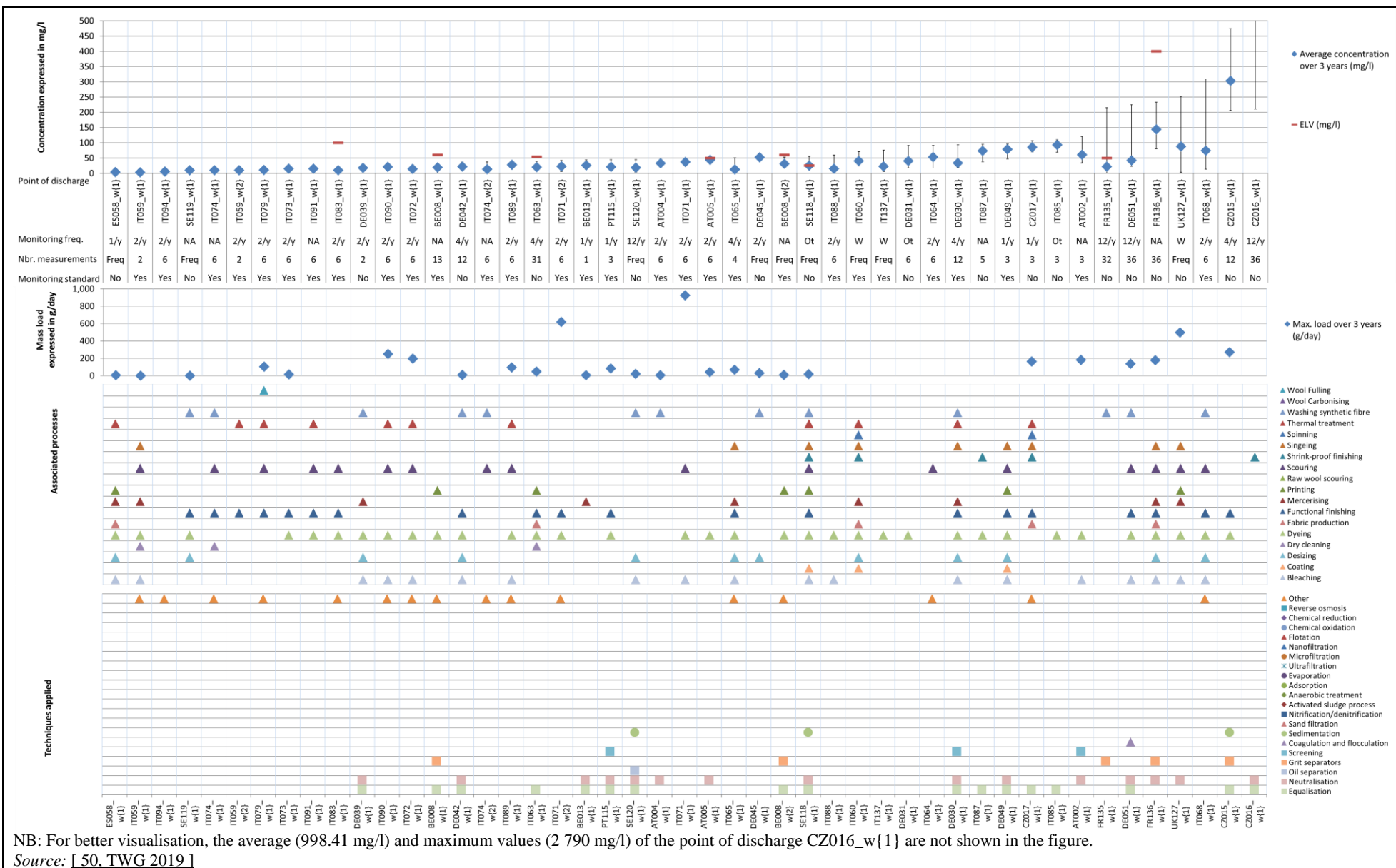


Figure 3.30: Total N emissions to water for indirect discharges

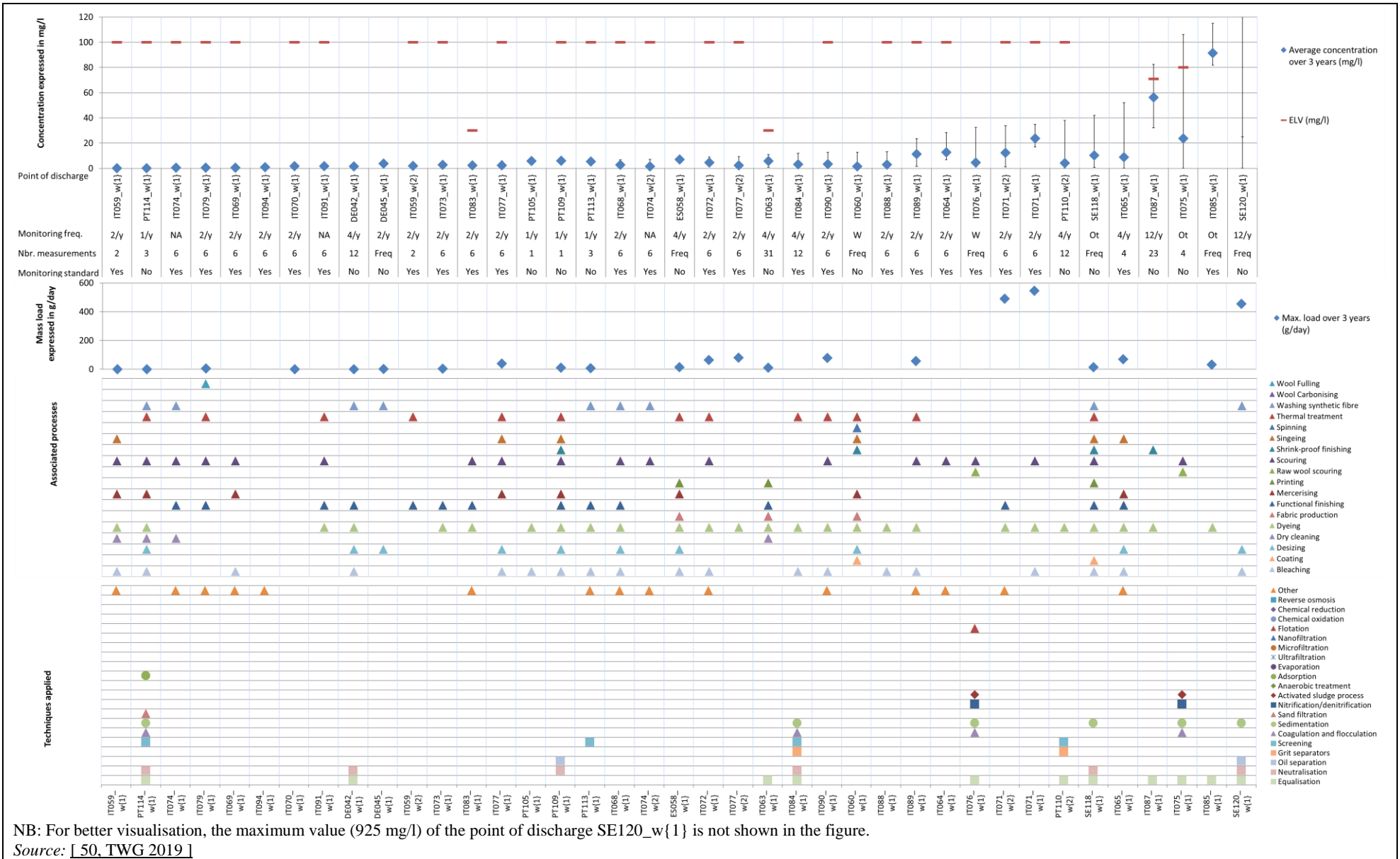


Figure 3.31: Ammonium emissions to water for indirect discharges

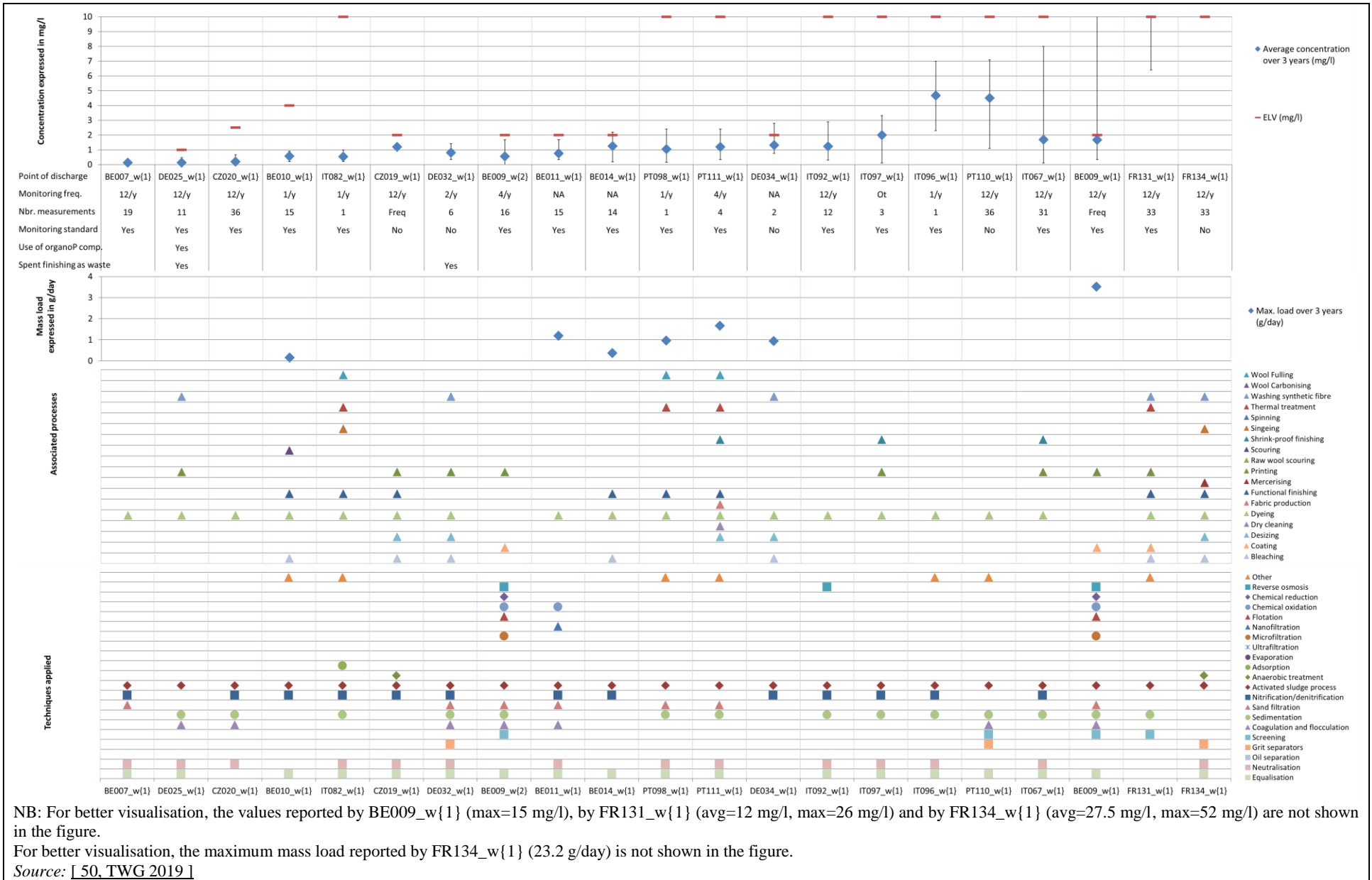
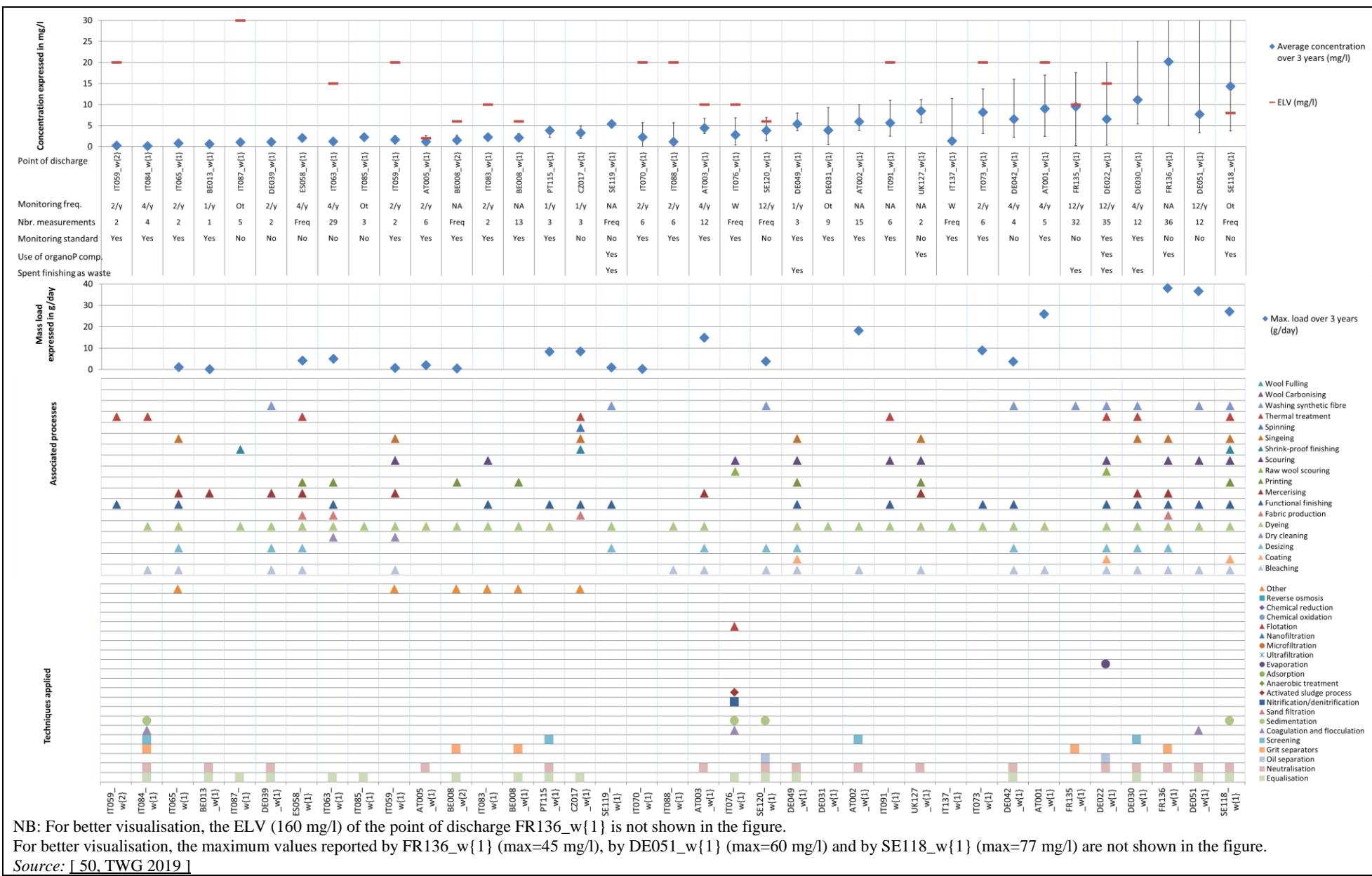


Figure 3.32: Total P emissions to water for direct discharges



NB: For better visualisation, the ELV (160 mg/l) of the point of discharge FR136\_w{1} is not shown in the figure.  
 For better visualisation, the maximum values reported by FR136\_w{1} (max=45 mg/l), by DE051\_w{1} (max=60 mg/l) and by SE118\_w{1} (max=77 mg/l) are not shown in the figure.

Source: [ 50, TWG 2019 ]

Figure 3.33: Total P emissions to water for indirect discharges

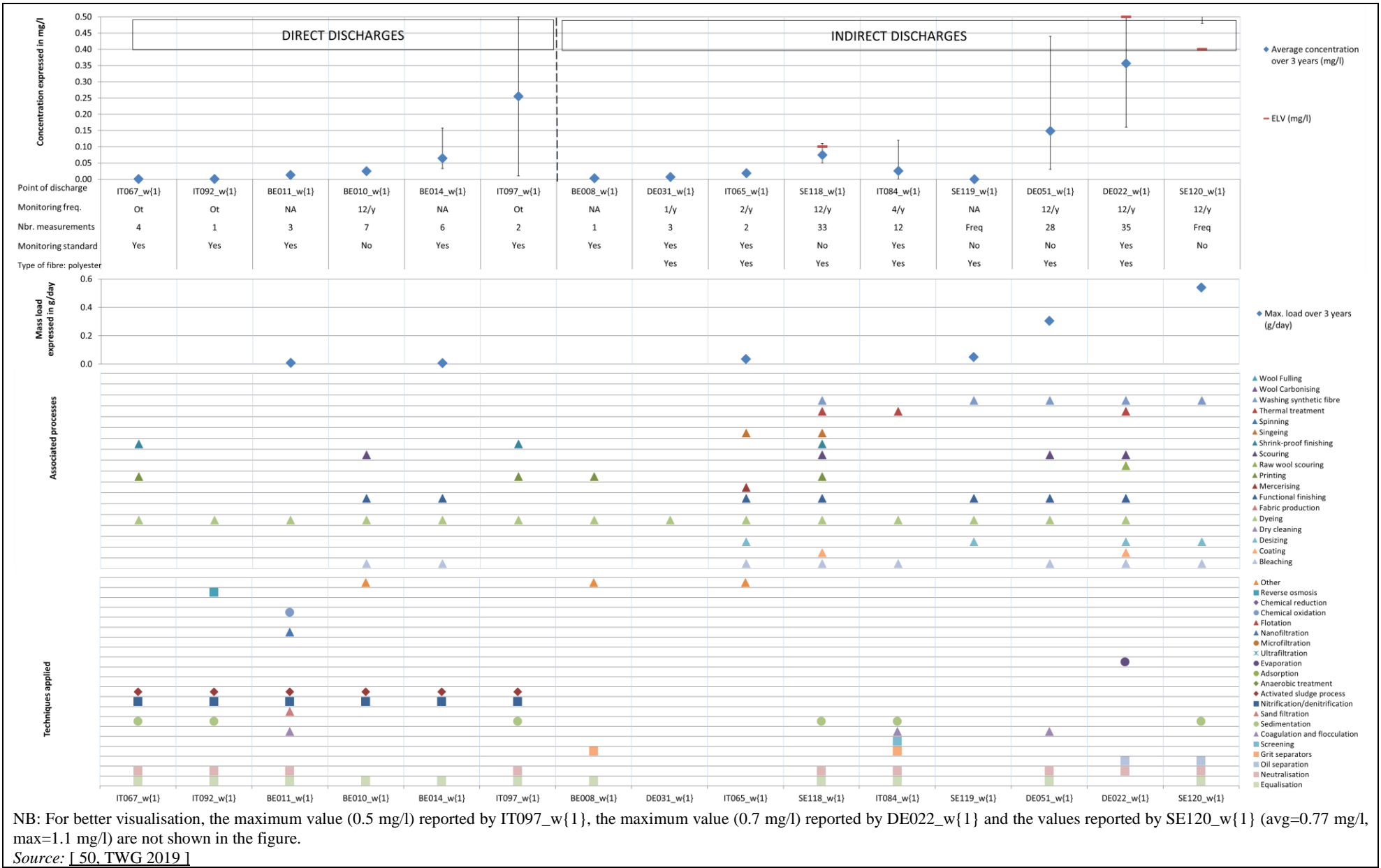
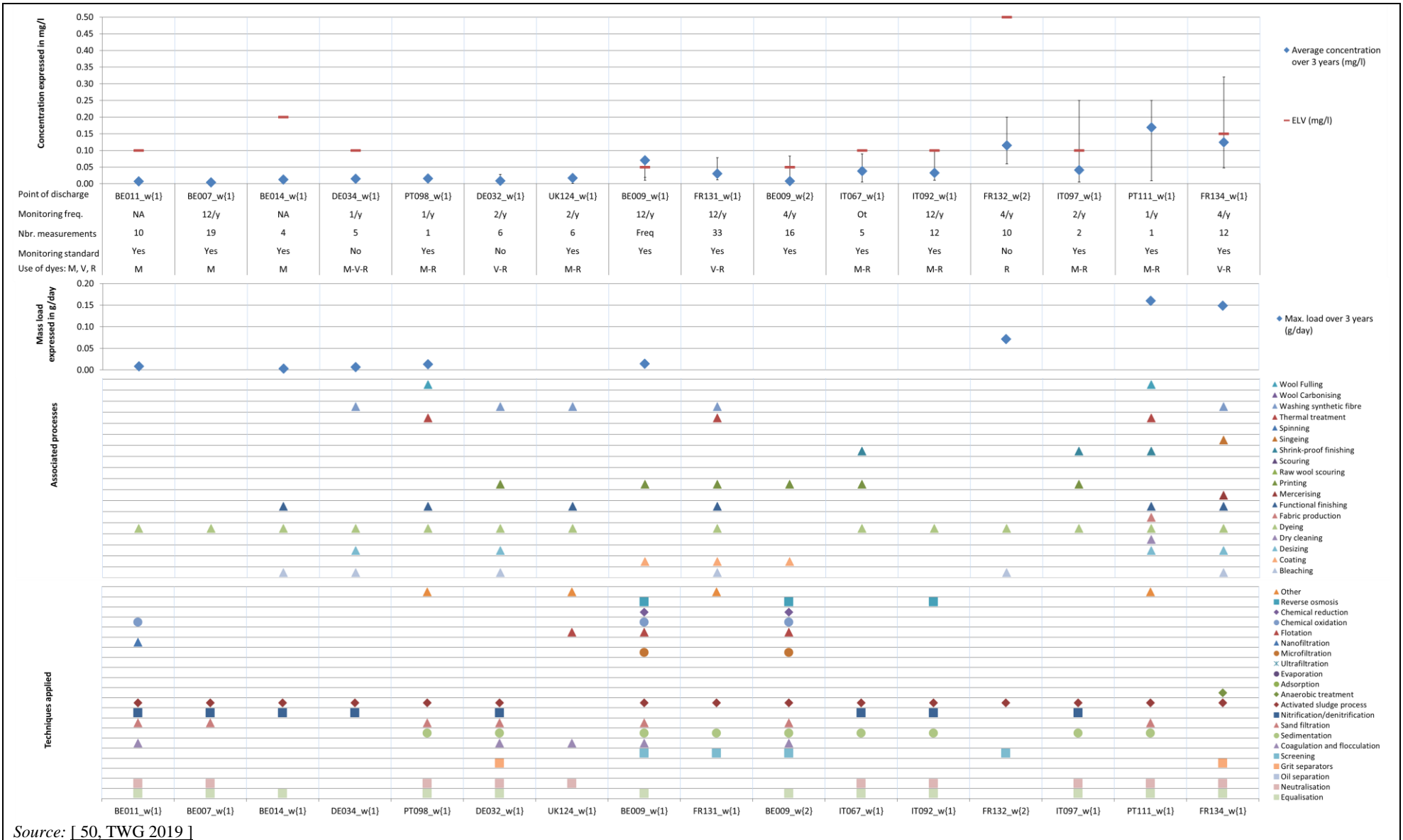


Figure 3.34: Antimony emissions to water for direct and indirect discharges





Source: [ 50, TWG 2019 ]

Figure 3.35: Copper emissions to water for direct discharges

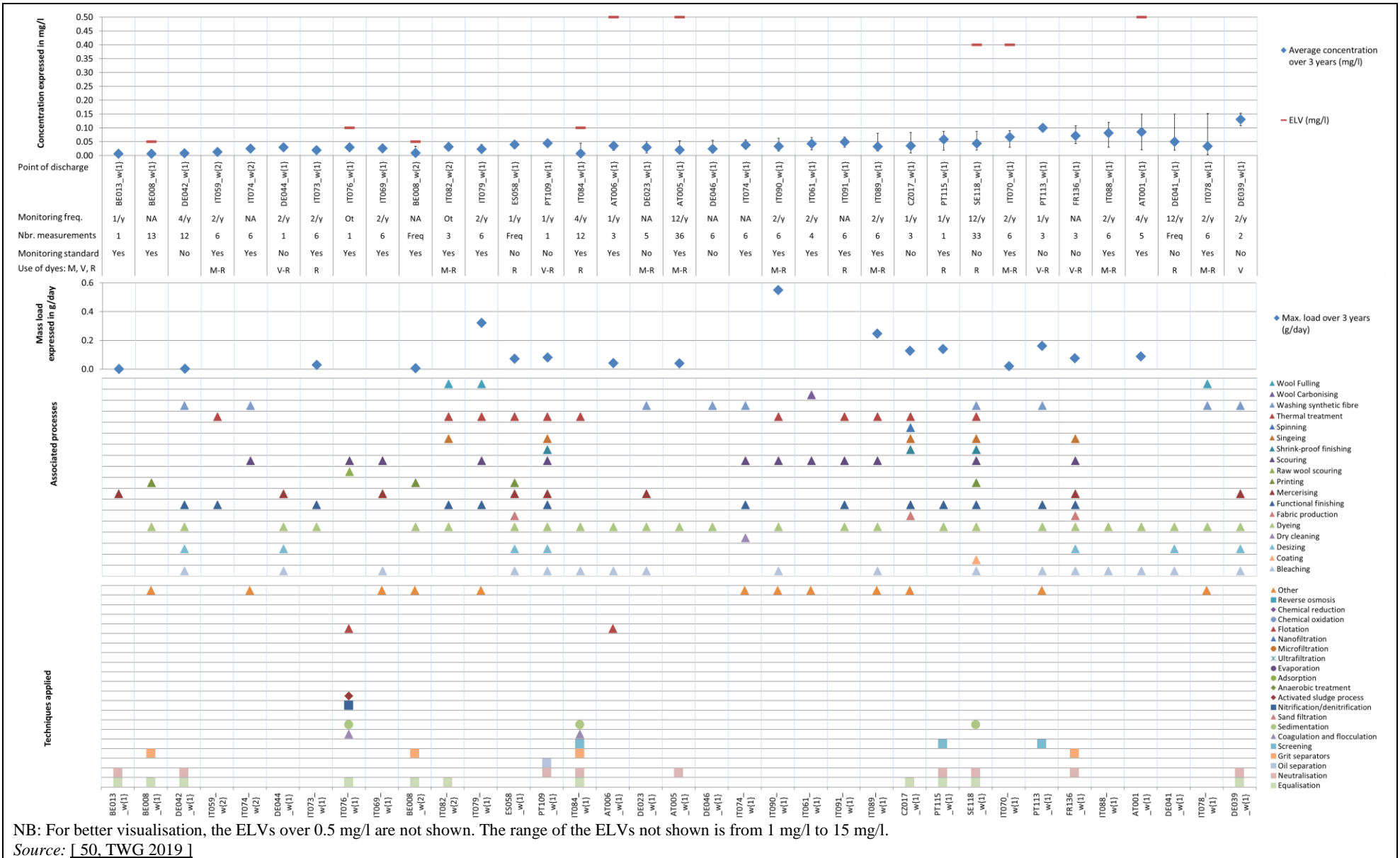


Figure 3.36: Copper emissions to water for indirect discharges (Part 1 of 2)

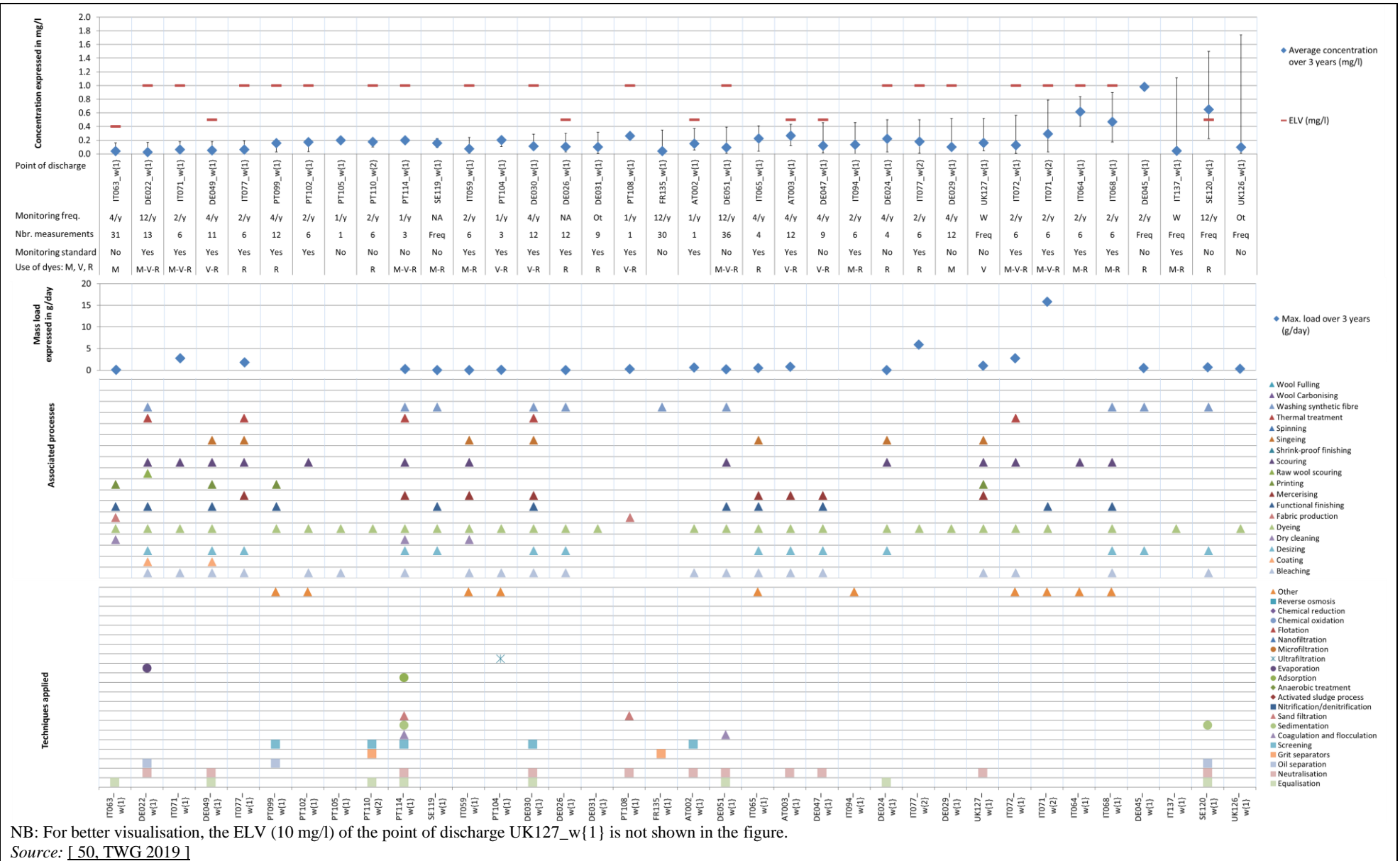


Figure 3.37: Copper emissions to water for indirect discharges (Part 2 of 2)

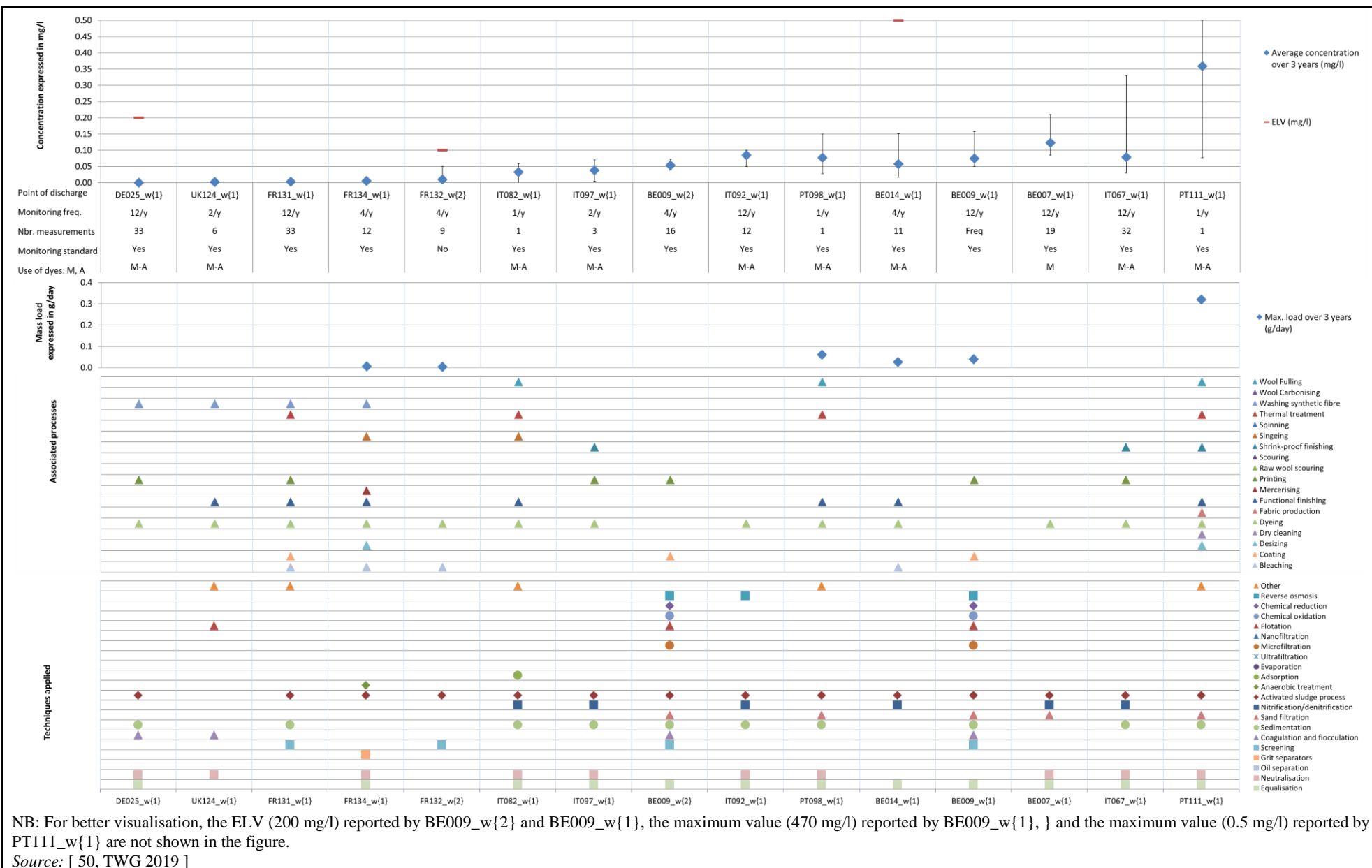


Figure 3.38: Chromium emissions to water for direct discharges

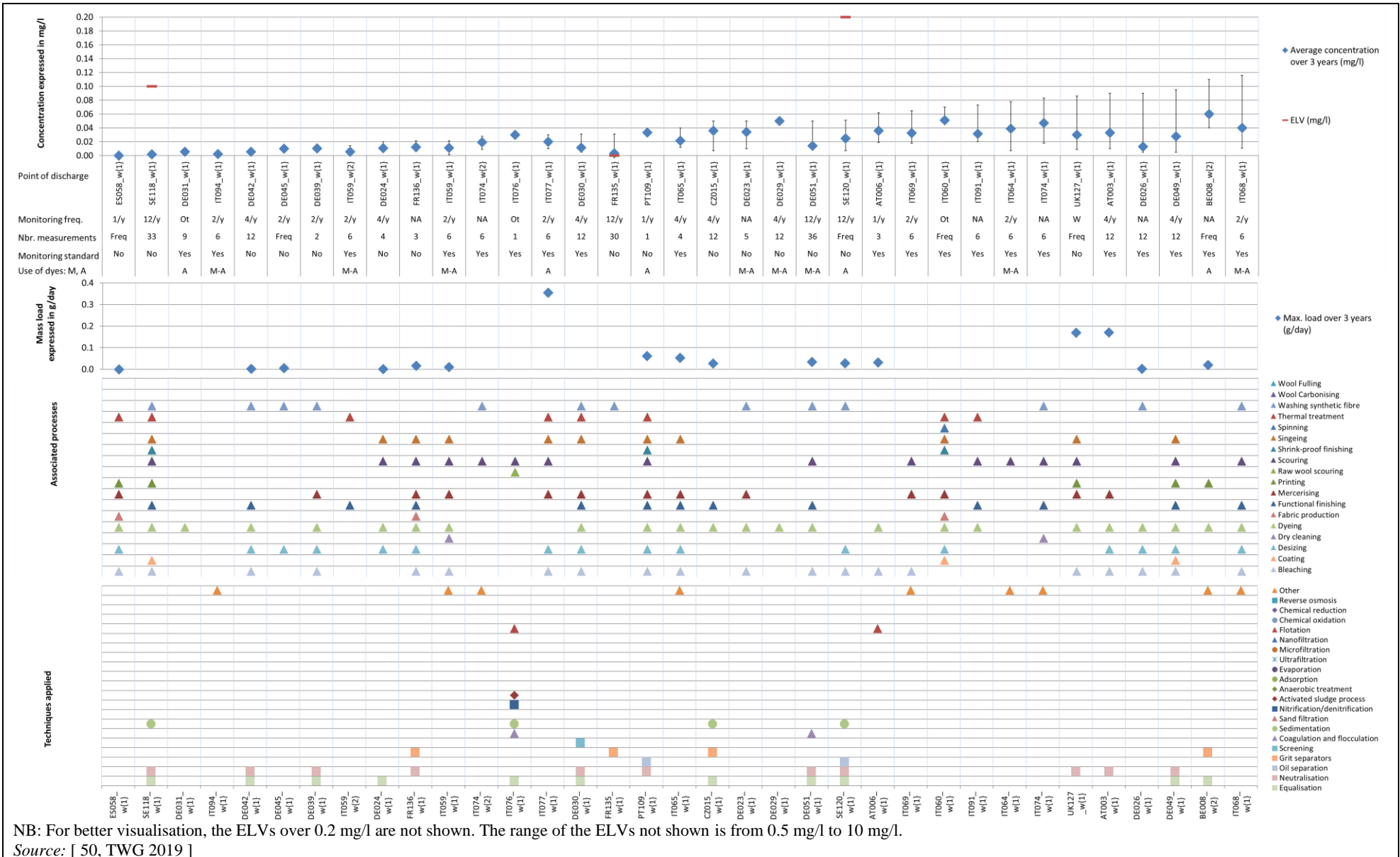
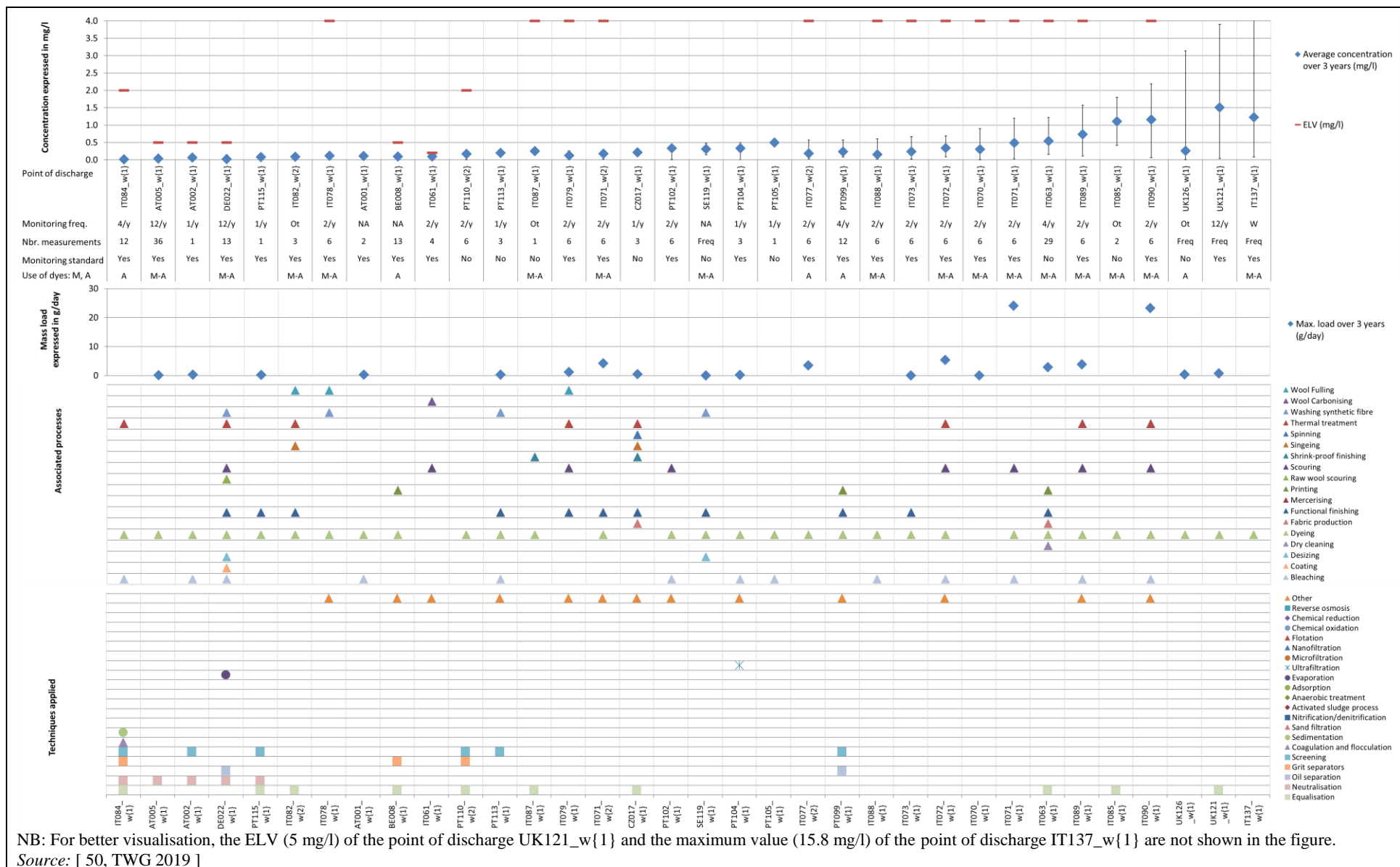


Figure 3.39: Chromium emissions to water for indirect discharges (Part 1 of 2)



NB: For better visualisation, the ELV (5 mg/l) of the point of discharge UK121\_w{1} and the maximum value (15.8 mg/l) of the point of discharge IT137\_w{1} are not shown in the figure.  
 Source: [ 50, TWG 2019 ]

Figure 3.40: Chromium emissions to water for indirect discharges (Part 2 of 2)

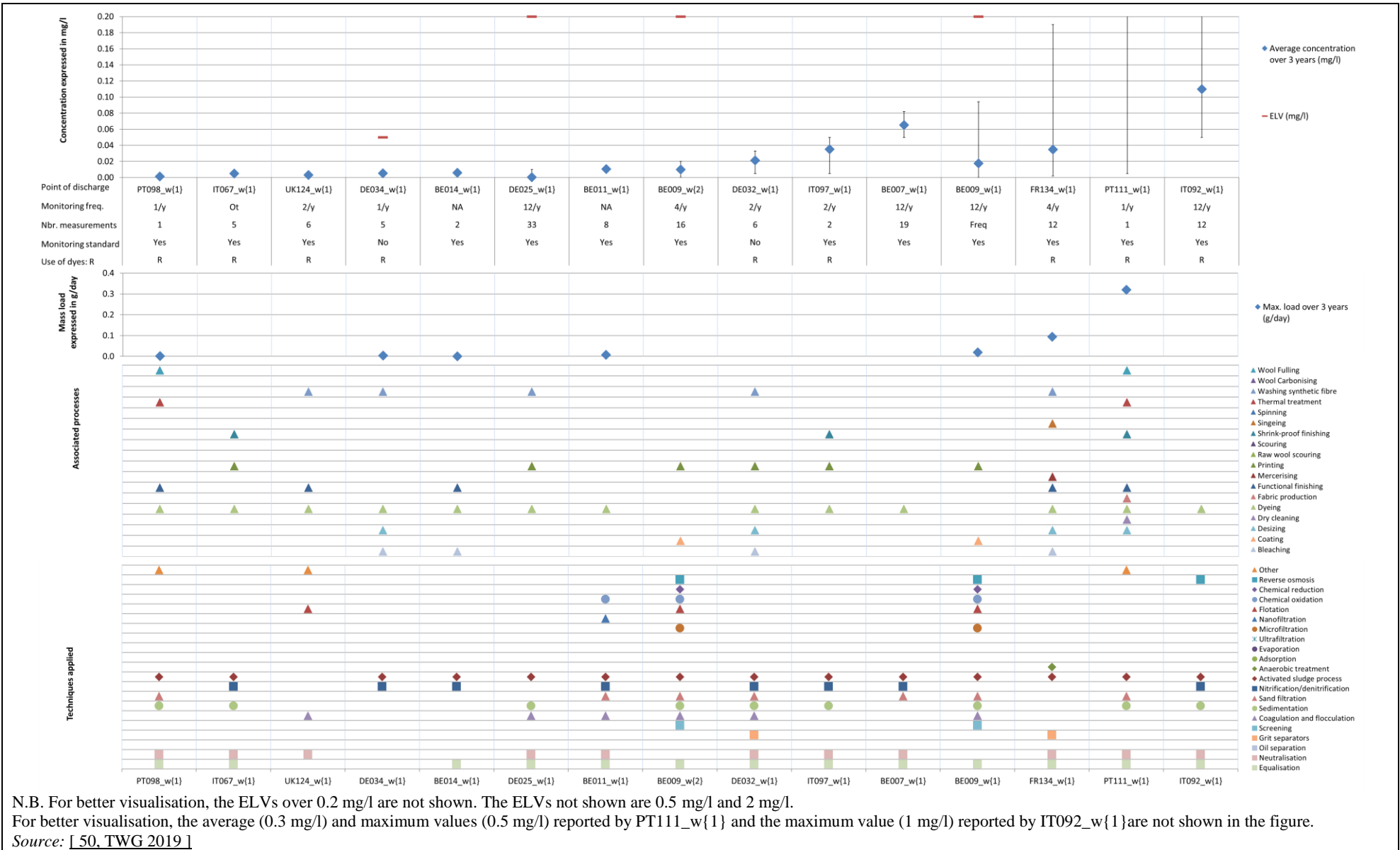


Figure 3.41: Nickel emissions to water for direct discharges

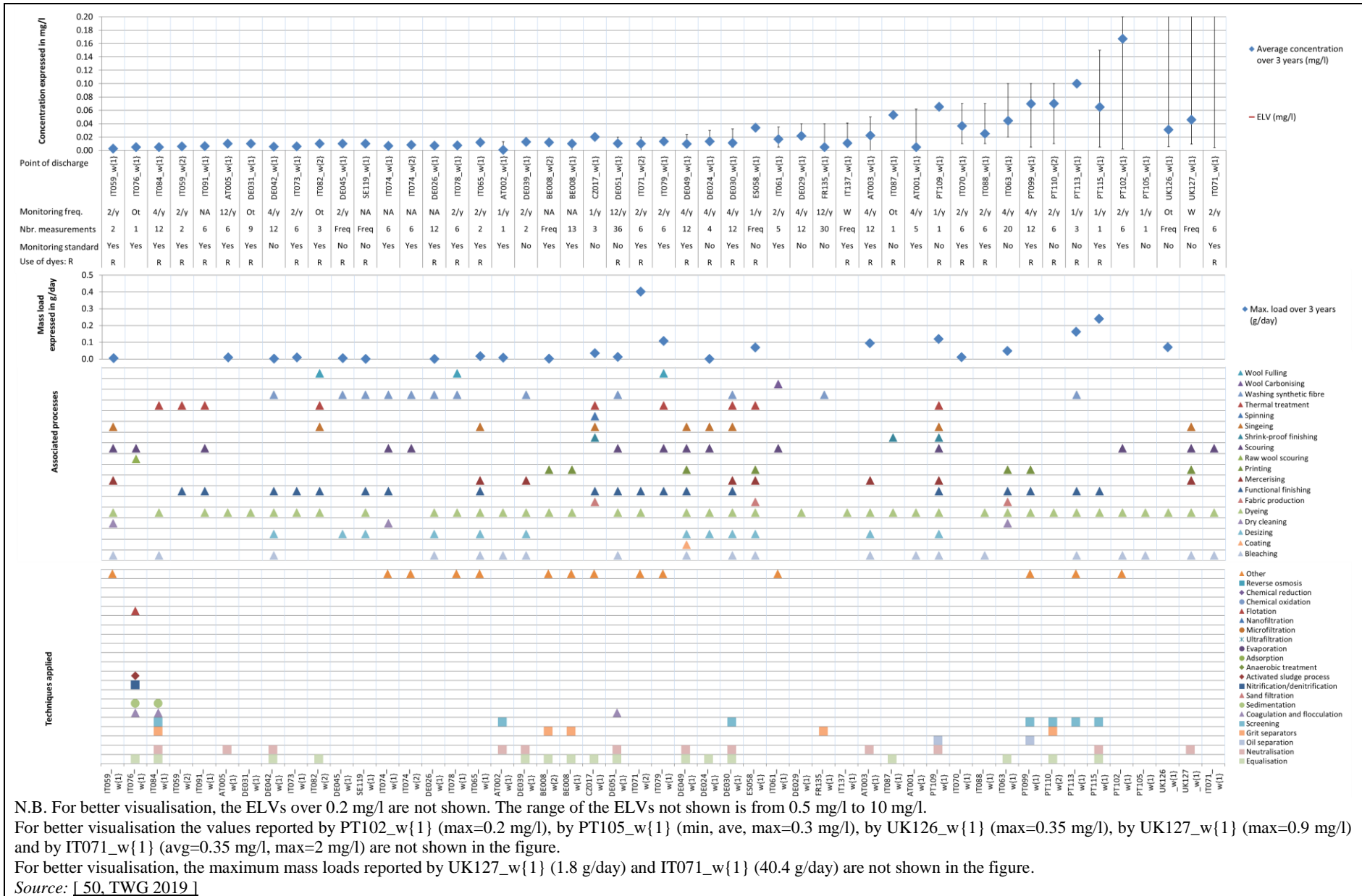
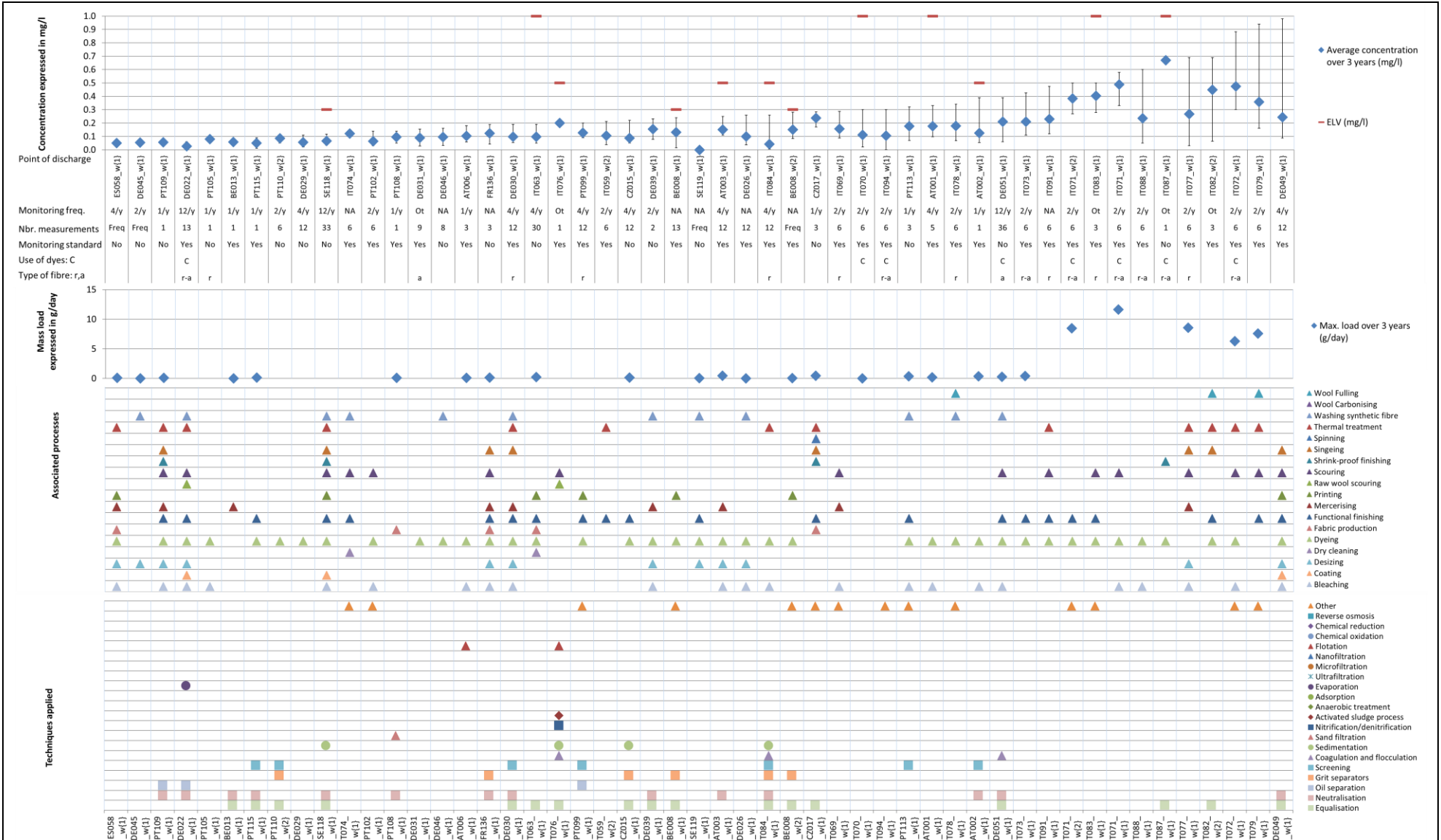


Figure 3.42: Nickel emissions to water for indirect discharges







NB: For better visualisation, the ELVs over 1 mg/l are not shown. The range of the ELVs not shown is from 2 mg/l to 15 mg/l.

Source: [ 50, TWG 2019 ]

Figure 3.44: Zinc emissions to water for indirect discharges (Part 1 of 2)

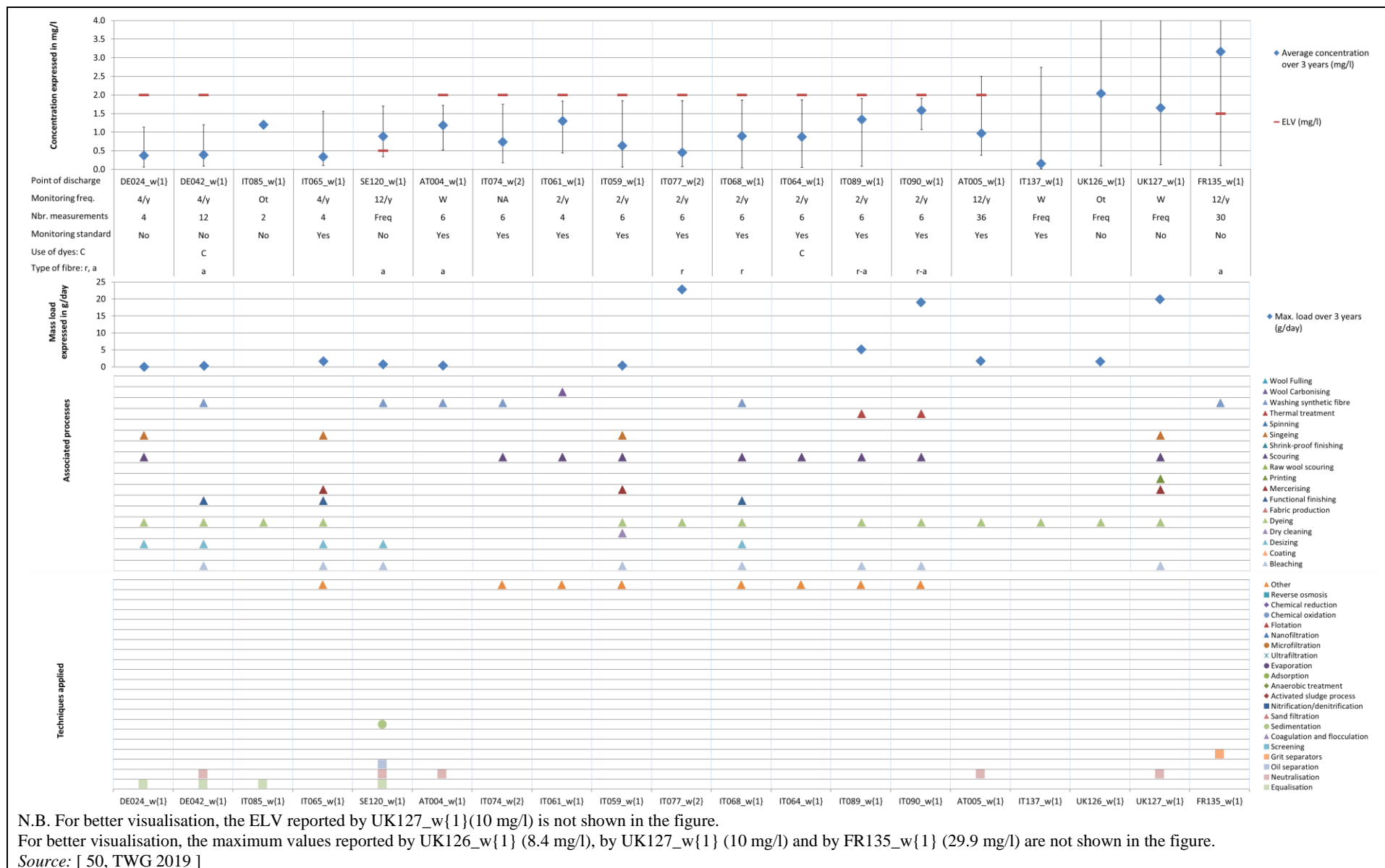


Figure 3.45: Zinc emissions to water for indirect discharges (Part 2 of 2)

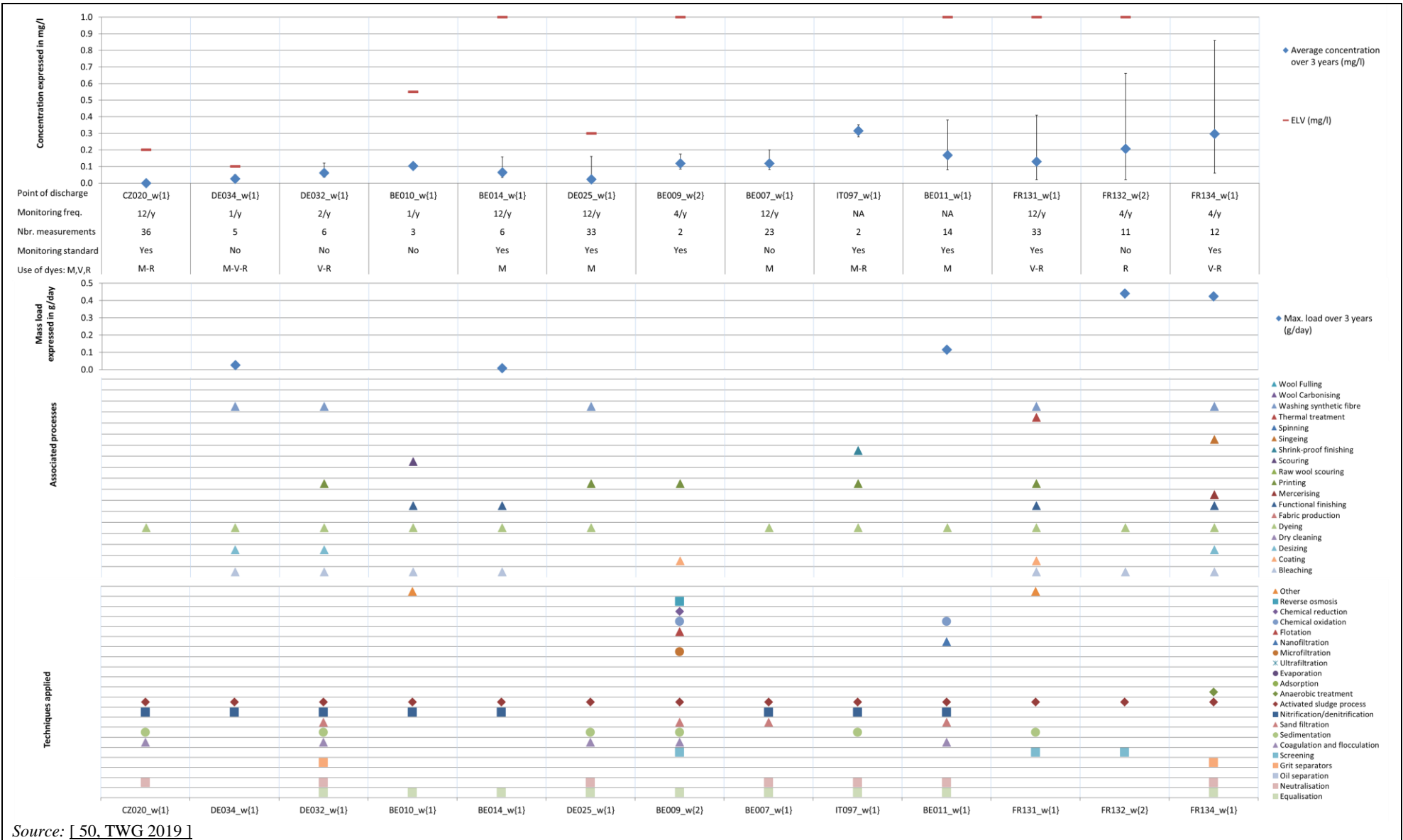
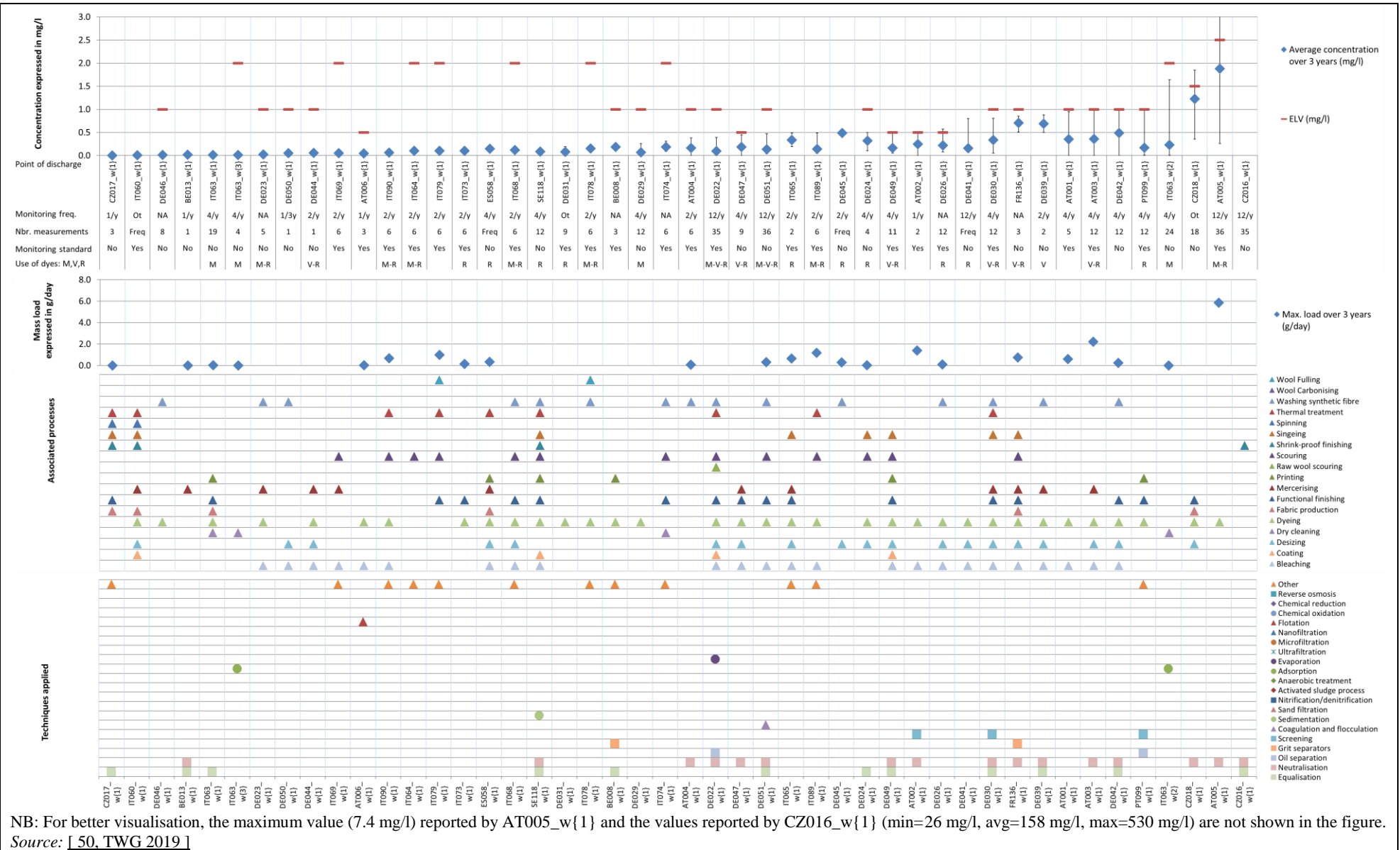


Figure 3.46: AOX emissions to water for direct discharges



NB: For better visualisation, the maximum value (7.4 mg/l) reported by AT005\_w{1} and the values reported by CZ016\_w{1} (min=26 mg/l, avg=158 mg/l, max=530 mg/l) are not shown in the figure.  
 Source: [ 50, TWG 2019 ]

Figure 3.47: AOX emissions to water for indirect discharges

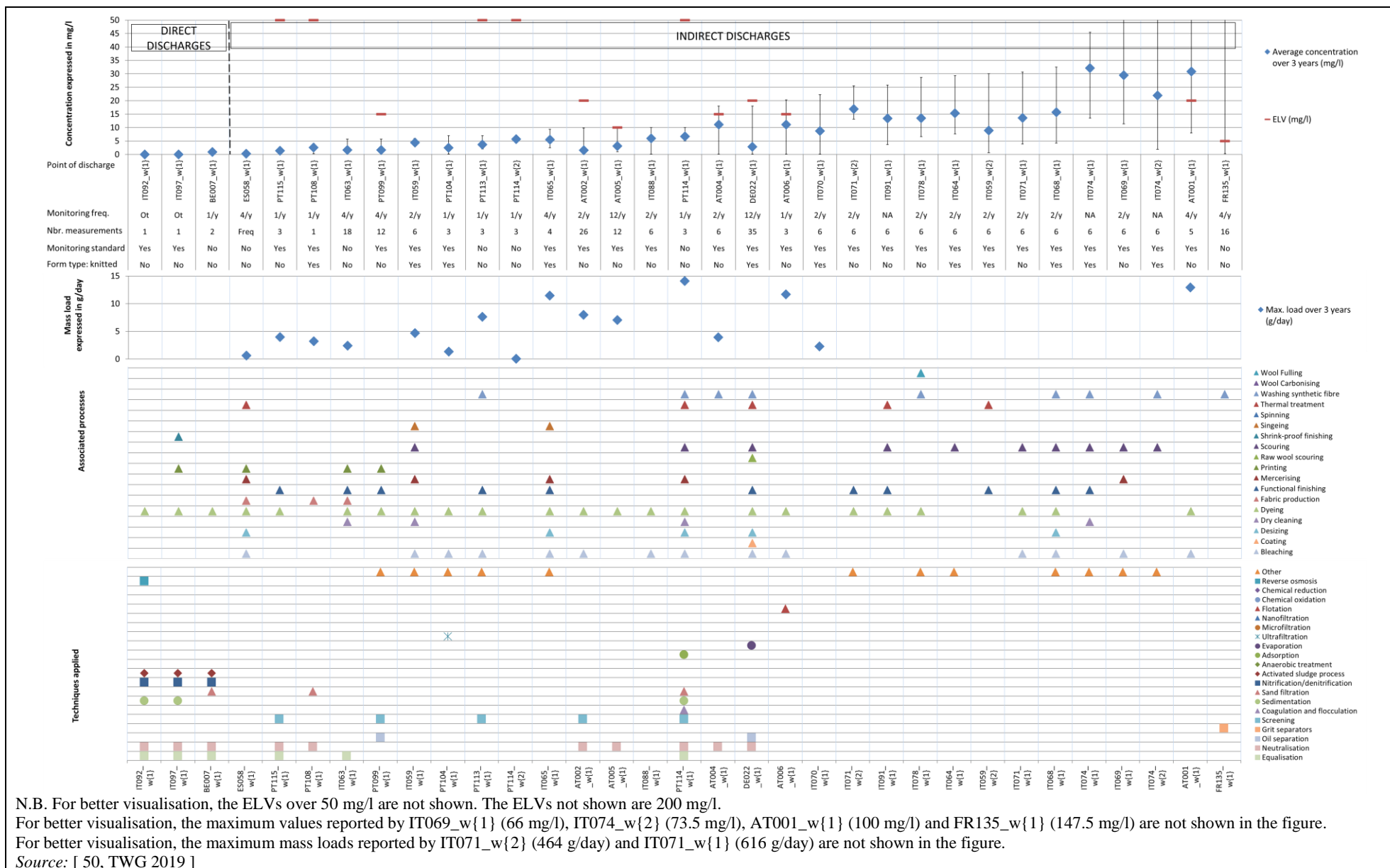


Figure 3.48: HOI emissions to water for direct and indirect discharges

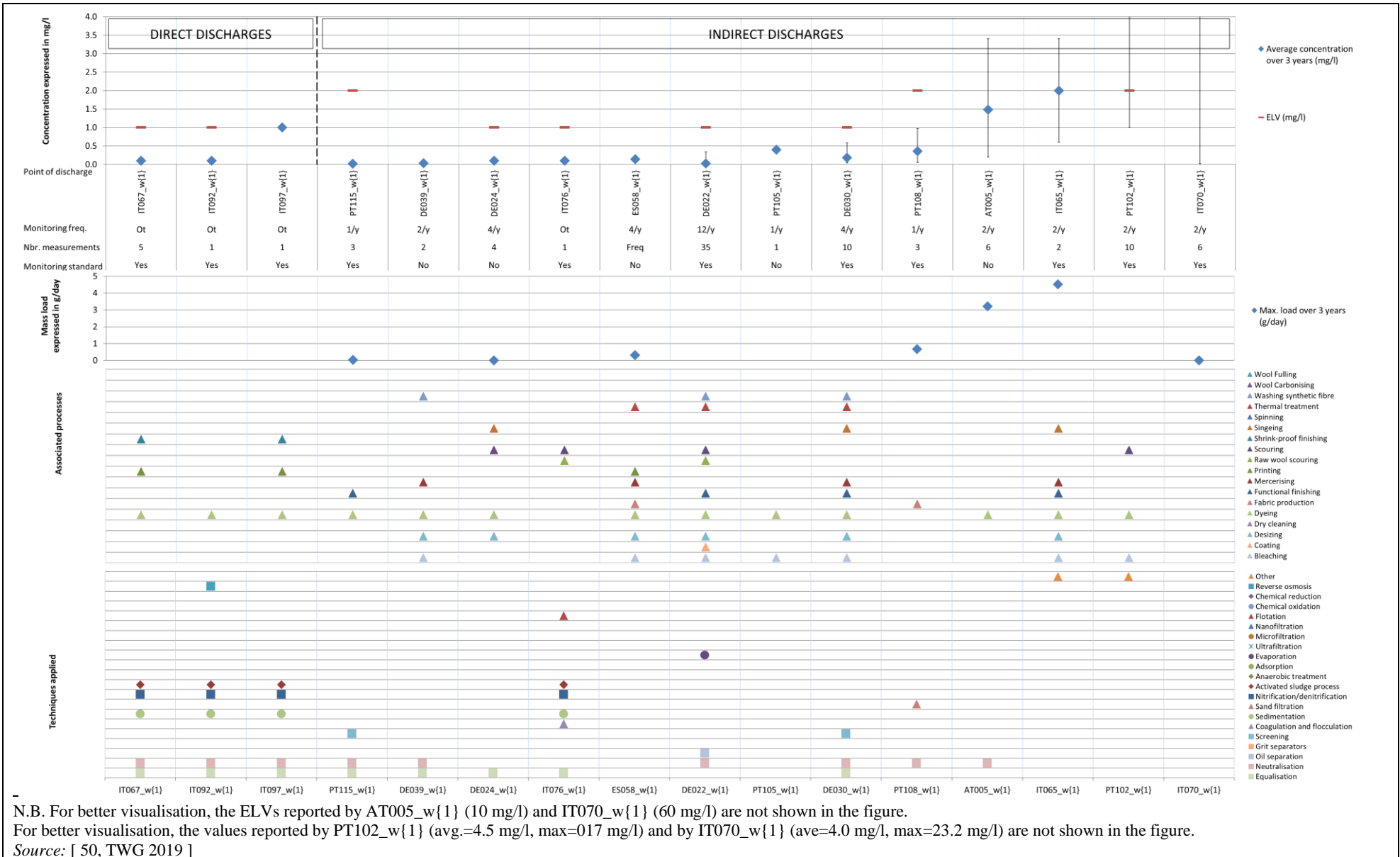


Figure 3.49: Sulphide emissions to water for direct and indirect discharges

Table 3.5: Alkylphenols and alkylphenol ethoxylates emissions to water

Emission point	Parameter	Type of discharge	Minimum concentration over 3 years (mg/l)	Average concentration over 3 years (mg/l)	Maximum concentration over 3 years (mg/l)	Maximum mass flow over 3 years (g/day)	ELV (mg/l)	Combination of techniques	Monitoring standard
FR134_w{1}	4-Nonylphenol	DIR				NI	0.025	Equalisation - Neutralisation - Grit separators - Activated sludge process - Anaerobic treatment	No information
IT064_w{1}	4-Nonylphenol	INDIR	0.0002	0.0002	0.0002	NI	NI	Other	UNI EN ISO 18857-2:2012
IT071_w{1}	4-Nonylphenol	INDIR	0.0002	0.0002	0.0002	0.0040	NI	No information	UNI EN ISO 18857-2:2012
IT089_w{1}	4-Nonylphenol	INDIR	0.0002	0.0002	0.0002	0.0004	NI	Other	UNI EN ISO 18857-2:2012
IT090_w{1}	4-Nonylphenol	INDIR	0.0002	0.0002	0.0002	0.0012	NI	Other	UNI EN ISO 18857-2:2012
SE118_w{1}	4-Nonylphenol	INDIR	0.0018	0.0018	0.0018	NI	NI	Sedimentation - Equalisation - Neutralisation	In-house method, UPLC/MS/MS
IT078_w{1}	4-Nonylphenol	INDIR	0.0002	0.0017	0.0053	NI	NI	Other	UNI EN ISO 18857-2:2012
FR134_w{1}	4-Nonylphenol -di-ethoxylat	DIR				NI	0.025	Equalisation - Neutralisation - Grit separators - Activated sludge process - Anaerobic treatment	No information
SE118_w{1}	4-Nonylphenol -di-ethoxylate	INDIR	0.0001	0.0001	0.0001	NI	NI	Sedimentation - Equalisation - Neutralisation	In-house method, UPLC/1vfS /MS



FR134_w{1}	4-Nonylphenol -mono- ethoxylate	DIR				NI	0.025	Equalisation - Neutralisation - Grit separators - Activated sludge process - Anaerobic treatment	No information
SE118_w{1}	4-Nonylphenol -mono- ethoxylate	INDIR	0.0011	0.0011	0.0011	NI	NI	Sedimentation - Equalisation - Neutralisation	In-house method, UPLC/MS/MS
IT065_w{1}	Alkylphenol s ethoxylate: OPEO1 , OPEO2; NEPEO1; NEPEO2; OPEO3-20; NEPEO3-20	INDIR	0.00001	0.00001	0.00001	0.000013	NI	Other	ISO 18857-2 :2009
IT065_w{1}	AP	INDIR	0.00001	0.00001	0.00001	0.000013	NI	Other	ISO 18857-1 2005
FR131_w{1}	AP	DIR	0	0.0005	0.0023	NI	NI	Screening - Sedimentation - Activated sludge process - Sedimentation - Other	ISO 18857-1/-2
FR131_w{1}	APEO	DIR	0	0.000017	0.0001	NI	NI	Screening - Sedimentation - Activated sludge process - Sedimentation - Other	ISO 18857-1/-2
SE119_w{1}	APEO	INDIR		0.0040		0.0006	NI	No technique used	No information

BE011_w{1}	APEO C15	DIR	0.1000	0.1633	0.2700	0.1165	NI	Equalisation - Neutralisation - Coagulation and flocculation - Activated sludge process - Nitrification/ denitrification - Sand filtration - Nanofiltration - Chemical oxidation (incl. Advanced oxidation)	WAC/IV/A/001- WAC/IV/A/005
BE011_w{1}	APEO C16	DIR	0.0240	0.0240	0.0240	0.0102	NI	Equalisation - Neutralisation - Coagulation and flocculation - Activated sludge process - Nitrification/ denitrification - Sand filtration - Nanofiltration - Chemical oxidation (incl. Advanced oxidation)	WAC/IV/A/001- WAC/IV/A/005
BE011_w{1}	APEO C17	DIR	0.1900	0.2300	0.3100	0.1338	NI	Equalisation - Neutralisation - Coagulation and flocculation - Activated sludge process - Nitrification/ denitrification - Sand filtration - Nanofiltration - Chemical oxidation (incl. Advanced oxidation)	WAC/IV/A/001- WAC/IV/A/005
SE120_w{1}	NF	INDIR	0.0002	0.0023	0.0045	NI	NI	Neutralisation - Oil separation - Sedimentation - Equalisation	No information
SE120_w{1}	NFE	INDIR	0.0015	0.0017	0.0018	NI	NI	Neutralisation - Oil separation - Sedimentation - Equalisation	No information

AT002_w{1}	Nonylphenol	INDIR	0	0.0006	0.0013	0.0010	NI	Screening - Neutralisation	DIN EN ISO 18857-1
BE007_w{1}	Nonylphenol	DIR	0.0001	0.0008	0.0036			Equalisation - Neutralisation - Sand filtration - Activated sludge process - Nitrification/ denitrification	WAC/IV/A/001- WAC/IV/A/005
FR134_w{1}	Nonylphenol	DIR	0	0.0014	0.0049	0.0024	0.025	Equalisation - Neutralisation - Grit separators - Activated sludge process - Anaerobic treatment	No information
AT004_w{1}	Nonylphenol	INDIR	0	0.0072	0.0200	0.0021	NI	Neutralisation	DIN EN ISO 18857-2
IT092_w{1}	Nonylphenol ethoxylate (NPEO)	DIR	0.0002	0.0002	0.0002	NI	NI	Equalisation - Neutralisation - Activated sludge process- Nitrification/ denitrification - Sedimentation - Reverse osmosis	ISO 18857-1:2005
IT097_w{1}	Nonylphenol ethoxylate (NPEO)	DIR	0.0004	0.0004	0.0004	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/ denitrification - Sedimentation	ISO 18857-1:2005
BE010_w{1}	NP	DIR	0.0002	0.0004	0.0011	NI	NI	Equalisation - - Activated sludge process - Nitrification/ denitrification - Other	WAC/IV/A/001- WAC/IV/A/005
BE014_w{1}	NP	DIR	0.0001	0.0006	0.0015	0.0001	0.00008	Equalisation - Activated sludge process - Nitrification/ denitrification	WAC/IV/A/01-05
UK127_w{1}	NP	INDIR	0.0020	0.0110	0.0200	NI	NI	Neutralisation	No information

BE014_w{1}	Octylphenol	DIR	0.00003	0.00003	0.00003	0.000003	0.00008	Equalisation - Activated sludge process - Nitrification/ denitrification	WAC/IV/A/01-05
AT002_w{1}	Octylphenol	INDIR	0	0.0002	0.0009	0.0007	NI	Screening - Neutralisation	DIN EN ISO 18857-1
UK127_w{1}	Octylphenol	INDIR	0.0010	0.0055	0.0100	NI	NI	Neutralisation	No information
AT004_w{1}	Octylphenol	INDIR	0	0.0062	0.02	0.0001	NI	Neutralisation	DIN EN ISO 18857-2
IT092_w{1}	OP, NP, OPEO, NPEO	DIR	0.00001	0.00001	0.00001	NI	NI	Equalisation - Neutralisation - Activated sludge process- Nitrification/ denitrification - Sedimentation - Reverse osmosis	ISO 18857-1:2005
IT097_w{1}	OP, NP, OPEO, NPEO	DIR	0.0050	0.0050	0.0050	NI	NI	Equalisation - Neutralisation - Activated sludge process- Nitrification/ denitrification - Sedimentation	with reference to ISO 18857-2, ISO 18254-1 or ASTM D7065
DE031_w{1}	OP, OP1EO;NP, NPEO	INDIR	0			NI	NI	No information	ASTM D7065

NB:

AP = Alkylphenols;

APEO = Alkylphenol ethoxylates;

DIR = Direct discharge;

ELV = Emission limit value;

IND = Indirect discharge;

NI = No information;

NP = Nonylphenol;

NPEO = Nonylphenol ethoxylates;

OP = Octylphenol;

OP1EO = Octylphenol monoethoxylate.

Source: [ 50, TWG 2019 ]

Table 3.6: Perfluorocarbons emissions to water

Emission point	Parameter	Type of discharge	Minimum concentration over 3 years (mg/l)	Average concentration over 3 years (mg/l)	Maximum concentration over 3 years (mg/l)	Maximum mass flow over 3 years (g/day)	ELV (mg/l)	Combination of techniques	Monitoring standard
IT097_w{1}	6 substances	DIR	0.001	0.001	0.001	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/ denitrification - Sedimentation	With reference to DIN38407-42 or CEN/TS15968 and followed by LCMS or LC/MS/MS analysis
SE120_w{1}	Perfluorodecanoic acid (PFDA)	INDIR	0.00001	0.00001	0.00001	NI	NI	Neutralisation - Oil separation - Sedimentation - Equalisation	No information
IT092_w{1}	Perfluoroheptanoic acid (PFHpA)	DIR	0.0002	0.0002	0.0002	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/ denitrification - Sedimentation - Reverse osmosis	MI1207 rev2:2018
BE014_w{1}	Perfluoroheptanoic acid (PFHpA)	DIR	0.0002	0.0005	0.0007	0.0002	NI	Equalisation - Activated sludge process - Nitrification/ denitrification	WAC/IV/A/025
SE120_w{1}	Perfluorohexanoic acid (PFHxA)	INDIR	0.00001	0.00001	0.00001	NI	NI	Neutralisation - Oil separation - Sedimentation - Equalisation	No information
IT092_w{1}	Perfluorohexanoic acid (PFHxA)	DIR	0.00003	0.00003	0.00003	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/ denitrification - Sedimentation - Reverse osmosis	MI1207 rev2:2018
DE034_w{1}	Perfluorohexanoic acid (PFHxA)	DIR	0.0005	0.0005	0.0005	0.0003	NI	Activated sludge process - Nitrification/ denitrification	DIN 38407-42

BE014_w{1}	Perfluorohexanoic acid (PFHxA)	DIR	0.0001	0.0002	0.001	0.00005	NI	Equalisation - Activated sludge process - Nitrification/ denitrification	WAC/IV/A/025
SE120_w{1}	Perfluorooctanoic acid (PFOA)	INDIR	0.00001	0.00001	0.00001	NI	NI	Neutralisation - Oil separation - Sedimentation - Equalisation	No information
IT097_w{1}	Perfluorooctanoic acid (PFOA)	DIR	0.00001	0.00001	0.00001	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/ denitrification - Sedimentation	MI1207 Rev.2:2018
DE026_w{1}	Perfluorooctanoic acid (PFOA)	INDIR	0.00001	0.00002	0.00003	0.000005	NI	No information	DIN 38407-42
PT105_w{1}	Perfluorooctanoic acid (PFOA)	INDIR	0.00004	0.00004	0.00004	NI	NI	No information	LCMS – Direct Injection (Liquid Chromatography coupled to Mass Spectrometry)
DE034_w{1}	Perfluorooctanoic acid (PFOA)	DIR	0.0001	0.0001	0.0001	0.00004	NI	Activated sludge process - Nitrification/ denitrification	DIN 38407-42
IT092_w{1}	Perfluorooctanoic acid (PFOA)	DIR	0.0001	0.0001	0.0001	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/ denitrification - Sedimentation - Reverse osmosis	MI1207 rev2:2018
BE010_w{1}	Perfluorooctanoic acid (PFOA)	DIR	0.00001	0.0001	0.0001	NI	NI	Equalisation - Activated sludge process - Nitrification/ denitrification - Other	WAC/IV/A/025
DE039_w{1}	Perfluorooctanoic acid (PFOA)	INDIR	0.0002	0.0002	0.0002	NI	NI	Equalisation - Neutralisation	DIN 38407-42

BE011_w{1}	Perfluorooctanoic acid (PFOA)	DIR	0.0000004	0.0001	0.0002	0.0001	NI	Equalisation - Neutralisation - Coagulation and flocculation - Activated sludge process - Nitrification/ denitrification - Sand filtration - Nanofiltration - Chemical oxidation (incl. Advanced oxidation)	No information - WAC/IV/A/025
BE014_w{1}	Perfluorooctanoic acid (PFOA)	DIR	0.01	0.03	0.04	0.01	0.05	Equalisation - Activated sludge process - Nitrification/ denitrification	WAC/IV/A/025
IT092_w{1}	Perfluoropentane acid (PFPeA)	DIR	0.0001	0.0001	0.0001	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/ denitrification - Sedimentation - Reverse osmosis	MI1207 rev2:2018
SE119_w{1}	PFAS	INDIR		0.00		0.00	NI	No technique used	No information
SE118_w{1}	PFBA perfluorobutyrate	INDIR	0.00001	0.00001	0.00001	NI	NI	Sedimentation - Equalisation - Neutralisation	No information

IT065_w{1}	PFC: PFBA; PFPeA; PFHxA; PFHpA; PFOA; PFNA; PFDA; PFUnA; PFDoA; PFTrA; PFTA; PFBS; PFHxS; PFHpS; PFOS; PFDS; PFOSA; PFHxO; PFOcO; PFDeO; PFOcAc; FTOH 10-2; PFHxS; N- MeFOSE; N- EtFOSE; N- MeFOSA; N- EtFOSA; FTA 10- 2; H2PFDA; HPFHpA; HPFUnA; H4PFOS 6-2; PFHx; PFPe; PFCB; 7H- DoFHpA; 2H- PFDeA; 1H-2H- PFOS; 8:2FTS; H2PFDeA; POSF	INDIR	0.00001	0.00001	0.00002	0.00003	NI	Other	MIP_CW1207_rev2:2018
BE010_w{1}	PFHxS	DIR	0.00001	0.00002	0.0001	NI	NI	Equalisation - Activated sludge process - Nitrification/ denitrification - Other	No information
SE120_w{1}	PFOS	INDIR	0.000004	0.000004	0.000004	NI	NI	Neutralisation - Oil separation - Sedimentation - Equalisation	No information
DE039_w{1}	PFOS	INDIR	0.00001	0.00001	0.00001	NI	NI	Equalisation - Neutralisation	DIN 38407-42



PT105_w{1}	PFOS	INDIR	0.00001	0.00001	0.00001	NI	NI	No information	LCMS – Direct Injection (Liquid Chromatography coupled to Mass Spectrometry)
BE010_w{1}	PFOS	DIR	0.000002	0.00002	0.00004	NI	NI	Equalisation - Activated sludge process - Nitrification/ denitrification - Other	WAC/IV/A/025
BE014_w{1}	PFOS	DIR	0.0005	0.0005	0.0005	0.00	10	Equalisation - Activated sludge process - Nitrification/ denitrification	WAC/IV/A/025
SE118_w{1}	PFOS	INDIR	0.00003	0.00003	0.00003	NI	NI	Sedimentation - Equalisation - Neutralisation	No information
DE031_w{1}	PFOS; PFOA	INDIR	0			NI	NI	No information	Liquid Chromatograph Mass Spectrometry
DE034_w{1}	PFPeH	DIR	0.001	0.001	0.001	0.001	NI	Activated sludge process - Nitrification/ denitrification	DIN 38407-42
DE026_w{1}	POSF/PFOS	INDIR	0.00002	0.00002	0.00002	0.000004	NI	No information	DIN 38407-42
DE032_w{1}	Sum10PFT	DIR	0.0006	0.0008	0.0011	NI	NI	Equalisation - Neutralisation - Grit separators - Coagulation and flocculation - Sedimentation - Sand filtration - Nitrification/ denitrification - Activated sludge process	No information

DE032_w{1}	Sum2PFT	DIR	0.00004	0.00009	0.00015	NI	NI	Equalisation - Neutralisation - Grit separators - Coagulation and flocculation - Sedimentation - Sand filtration - Nitrification/ denitrification - Activated sludge process	No information
<p>NB:  DIR = Direct discharge;  ELV = Emission limit value;  IND = Indirect discharge;  NI = No information;  PFAS = Per- and polyfluoroalkyl substances;  PFBA = Perfluorobutanoic acid;  PFDA = Perfluorodecanoic acid;  PFHpA = Perfluoroheptanoic acid;  PFHxA = Perfluorohexanoic acid;  PFOA = Perfluorooctanoic acid;  PFOS = Perfluorooctanesulfonic acid;  PFPeA = Perfluoropentanoic acid.  Source: [ 50, TWG 2019.]</p>									

Table 3.7: Pesticides emissions to water

Emission point	Parameter	Type of discharge	Minimum concentration over 3 years (mg/l)	Average concentration over 3 years (mg/l)	Maximum concentration over 3 years (mg/l)	Maximum mass flow over 3 years (g/day)	ELV (mg/l)	Combination of techniques	Monitoring standard
IT097_w{1}	277 substances	DIR	0.00003	0.00003	0.00003	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation	APAT CNR IRSA 5060 Man 29 2003
IT092_w{1}	63 substances	DIR	0.00001	0.00001	0.00001	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Reverse osmosis	APAT CNR IRSA 5060 Man 29 2003
IT076_w{1}	Atrazine	INDIR	0.0005	0.0005	0.0005	NI	NI	Equalisation - Flotation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sedimentation - Membrane bioreactor	APAT CNR IRSA 5060 Man 29 2003
IT076_w{1}	Desetilatraine	INDIR	0.0001	0.0001	0.0001	NI	NI	Equalisation - Flotation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sedimentation - Membrane bioreactor	APAT CNR IRSA 5060 Man 29 2003
IT097_w{1}	Imidacloprid	DIR	0.00005	0.00005	0.00005	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation	APAT CNR IRSA 5060 Man 29 2003
IT092_w{1}	Imidacloprid	DIR	0.00017	0.00017	0.00017	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Reverse osmosis	APAT CNR IRSA 5060 Man 29 2003
UK128_w{1}	Organochlorine	INDIR	0	0.0002	0.0017	NI	0.025	Coagulation and flocculation - Neutralisation - Sedimentation	No information

UK129_w{1}	Organochlorine pesticides	INDIR	0.00004	0.0010	0.004	NI	0.013	Grit separators - Screening - Oil separation - Coagulation and flocculation - Ultrafiltration - Flotation	liquid/liquid extraction, GPC/SPE cleanup, GC-MS analysis
UK128_w{1}	Organophosphate	INDIR	0.0025	0.07	0.22	NI	1.7	Coagulation and flocculation - Neutralisation - Sedimentation	No information
UK129_w{1}	Organophosphorus pesticides	INDIR	0.00025	0.02018	0.09447	NI	0.985	Grit separators - Screening - Oil separation - Coagulation and flocculation - Ultrafiltration - Flotation	liquid/liquid extraction, GPC/SPE cleanup, GC-MS analysis
UK129_w{1}	Phenylurea pesticides	INDIR	0.05	0.05	0.05	NI	0.35	Grit separators - Screening - Oil separation - Coagulation and flocculation - Ultrafiltration - Flotation	liquid/liquid extraction, GPC/SPE cleanup, GC-MS analysis
IT076_w{1}	Simazina	INDIR	0.0007	0.0007	0.0007	NI	NI	Equalisation - Flotation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sedimentation - Membrane bioreactor	APAT CNR IRSA 5060 Man 29 2003
UK128_w{1}	Synthetic pyrethroid	INDIR	0	0.077	0.35	NI	0.537	Coagulation and flocculation - Neutralisation - Sedimentation	No information
UK129_w{1}	Synthetic pyrethroid pesticides	INDIR	0.0002	0.0083	0.0817	NI	0.114	Grit separators - Screening - Oil separation - Coagulation and flocculation - Ultrafiltration - Flotation	liquid/liquid extraction, GPC/SPE cleanup, GC-MS analysis

IT076_w{1}	Total pesticides	INDIR	0.0013	0.0013	0.0013	NI	NI	Equalisation - Flotation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sedimentation - Membrane bioreactor	APAT CNR IRSA 5060 Man 29 2003
<p>NB: DIR = Direct discharge; ELV = Emission limit value; IND = Indirect discharge; NI = No information. <i>Source: [ 50, TWG 2019 ]</i></p>									

Table 3.8: Brominated and flame retardants emissions to water

Point of discharge	Substance	Type of discharge	Minimum concentration over 3 years (mg/l)	Average concentration over 3 years (mg/l)	Maximum concentration over 3 years (mg/l)	Maximum mass flow over 3 years (g/day)	ELV (mg/l)	Combination of techniques	Monitoring standard
IT097_w {1}	13 substances	DIR	0.005	0.005	0.005	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation	EPA 527, EPA 8270, EPA 8321B, ISO 22032
DE031_w {1}	Brominated and chlorinated flame retardants	IND	0			NI	NI	No information	U.S. EPA 527+ U.S. EPA 8321 B
BE011_w {1}	DecaBDE	DIR	0.00018	0.00018	0.00018	0.126171	0.001	Equalisation - Neutralisation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sand filtration - Nanofiltration - Chemical oxidation (incl. Advanced oxidation)	WAC/IV/A/030
BE010_w {1}	DecaBDE	DIR	0.00016	0.000413333	0.00064	0.09792	0.02	Equalisation - Activated sludge process - Nitrification/denitrification - Other	No information
DE026_w {1}	DecaBDE	IND	0.0014	0.0014	0.0014	0.2296	NI	No information	No information
AT004_w {1}	DecaBDE	IND	0.00046	0.016992	0.052	8.684	NI	Neutralisation - Activated sludge process	EPA 8270
SE120_w {1}	DecaBDE	IND	10	10	10	NI	NI	Neutralisation - Oil separation - Sedimentation - Equalisation	No information

IT065_w {1}	Flame retardants: TRIS; TEPA; TCEP; PBB; BDBPT; BBP; PBDE; OctaBDE; DecaBDE; HBCDD; TSCPP; TCPP; TBB; TBPH; TPP; TMP; TBBPA; BBMP; TetraBDE; HexaBDE; HeptaBDE; NonaBDE	IND	0.00001	0.00001	0.00001	NI	NI	Other	No information
SE120_w {1}	HpBDE	IND	0.000001	0.000001	0.000001	NI	NI	Neutralisation - Oil separation - Sedimentation - Equalisation	No information
DE026_w {1}	NonaBDE	IND	0.00032	0.00032	0.00032	0.05248	NI	No information	No information
<p>NB: DecaBDE = Decabromodiphenyl ether; DIR = Direct discharge; ELV = Emission limit value; HpBDE = Heptabromodiphenyl ether; IND = Indirect discharge; NI = No information; NonaBDE = Nonabromodiphenyl ether. <i>Source: [ 50, TWG 2019 ]</i></p>									

Table 3.9: Surfactants emissions to water

Emission point	Parameter	Type of discharge	Minimum concentration over 3 years (mg/l)	Average concentration over 3 years (mg/l)	Maximum concentration over 3 years (mg/l)	Maximum mass flow over 3 years (g/day)	ELV (mg/l)	Combination of techniques	Monitoring standard
UK124_w{1}	Anionic and Non-ionic Detergents	DIR	0.06	0.33	1.20	1.47	5	Neutralisation - Coagulation and flocculation - Flotation - Other	OPPE / BAC Detergents
UK127_w{1}	Anionic detergent	INDIR	0.27	3.50	56.40	111.34	NI	Neutralisation	No information
IT096_w{1}	Anionic surfactants	DIR	0.10	0.13	0.20	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Other	APAT CNR IRSA 5170 Man 29 2003
IT097_w{1}	Anionic surfactants	DIR	0.10	0.21	0.30	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation	IRSA 5170 - APAT CNR IRSA 5170 5170 Man 29 2003
IT067_w{1}	Anionic surfactants	DIR	0.10	0.18	0.50	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation	APAT CNR IRSA 5170 Man 29 2003
IT092_w{1}	Anionic surfactants	DIR	0.07	0.39	0.50	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Reverse osmosis	ISO 16265:2009 - EPA 425.1
IT074_w{1}	Anionic surfactants	INDIR	0.50	0.52	0.60	NI	300	Other	APAT CNR IRSA 5170 MAN 29 2003
IT071_w{1}	Anionic surfactants	INDIR	0.50	0.65	0.90	16.05	300	No information	APAT CNR IRSA 5170 MAN 29 2003
IT072_w{1}	Anionic surfactants	INDIR	0.50	0.80	1.20	8.54	300	Other	APAT CNR IRSA 5170 MAN 29 2003



IT078_w{1}	Anionic surfactants	INDIR	0.80	1.10	1.50	NI	300	Other	APAT CNR IRSA 5170 MAN 29 2003
IT074_w{2}	Anionic surfactants	INDIR	0.50	0.85	1.60	NI	300	Other	APAT CNR IRSA 5170 MAN 29 2003
IT064_w{1}	Anionic surfactants	INDIR	0.50	1.04	1.70	NI	300	Other	APAT CNR IRSA 5170 MAN 29 2003
IT077_w{2}	Anionic surfactants	INDIR	0.37	0.79	1.80	22.29	300	No information	APAT IRSA CNR 5170 MAN 29 2003
IT068_w{1}	Anionic surfactants	INDIR	0.50	1.15	2.00	NI	300	Other	APAT CNR IRSA 5170 MAN 29 2003
IT069_w{1}	Anionic surfactants	INDIR	0.80	1.54	2.10	NI	300	Other	APAT CNR IRSA 5170 MAN 29 2003
IT090_w{1}	Anionic surfactants	INDIR	1.00	1.56	2.20	17.09	300	Other	APAT CNR IRSA 5170 MAN 29 2003
IT077_w{1}	Anionic surfactants	INDIR	0.47	0.93	2.60	30.80	300	No information	APAT IRSA CNR 5170 MAN 29 2003
IT089_w{1}	Anionic surfactants	INDIR	0.60	1.75	2.80	7.33	300	Other	APAT CNR IRSA 5170 MAN 29 2003
IT091_w{1}	Anionic surfactants	INDIR	0.80	1.41	2.87	NI	300	No information	APAT CNR IRSA 5170 MAN 29 2003
IT079_w{1}	Anionic surfactants	INDIR	0.50	1.57	3.40	28.02	300	Other	APAT CNR IRSA 5170 MAN 29 2003
IT087_w{1}	Anionic surfactants	INDIR	0.18	1.20	3.50	NI	NI	Equalisation	No information
IT061_w{1}	Anionic surfactants	INDIR	1.20	2.90	7.60	NI	300	Other	APAT CNR IRSA 5170 MAN 29 2003
IT071_w{2}	Anionic surfactants	INDIR	0.70	3.50	11.20	189.43	300	Other	APAT CNR IRSA 5170 MAN 29 2003

IT082_w{1}	Anionic surfactants (MBAS)	DIR				NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Adsorption (e.g. powdered/granular activated carbon, lignite coke, etc.) - Other	IRSA 5170:2003*
BE011_w{1}	Anionic surfactants (MBAS)	DIR	0.24	0.24	0.24	0.10	NI	Equalisation - Neutralisation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sand filtration - Nanofiltration - Chemical oxidation (incl. Advanced oxidation)	WAC/IV/A/22
IT073_w{1}	Anionic surfactants (MBAS)	INDIR	0.60	1.55	3.00	3.00	300	No technique used	ARPAT CNR IRSA 5170 MAN 29 2003
IT082_w{2}	Anionic surfactants (MBAS)	INDIR	0.10	1.18	3.34	NI	NI	Equalisation	APAT IRSA -CNR 5170 Man 29 2003
IT094_w{1}	Anionic surfactants (MBAS)	INDIR	0.71	2.04	4.50	NI	NI	Other	APAT IRSA 5180 Volume 2:2003
IT065_w{1}	Anionic surfactants (MBAS)	INDIR	0.20	4.18	8.30	11.05	NI	Other	MIESC01/09 rev 4/2011
IT063_w{1}	Anionic surfactants (MBAS)	INDIR	0.10	3.33	11.90	8.88	30	Equalisation	No information
IT070_w{1}	Anionic surfactants (MBAS)	INDIR	0.70	7.53	22.30	0.37	NI	No information	APAT-IRSA CNR 29-2003 5170
PT113_w{1}	Anionic surfactants (MBAS)	INDIR	3.00	10.00	23.00	36.23	50	Screening - Other	No information

IT067_w{1}	Cationic surfactants	DIR	0.10	0.15	0.20	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation	M008:2005 Rev.0
IT096_w{1}	Cationic surfactants	DIR	0.10	0.17	0.20	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Other	M008:2005 Rev.0
IT069_w{1}	Cationic surfactants	INDIR	0.20	0.30	0.50	NI	300	Other	INTERNAL METHOD
IT092_w{1}	Cationic surfactants	DIR	0.05	0.22	0.64	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Reverse osmosis	Bromophenol blue (Dr Lange LCK 331) - DIN 38409-20:1989
IT077_w{2}	Cationic surfactants	INDIR	0.20	0.48	0.70	8.67	300	No information	MARCONCINI SRL INTERNAL METHOD 22
IT064_w{1}	Cationic surfactants	INDIR	0.20	0.60	0.90	NI	300	Other	INTERNAL METHOD
IT091_w{1}	Cationic surfactants	INDIR	0.40	0.70	1.00	NI	300	No information	INTERNAL METHOD
IT072_w{1}	Cationic surfactants	INDIR	0.40	0.70	1.20	8.82	300	Other	INTERNAL METHOD
IT061_w{1}	Cationic surfactants	INDIR	0.30	0.68	1.30	NI	300	Other	INTERNAL METHOD
IT071_w{2}	Cationic surfactants	INDIR	0.40	0.93	1.50	23.36	300	Other	INTERNAL METHOD
IT078_w{1}	Cationic surfactants	INDIR	0.30	0.92	1.80	NI	300	Other	INTERNAL METHOD
IT071_w{1}	Cationic surfactants	INDIR	0.40	1.20	2.50	50.50	300	No information	INTERNAL METHOD
IT073_w{1}	Cationic surfactants	INDIR	0.90	1.43	2.90	2.90	300	No technique used	Metedo interno n°22

IT077_w{1}	Cationic surfactants	INDIR	0.20	1.18	2.90	17.95	300	No information	MARCONCINI SRL INTERNAL METHOD 22
IT068_w{1}	Cationic surfactants	INDIR	0.40	1.83	3.00	NI	300	Other	INTERNAL METHOD
IT097_w{1}	Cationic surfactants	DIR	0.10	0.42	3.00	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation	M.I. (d) - M008:2005 Rev.0
IT079_w{1}	Cationic surfactants	INDIR	0.20	1.50	3.90	31.38	300	Other	MARCONCINI SRL INTERNALMETHOD 22
IT074_w{2}	Cationic surfactants	INDIR	0.20	1.60	4.10	NI	300	Other	INTERNAL METHOD
IT089_w{1}	Cationic surfactants	INDIR	0.40	1.63	4.10	10.71	300	Other	MARCONCINI SRL INTERNALMETHOD 22
IT065_w{1}	Cationic surfactants	INDIR	0.20	2.48	5.00	5.17	NI	Other	MIESO06/11 REV 0
IT074_w{1}	Cationic surfactants	INDIR	0.20	2.85	5.00	NI	300	Other	INTERNAL METHOD
IT090_w{1}	Cationic surfactants	INDIR	1.00	2.63	5.50	33.84	300	Other	MARCONCINI SRL INTERNALMETHOD 22
IT087_w{1}	Cationic surfactants	INDIR	0.07	3.15	8.20	NI	NI	Equalisation	No information
IT082_w{2}	Cationic surfactants (CBAS)	INDIR	0.20	0.20	0.20	NI	NI	Equalisation	Kit colorimetrico Tensiattivi cationici

IT082_w{1}	Cationic surfactants (CTAB)	DIR					NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Adsorption (e.g. powdered/granular activated carbon, lignite coke, etc.) - Other	DIN 38409-20:1989*
IT070_w{1}	Cationic surfactants (CTAB)	INDIR	0.20	11.13	34.20	0.05	NI	NI	No information	DIN 38409
IT094_w{1}	Cationic surfactants (DBAS)	INDIR	0.50	0.50	0.50	NI	NI	NI	Other	Internal method
IT097_w{1}	Non-ionic surfactants	DIR	0.20	0.39	0.62	NI	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation	IRSA 5180 - APAT CNR IRSA 5180 Man 29 2003
IT096_w{1}	Non-ionic surfactants	DIR	0.40	0.67	1.10	NI	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Other	APAT CNR IRSA 5180 Man 29 2003
IT092_w{1}	Non-ionic surfactants	DIR	0.02	0.31	1.20	NI	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Reverse osmosis	UNI 10511/1:1996 + A1 2000 - Specroquant Merck 01787
IT067_w{1}	Non-ionic surfactants	DIR	0.10	0.75	1.70	NI	NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation	APAT CNR IRSA 5180 Man 29 2003
IT087_w{1}	Non-ionic surfactants	INDIR	0.62	4.31	11.60	NI	NI	NI	Equalisation	No information
IT077_w{2}	Non-ionic surfactants	INDIR	0.17	9.36	36.00	445.72	300	300	No information	UNI 10511-1:1996/A1:2000

IT072_w{1}	Non-ionic surfactants	INDIR	6.50	18.87	37.00	263.26	300	Other	UNI 10511-1:1996/A1:2000
IT078_w{1}	Non-ionic surfactants	INDIR	2.80	17.70	40.00	NI	300	Other	UNI 10511-1:1996/A1:2000
IT074_w{2}	Non-ionic surfactants	INDIR	19.40	33.33	42.00	NI	300	Other	UNI 10511-1:1996/A1:2000
IT068_w{1}	Non-ionic surfactants	INDIR	22.60	35.90	45.00	NI	300	Other	UNI 10511-1:1996/A1:2000
IT074_w{1}	Non-ionic surfactants	INDIR	13.00	28.78	46.00	NI	300	Other	UNI 10511-1:1996/A1:2000
IT061_w{1}	Non-ionic surfactants	INDIR	15.00	32.80	47.00	NI	300	Other	UNI 10511-1:1996/A1:2000
IT091_w{1}	Non-ionic surfactants	INDIR	20.00	31.67	51.00	NI	300	No information	UNI 10511-1:1996/A1:2000
IT071_w{2}	Non-ionic surfactants	INDIR	22.00	33.98	55.00	800.42	300	Other	UNI 10511-1:1996/A1:2000
IT071_w{1}	Non-ionic surfactants	INDIR	20.00	37.67	56.00	1019.54	300	No information	UNI 10511-1:1996/A1:2000
IT077_w{1}	Non-ionic surfactants	INDIR	0.14	31.19	57.00	675.17	300	No information	UNI 10511-1:1996/A1:2000
IT064_w{1}	Non-ionic surfactants	INDIR	34.80	49.63	60.00	NI	300	Other	UNI 10511-1:1996/A1:2000
IT089_w{1}	Non-ionic surfactants	INDIR	21.00	50.08	88.00	211.90	300	Other	UNI 10511-1:1996a1:2000
IT090_w{1}	Non-ionic surfactants	INDIR	18.00	68.00	110.00	975.04	300	Other	UNI 10511-1:1996a1:2000
IT079_w{1}	Non-ionic surfactants	INDIR	27.20	99.73	174.00	1162.05	300	Other	UNI 10511-1:1996a1:2000
IT069_w{1}	Non-ionic surfactants	INDIR	39.00	110.45	176.70	NI	300	Other	UNI 10511-1:1996/A1:2000

IT082_w{1}	Non-ionic surfactants (BIAS)	DIR				NI	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Adsorption (e.g. powdered/granular activated carbon, lignite coke, etc.) - Other	IRSA 5180:2003*
IT082_w{2}	Non-ionic surfactants (BIAS)	INDIR	0.20	10.50	31.10	NI	NI	Equalisation	APAT IRSA -CNR 5180 Man 29 2003 con variazione
IT065_w{1}	Non-ionic surfactants (BIAS)	INDIR	9.50	25.32	40.00	41.40	NI	Other	MIES001/10 rev3/2011
IT094_w{1}	Non-ionic surfactants (BIAS)	INDIR	14.90	27.47	45.20	NI	NI	Other	APAT IRSA 5180 Volume 2:2003
IT070_w{1}	Non-ionic surfactants (BIAS)	INDIR	1.80	18.88	89.10	1.10	NI	No information	APAT-IRSA CNR 29-2003 5180
IT063_w{1}	TAS non ionic	INDIR	1.00	10.62	26.10	37.20	30	Equalisation	No information
IT073_w{1}	TAS surfactants	INDIR	16.00	33.67	65.00	26.00	300	No technique used	UNI 10511-1:1996/A1:2000
IT097_w{1}	Total surfactants	DIR	0.10	0.59	1.13	NI	2	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation	No information - M008:2005 Rev.0
IT096_w{1}	Total surfactants	DIR	0.60	0.80	1.20	NI	2	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Other	M009:2013 Rev.0
IT075_w{1}	Total surfactants	INDIR	0.50	0.61	1.30	NI	4	Equalisation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sedimentation	No information

IT076_w{1}	Total surfactants	INDIR	0.34	0.50	1.48	NI	10	Equalisation - Flotation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sedimentation - Membrane bioreactor	No information
IT092_w{1}	Total surfactants	DIR	0.23	0.58	1.60	NI	2	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Reverse osmosis	Calculated
IT067_w{1}	Total surfactants	DIR	0.30	0.94	1.80	NI	2	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation	M009:2013 Rev.0
IT084_w{1}	Total surfactants	INDIR	0.10	0.88	1.80	NI	NI	Equalisation - Neutralisation - Grit separators - Screening - Coagulation and flocculation - Sedimentation	APAT CNR IRSA 5170 + APAT CNR IRSA 5180 Man. 29 2003 + MPI
IT060_w{1}	Total surfactants	INDIR	6.80	10.89	14.90	NI	75	No information	UNI 10511-1:1996/A1:2000 + APAT CNR IRSE 5170Man 29 2005
IT087_w{1}	Total surfactants	INDIR	2.70	7.97	17.10	NI	20.72	Equalisation	No information
IT082_w{2}	Total surfactants	INDIR	0.20	11.61	34.44	NI	NI	Equalisation	Calcolo



IT070_w{1}	Total surfactants	INDIR	2.50	37.45	145.60	1.47	300	No information	SUMMATION MBAS+BIAS+CTAB
IT085_w{1}	Total surfactants	INDIR	80.00	88.30	157.00	53.38	NI	Equalisation	No information
<p>NB:  BIAS = Bismuth active substance method;  CTAB = Cetyltrimethylammonium bromide method;  DBAS = Disulphine blue active substance method;  DIR = Direct discharge;  ELV = Emission limit value;  IND = Indirect discharge;  MBAS = Methylene blue active substances assay;  NI = No information;  TAS = Test aimed at determining the content of non-ionic surfactants.  Source: [ 50, TWG 2019 ]</p>									

Table 3.10: Toxicity of waste waters (before discharge)

Point of discharge	Toxicity test	Monitoring frequency	Type of sampling	Unit	Individual measurements (unless mentioned otherwise)	ELV	Standard monitoring method	Additional information
BE009 w{2}	Daphnia magna	No information	Grab/spot sample	%	10		OECD202	One time measurement (2012) Daphnia Magna;
FR131 w{1}	Daphnia magna	4 times per year	24-hour flow-proportional composite sample	No information	Report 12 measurements, all equal to 0	none	NF EN ISO 6341	Measurements carried out for water agencies to calculate a fee
FR134 w{1}	Daphnia magna	Twice per year	Grab/spot sample	No information	Report 6 measurements, all equal to 0	not detected	NF EN ISO 6341	
IT096 w{1}	Daphnia magna	Yearly	Grab/spot sample	%	Report 3 measurements, all equal to 0	50	APAT CNR IRSA 8020B Man 29 2003	Value referred to sampling period
IT067 w{1}	Daphnia magna	No information	Grab/spot sample	%-24h	3	50	APAT CNR IRSA 8020B Man 29 2003	Value referred to sampling period - test n Daphnea Magna
IT092 w{1}	Daphnia magna	Other (see in "additional information")	Grab/spot sample	%	0	50	APAT CNR IRSA 8020B Man 29 2003	Monitoring frequency: spot Value referred to sampling period - Test on Daphnia
IT097 w{1}	Daphnia magna	Yearly	Grab/spot sample	%	0-0-3	50	APAT CNR IRSA 8020B Man 29 2003	value referred to sampling period - Test on Daphnea Magna
IT067 w{1}	Vibrio fischeri	No information	Grab/spot sample	%I 30'	11	50	UNI EN ISO 11348-3:2009	Value referred to sampling period - test on Vibrio fischeri
IT092 w{1}	Vibrio fischeri	Other (see in "additional information")	Grab/spot sample	%	3	50	UNI EN ISO 11348-1:2009	Monitoring frequency: spot Value referred to sampling period - Test on Vibrio Fischeri
SE119 w{1}	Vibrio fischeri	Other (see in "additional information")	24-hour flow-proportional composite sample 24-hour flow-proportional composite sample	%	4.2 ; 5.5	1,3 % (15 min exp) 1,3 % (15 min exp)	SS-EN ISO 11348-3:2008 (mod);;SS-EN ISO 11348-3:2008 (mod)	Microtox Ec50 (15 min exp). Once every second year (flow-proportional over one week)

IT097 w{1}	Vibrio fischeri	Yearly	Grab/spot sample	%	11-7-14	50	UNI EN ISO 11348-3:2009	Value referred to sampling period - Test on vibrio fischeri
BE009 w{2}	Vibrio fischeri	No information	Grab/spot sample	%	8.9		ISO 11348-3:1996E	One time measurement 2012 (Virbrio Fischeri)
BE007 w{1}	Vibrio fischeri	Yearly	Grab/spot sample; Not applicable	LC50 (96h)	0.431		WAC/V/B/004	
ES058 w{1}	Vibrio fischeri	4 times per year	Grab/spot sample	Equitox	2.45-0-0			
BE011 w{1}	Fish	No information	Grab/spot sample	OECD203	11.1-11-42-41.7	50	OECD203	2 measurements < 10%, expressed in %effect
BE009 w{2}	Fish	No information	Grab/spot sample	%	45-12.5-78.4-0		OECD203	4 measurement (Oncorhynchus Mykiss) to determine if further actions were needed
DE025 w{1}	Fish eggs	4 times per year	Grab/spot sample	GEI	Report 11 measurements: six times 1, five times 2	2	DIN EN ISO 15088	(Giftigkeit gegenüber Fischeiern ) Toxicity to fish-spawn
IT097 w{1}	Algae	Yearly	Grab/spot sample	%	0-16-31	50	UNI EN ISO 8692:2005 rev.2012	Value referred to sampling period - Test on Pseudokirchneriella Subcapitata
IT067 w{1}	Algae	No information	Grab/spot sample	%-72h	53	50	UNI EN ISO 8692:2012	Value referred to sampling period - test on Pseudokirchneriella Subcapitata
IT092 w{1}	Algae	Other (see in "additional information")	Grab/spot sample	%	26	50	UNI EN ISO 8692:2012	Monitoring frequency: spot Value referred to sampling period - Test on Pseudokirchneriella subcapitata
BE009 w{2}	Algae	No information	Grab/spot sample	%	7.9		OECD201	One time measurement (2012) P. Subcapitata;
SE120 w{1}	Activated sludge (nitr. inhib.)	Other (see in "additional information")	Flow-proportional composite sample	%	5; 14		EN ISO 9509:2006;;EN ISO 9509:2006	One week every two years, See Appendix 2, <10; See Appendix 1

SE119 w{1}	Activated sludge (nitr. inhib.)	Other (see in "additional information")	24-hour flow- proportional composite sample 24-hour flow- proportional composite sample	%	100; 5	No inhibition;;No inhibition	EN ISO 9509:2006;;EN ISO 9509:2006	Once every second year (flow-proportional over one week). 40 vol% sample (%)
SE119 w{1}	Activated sludge inhibition	Other (see in "additional information")	24-hour flow- proportional composite sample 24-hour flow- proportional composite sample	%	35; 8	No inhibition;;No inhibition	EN 8192- 1995B;;EN 8192- 1995B	Once every second year (flow-proportional over one week). 40 vol% sample, 180 minutes)
IT063 w{1}	No information	Yearly	Other or more than one type	No information	17-3			Average sample of 3 hours
Source: [ 50, TWG 2019 ]								

Table 3.11: Colour emissions to water

Point of discharge	Type of discharge	Unit	Measurements reported in 2016	Measurements reported in 2017	Measurements reported in 2018	ELV	Monitoring standard	Combination of techniques
BE011_w{1}	DIR	No information		0.8				Equalisation - Neutralisation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sand filtration - Nanofiltration - Chemical oxidation (incl. Advanced oxidation)
DE032_w{1}	DIR	[m-1] (SAC:436nm - 525 - 620nm)	M1: <0.5/1.0/1.3 - M2: 0.61/1.0/1.7 - M3: <0.50/0.69/1.1 - M4: <0.50/<0.50/1.0 - M5: <0.50/<0.50/<0.50 - M6: <0.50/1.5/1.6	M1: <0.50/1.1/2.1 - M2: <0.50/<0.50/1.1 - M3: <0.50/<0.50/1.5 - M4: <0.50/0.92/2.2 - M5: <0.50/0.96/2.2 - M6: <0.50/1.2/2.1 - M7: <0.50/1.2/3.3 - M8: <0.50/0.87/1.7	M1: 0.72/1.4/1.9 - M2: <0.50/<0.50/0.91 - M3: 0.63/1.3/2.2 - M4: <0.50/<0.50/1.1 - M5: <0.50/1.1/2.2 - M6: 0.7/1.5/2.5 - M7: <0.50/0.79/2.0 - M8: 0.53/1.1/2.0			Equalisation - Neutralisation - Grit separators - Coagulation and flocculation - Sedimentation - Sand filtration - Nitrification/denitrification - Activated sludge process

IT092_w{1}	DIR	No information	N.P. 1:10 (not perceptible with dilution 1:10) - N.P. 1:20 (not perceptible with dilution 1:20)	N.P. 1:10 (not perceptible with dilution 1:10) - N.P. 1:20 (not perceptible with dilution 1:20)	N.P. 1:10 (not perceptible with dilution 1:10) - N.P. 1:20 (not perceptible with dilution 1:20)		APAT CNR IRSA 2020A Man 29 2003	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Reverse osmosis
IT096_w{1}	DIR	No information	N.P. 1:20 (not perceptible with dilution 1:20)	N.P. 1:20 (not perceptible with dilution 1:20)	N.P. 1:20 (not perceptible with dilution 1:20)	N.P. 1:20: not perceptible with dilution 1:20	APAT CNR IRSA 2020A Man 29 2003	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Other
IT097_w{1}	DIR	No information	N.P. 1:20 (not perceptible with dilution 1:20)	N.P. 1:20 (not perceptible with dilution 1:20)	N.P. 1:20 (not perceptible with dilution 1:20)		APAT CNR IRSA 2020A Man 29 2003	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation
PT110_w{1}	DIR	mg/l Pt	M1: 8.4 - M2: 4.6 - M3: 5.6 - M4: 6.8 - M5: 4.8 - M6: 6.1 - M7: 5.1 - M8: 5.4 - M9: 6.1 - M10: 5.6 - M11: 5.9 - M12: 2	M1: 2 - M2: 6.3 - M3: 6.1 - M4: 6.2 - M5: 6.4 - M6: 5.4 - M7: 5.7 - M8: 5.4 - M9: 5.8 - M10: 6.4 - M11: 6.4 - M12: 5.2	M1: 5.4 - M2: 5.6 - M3: 5.6 - M4: 6 - M5: 5.3 - M6: 6.3 - M7: 32 - M8: 24 - M9: 7 - M10: 5 - M11: 5.2 - M12: 5	N.P. 1:20: not perceptible with dilution 1:20		Equalisation - Grit separators - Screening - Coagulation and flocculation - Sedimentation - Activated sludge process - Other
UK124_w{1}	DIR	absorbance units nm				0.1	SCA blue book 103 ISBN 0117519533 Absorbance Scan - determined by scanning UV/visible spectrometry	Neutralisation - Coagulation and flocculation - Flotation - Other
AT001_w{1}	INDIR	[m-1] (SAC:436nm - 525 - 620nm)			M1: 148/129/105			No technique used

AT002_w{1}	INDIR	[m-1] (SAC:436nm - 525 - 620nm)	M1: 43/43/28 - M2: 27/27/19 - M3: 49/44/28 - M4: 24/25/13 - M6: 23/20/22 - M7: 33/30/18 - M8: 26/23/17 - M9: 28/23/25 - M10: 33/34/38 - M11: 33/28/29 - M12: 48/47/43	M1: 24/22/19		28/24/20	EN ISO 7887	Screening - Neutralisation
AT004_w{1}	INDIR	[m-1] (SAC:436nm - 525 - 620nm)	M1: 8.2/5/3.2; M2: 8.1/6.2/4.4	M1: 2.1/1.6/0.81; M2: 10/5.5/3.8	M1: 8.8/6.1/4.6 - M2: 4.5/2.8/3.5	28/24/20	EN ISO 7887	Neutralisation
AT005_w{1}	INDIR	[m-1] (SAC:436nm - 525 - 620nm)	M1: 32/30/35 - M2: 32/29/33	M1: 46/15/8 - M2: 39/52/61	M1: 35/32/36 - M2: 33/21/16	20/28/24	EN ISO 7887	Neutralisation
AT006_w{1}	INDIR	[m-1] (SAC:436nm - 525 - 620nm)	M1: 3.4/2/1.2	M1: 3.6/1.7/1.3	M1: 2.4/0.8/0.5	28/24/20	EN ISO 7887	Flotation
BE013_w{1}	INDIR	Pt-Co scale	M1: 16	M1: 56	M1: 187		MEIN001	Distillation/rectification - Equalisation - Neutralisation
IT065_w{1}	INDIR	[m-1] (SAC:436nm - 525 - 620nm)			M1: 0.01 - M2: 0.01		EN ISO 7887	Other
IT076_w{1}	INDIR	No information			N.P. 1:20: not perceptible with dilution 1:20	N.P. 1:20: not perceptible with dilution 1:20	APAT CNR IRSA 2020A Man 29 2003	Equalisation - Flotation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sedimentation - Membrane bioreactor
IT083_w{1}	INDIR	No information	N.P. 1:40 (not perceptible with dilution 1:40)	N.P. 1:40 (not perceptible with dilution 1:40)	N.P. 1:40 (not perceptible with dilution 1:40)	0.1	APAT CNR IRSA 2020A Man 29 2003	Other

IT085_w{1}	INDIR	No information	N.P. 1:100 (not perceptible with dilution 1:100)	N.P. 1:80 (not perceptible with dilution 1:80)	N.P. 1:100 (not perceptible with dilution 1:100) - N.P. 1:40 (not perceptible with dilution 1:40)		APAT CNR IRSA 2020A Man 29 2003	Equalisation
IT087_w{1}	INDIR	No information	M1: 50 - M2: 20		M1: 20 - M2: 39 - M3: 9 - M4: 40	80		Equalisation
<p>N.B. In the columns for measurements, 'Mx' refers to the number of measurements reported for each year.  Source: [ 50, TWG 2019 ]</p>								

## 3.5 Emissions to air

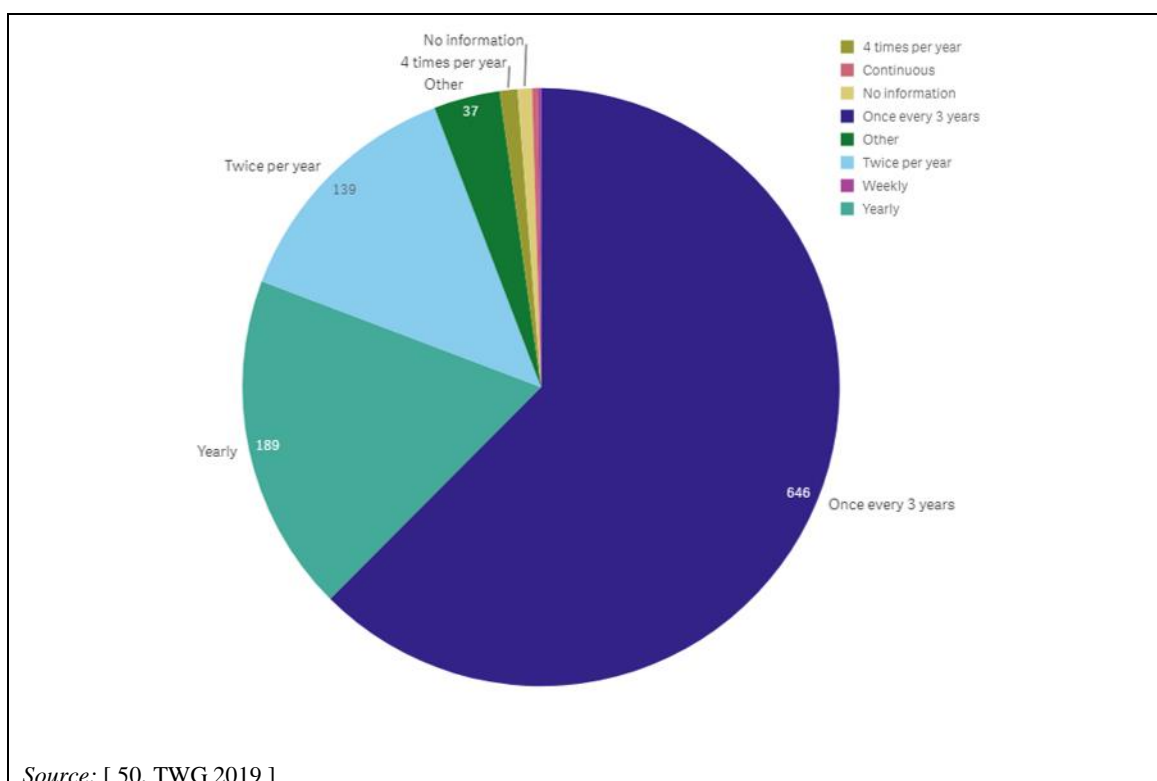
### 3.5.1 Overview

The 108 questionnaires submitted represent a total of 568 monitored points of emissions to air. Most of the plants reported between 1 and 10 monitored emission points to air. A total of 12 plants reported more than 10 monitored emission points, up to a maximum of 39 for Plant ES058. On the other hand, it should be noted that 29 plants did not report any monitored point of emissions to air. The overview is given in Figure 3.52.

Information about pollutant concentrations in emissions to air was not reported for all emission points but only for 482 emission points. As more than one pollutant may be monitored at a given emission point, this represents a total of 1 027 data sets. A data set corresponds to a combination of individual measurements for one given parameter at one given emission point.

For 62.5 % of the 1 027 data sets, the reported monitoring frequency is once every 3 years (which means in practice that the monitoring data sets concerned consist of only one value). The other main monitoring frequencies are once a year (about 18 %) and twice a year (about 13 %). More frequent monitoring represents a very small minority (see Figure 3.50 below).

For 8 data sets, corresponding to 5 emission points, no information was reported on the monitoring frequency.



**Figure 3.50: Distribution of the monitoring frequency (number of data sets concerned)**

Concerning the monitoring frequency reported as ‘other’, more details are given in Table 3.12 below.



Table 3.12: Other monitoring frequencies reported for emissions to air

Emission point	Parameter	Monitoring frequency
AT003_{1}	Dust	Once every 5 years
AT003_{1}	TVOC	Once every 5 years
AT003_{2}	TVOC	Once every 5 years
BE007_{1}	Dust	Measurements done in 2013
BE007_{1}	NO <sub>x</sub>	Measurements done in 2013
BE007_{1}	CO	Measurements done in 2013
BE007_{1}	TVOC	Measurements done in 2013
BE009_{1}	NO <sub>x</sub>	Measurements done in 2014
BE009_{1}	CO	Measurements done in 2014
BE009_{1}	TVOC	Measurements done in 2014
BE009_{2}	SO <sub>x</sub>	Measurements done in 2012
BE009_{2}	NO <sub>x</sub>	Measurements done in 2012
BE009_{2}	CO	Measurements done in 2012
BE009_{2}	TVOC	Measurements done in 2012
BE009_{3}	NO <sub>x</sub>	Measurements done in 2012
BE009_{3}	CO	Measurements done in 2012
BE009_{3}	TVOC	Measurements done in 2012
BE009_{4}	SO <sub>x</sub>	Measurements done in 2012
BE009_{4}	NO <sub>x</sub>	Measurements done in 2012
BE009_{4}	CO	Measurements done in 2012
BE009_{4}	TVOC	Measurements done in 2012
BE010_{1}	NO <sub>x</sub>	One measurement in 2016 for all parameters
BE010_{1}	CO	One measurement in 2016 for all parameters
BE010_{1}	TVOC	One measurement in 2016 for all parameters
BE010_{1}	NH <sub>3</sub>	One measurement in 2016 for all parameters
BE010_{2}	NO <sub>x</sub>	One measurement in 2016 for all parameters
BE010_{2}	CO	One measurement in 2016 for all parameters
BE010_{2}	TVOC	One measurement in 2016 for all parameters
BE010_{2}	NH <sub>3</sub>	One measurement in 2016 for all parameters
BE010_{3}	NO <sub>x</sub>	One measurement in 2016 for all parameters
BE010_{3}	CO	One measurement in 2016 for all parameters
BE010_{3}	TVOC	One measurement in 2016 for all parameters
DE023_{4}	NO <sub>x</sub>	No information
DE023_{4}	CO	No information
DE047_{5}	NO <sub>x</sub>	Every 2 years
DE047_{5}	CO	Every 2 years
SE120_{1}	SO <sub>x</sub>	No information
<i>Source: [ 50, TWG 2019 ]</i>		

Finally, in addition to the 1 027 data sets with periodic monitoring, continuous monitoring was reported for 1 data set (BE013\_{01}), concerning emissions of ammonia to air.

Concerning abatement techniques, no information was reported for 388 emission points (63 % of the emission points) and for 83 emission points (15 % of the emission points) it was reported that no techniques were used.

The use of abatement techniques was reported for 97 emission points (17 % of the total number of emission points). The distribution of abatement techniques is shown in Figure 3.51 below.

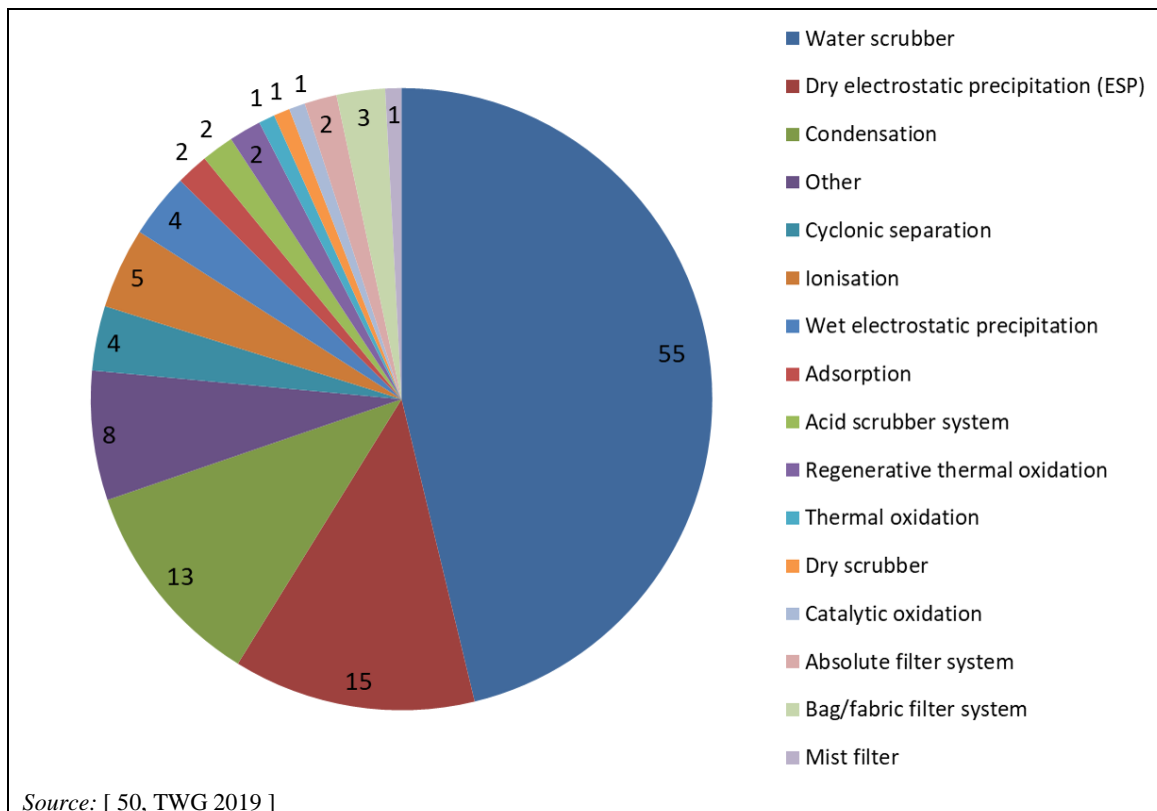


Figure 3.51: Number of emission points equipped with a given abatement technique

### 3.5.2 Presentation of the data

In the following sections, each graph presents the minimum, average and maximum emission concentrations over the 3-year reference period as well as the emission limit value (ELV), the maximum emission mass flow over the 3-year reference period and the abatement techniques applied at the emission points.

For a total of 133 emission points, the concentration values were reported as corrected to a reference O<sub>2</sub> level. In order to have all the data referenced under the same conditions, the concentration values have been recalculated to represent them without the correction to a reference O<sub>2</sub> level. Out of 133 emission points, 38 did not report the measured O<sub>2</sub> level, so those emission points have not been included in the presentation of the data. Table 3.13 shows those emission points that have not been included in the graphs.

**Table 3.13: Emission points that reported the concentration corrected to a reference O<sub>2</sub> level but that did not report the measured O<sub>2</sub> level**

Emission point	Parameter
CZ015_{5}	Dust, TVOC, CO, NO <sub>x</sub>
CZ016_{1}	CO, NO <sub>x</sub>
CZ016_{2}	NO <sub>x</sub>
CZ016_{3}	CO, NO <sub>x</sub>
CZ016_{4}	CO, NO <sub>x</sub>
CZ016_{5}	CO, NO <sub>x</sub>
CZ017_{2}	CO, NO <sub>x</sub>
CZ017_{3}	CO, NO <sub>x</sub>
CZ017_{4}	CO, NO <sub>x</sub>
CZ019_{1}	CO, NO <sub>x</sub>
CZ019_{10}	CO, NO <sub>x</sub>
CZ019_{2}	CO, NO <sub>x</sub>
CZ019_{3}	CO, NO <sub>x</sub>
CZ019_{4}	CO, NO <sub>x</sub>
CZ019_{5}	CO, NO <sub>x</sub>
CZ019_{6}	CO, NO <sub>x</sub>
CZ019_{7}	CO, NO <sub>x</sub>
CZ019_{8}	CO, NO <sub>x</sub>
CZ019_{9}	CO, NO <sub>x</sub>
FR131_{1}	TVOC, NO <sub>x</sub> , SO <sub>2</sub>
FR131_{2}	Dust, TVOC, NO <sub>x</sub> , SO <sub>2</sub>
FR131_{3}	TVOC, NO <sub>x</sub> , SO <sub>2</sub>
IT063_{10}	CO, NO <sub>x</sub>
IT063_{11}	CO, NO <sub>x</sub>
IT063_{12}	CO, NO <sub>x</sub>
IT076_{1}	Dust, CO, NO <sub>x</sub>
IT076_{2}	Dust, CO, NO <sub>x</sub>
IT076_{3}	Dust, CO, NO <sub>x</sub>
IT076_{4}	Dust, CO, NO <sub>x</sub>
IT083_{10}	CO, NO <sub>x</sub>
IT083_{13}	CO, NO <sub>x</sub>
IT083_{9}	CO, NO <sub>x</sub>
IT084_{5}	NO <sub>x</sub>
IT084_{6}	NO <sub>x</sub>
IT085_{1}	CO, NO <sub>x</sub>
IT085_{2}	CO, NO <sub>x</sub>
IT137_{6}	TVOC, CO, NO <sub>x</sub>
PT109_{5}	TVOC, NO <sub>x</sub>
<i>Source: [50, TWG 2019]</i>	

Finally, the data are shown in ascending order of maximum emission concentration.

As mentioned above, the data collection shows that 83 % of the emission points to air did not report the use of abatement techniques. Due to the large number of emission points without abatement techniques, an additional type of figure (scatter plot) has been prepared for the parameters TVOC (Figure 3.59, Figure 3.60 and Figure 3.61), formaldehyde (Figure 3.64) and dust (Figure 3.69, Figure 3.70 and Figure 3.71) to show, in a condensed form, the correlation between the concentration and the mass flow. The horizontal axis shows the maximum

concentration reported for each emission point and the vertical axis indicates the maximum mass flow reported.

### 3.5.3 Organic compounds

The emissions of total volatile organic carbon (TVOC) are shown in Figure 3.53, to Figure 3.58. The concentrations range from 0.2 mg/Nm<sup>3</sup> to 340 mg/Nm<sup>3</sup> and the mass flows from 0.04 g/h to 3 385 g/h, from each emission point. According to the data collection, the main processes linked to emissions to air of organic compounds are thermal treatment associated with wet processing, coating and laminating, printing and singeing.

Abatement techniques are used in a minority of cases (for 59 emission points out of 373 for which TVOC emissions were reported). In those cases, the techniques used are mainly wet scrubbing (see description in Section 4.1.8.2) and condensation (see Section 4.1.8.4). Thermal oxidation (see Section 4.1.8.5) is also used in three cases, ionisation in one case and adsorption (see Section 4.1.8.11) in one case.

When the emission points are equipped with those techniques, the maximal concentration ranges from 0.8 mg/Nm<sup>3</sup> to 119 mg/Nm<sup>3</sup>. They are shown in Figure 3.53.

TVOC emissions to air without abatement techniques are shown in Figure 3.54 to Figure 3.58. The maximal concentration ranges from 0.2 mg/Nm<sup>3</sup> to 340 mg/Nm<sup>3</sup>.

Figure 3.59 shows TVOC emission points to air without abatement techniques and with a maximum mass flow below 200 g/h from singeing and thermofixation or heat-setting as well as from coating, lamination, printing, dyeing and finishing (including thermal treatments associated with these processes). The majority of the concentration values reported are below 40 mg/Nm<sup>3</sup>; only 6 out of 196 of emission points with a maximum mass flow below 200 g/h have a maximum concentration over 40 mg/Nm<sup>3</sup>.

In the case of emission points to air without abatement techniques and with a maximum mass flow above 200 g/h from singeing and thermofixation or heat-setting as well as from coating, lamination, printing, dyeing and finishing (including thermal treatments associated with these processes), Figure 3.60 shows that around 50 % of the emission points reported a maximum concentration below 40 mg/Nm<sup>3</sup> and the other 50 % above 40 mg/Nm<sup>3</sup>.

For processes other than singeing and thermofixation or heat-setting as well as from coating, lamination, printing, dyeing and finishing (including thermal treatments associated with these processes), Figure 3.61 shows that the majority of the emission points reported a maximum TVOC concentration value below 25 mg/Nm<sup>3</sup>.

The information gathered via questionnaires shows that 199 out of 373 emission points reported TVOC concentration values in accordance with the standard EN 12619, 26 emission points reported the concentration values in accordance with the standard EPA 25A, 23 reported EN 13649, and 70 did not report information about the monitoring standard used.

In addition to TVOC, very limited data were reported for emissions to air of specific organic compounds, namely tetrachloroethylene (PER) (two data sets, associated with dry cleaning and with thermofixation after solvent scouring) and styrene (one data set associated with coating).

No information at all was reported on the other compounds considered as KEIs for the review of the BREF (see Section 1.1), namely N-methyl-2-pyrrolidone, N-ethyl-2-pyrrolidone, dimethylformamide, toluene, acrylonitrile, acrylamide and 1,3-butadiene.

### 3.5.4 Formaldehyde

The emissions of formaldehyde are shown in Figure 3.62 for the emission points equipped with abatement techniques, and in Figure 3.63, for the emission points without abatement techniques.

The concentrations range from 0.02 mg/Nm<sup>3</sup> to 20 mg/Nm<sup>3</sup> and the mass flows vary from 0.14 g/h to 328 g/h. According to the information reported, the processes associated with emissions of formaldehyde to air are coating and laminating, thermal treatment associated with finishing and printing, singeing and printing. Highest concentration values are typically reported for finishing processes with easy-care agents, water-/oil-/soil-repellents and/or flame retardants (e.g. Plants DE025 and DE026) [ 56, EURATEX 2021 ].

Out of the 67 emission points for which emissions of formaldehyde were reported, 21 are equipped with abatement techniques, which are the same as for TVOC (see Section 3.5.4). In those cases, the maximal concentration ranges from 0.02 mg/Nm<sup>3</sup> to 15 mg/Nm<sup>3</sup>.

Figure 3.64 shows the correlation between maximum concentration and maximum mass flow of formaldehyde emission points to air without abatement techniques. The majority of the emission points are below 50 g/h and with a maximum concentration in the range of 0.1 mg/Nm<sup>3</sup> and up to 6 mg/Nm<sup>3</sup>. A total of 8 out of 46 emission points reported a maximum mass flow over 50 g/h, with a maximum concentration in the range of 5.8 mg/Nm<sup>3</sup> to 20 mg/Nm<sup>3</sup>.

Regarding monitoring standards, at the time of publishing this document, no EN or ISO standards for formaldehyde measurements from stack emissions were available. Examples of national standards that are used are given below:

- In Germany, sampling and testing is carried out according to VDI 3862 / Part 2: Gaseous emission measurement - Measurement of aliphatic and aromatic aldehydes and ketones by DNPH method / Impinger method [ 70, UBA 2020 ], [ 71, EURATEX 2020 ].
- In Flanders the VITO standard 'LUC\_III\_004\_Formaldehyde' is being used [ 71, EURATEX 2020 ].
- In France, the French standard 'NF X 43-264: Air quality - Air in workplaces - Sampling and determination of aldehydes by pumping on a support impregnated with DNPH and determination by HPLC liquid chromatography.' can be used [ 72, Viers S. 2021 ].

Two different sampling methods have been reported in the data collection, impinging solution and adsorption tubes. The concentration range for formaldehyde is from 0.3 mg/Nm<sup>3</sup> to 14.83 mg/Nm<sup>3</sup> when sampling with impinging solutions (e.g. US EPA M316, VDI 3862 Blatt 2), and when it adsorption tubes (e.g. ASTM D 5197, CEN/TS 13649:2014) are used the concentration range is from 0.1 mg/Nm<sup>3</sup> to 1.25 mg/Nm<sup>3</sup>.

Formaldehyde shows a strong tendency to dissolve in water droplets and to bind to particles. In the case of waste gases containing aerosols or dust, the sampling method (i.e. isokinetic or non-isokinetic) therefore significantly influences the measurement result. Moreover, other factors may also come into play such as filter/probe heating and probe washing [ 73, Brinkmann et al. 2018 ].

The interference of these two measurements has been reported in other BREFs (e.g. Wood-based Panels Production). However, it was not confirmed in the TXT data collection that when there are high dust concentrations the sampling method selected is isokinetic, as no information was reported about the standard method used for high dust concentrations, e.g. FR135\_1, FR135\_2 or IT083\_3 (see Table 3.14).

Table 3.14 shows the 13 out of 67 emission points that reported concentration values for both formaldehyde and dust.

Table 3.14: Formaldehyde and dust concentration values

Emission point	Associated processes	Formaldehyde monitoring standard	Formaldehyde minimum concentration over 3 years (mg/Nm <sup>3</sup> )	Formaldehyde average concentration over 3 years (mg/Nm <sup>3</sup> )	Formaldehyde maximum concentration over 3 years (mg/Nm <sup>3</sup> )	Dust maximum concentration over 3 years (mg/Nm <sup>3</sup> )
IT083_{1}	Functional finishing	ASTM D 5197	0.10	0.10	0.10	1.28
IT083_{2}	Functional finishing	ASTM D 5197	0.10	0.10	0.10	2
IT083_{14}	Functional finishing	ASTM D 5197	0.10	0.10	0.10	8.08
IT083_{16}	Functional finishing	ASTM D 5197	0.10	0.10	0.10	3.85
IT083_{4}	Functional finishing	ASTM D 5197	0.10	0.11	0.14	1
IT083_{5}	Functional finishing	ASTM D 5197	0.10	0.16	0.28	2.22
AT006_{2}	Functional finishing - Thermal treatment (e.g drying, thermofixation, curing)	No information	0.20	0.23	0.30	1.4
IT063_{4}	Printing	No information	0.06	0.30	0.74	1.1
IT063_{1}	Thermal treatment (e.g drying, thermofixation, curing) - Functional finishing	No information	0.06	0.31	0.80	3.9
AT006_{1}	Functional finishing - Thermal treatment (e.g drying, thermofixation, curing)	VDI 3484/1	1.00	1.08	1.20	2.2
IT083_{3}	Functional finishing	ASTM D 5197	0.10	0.48	1.25	3.75
FR135_{2}	Thermal treatment (e.g drying, thermofixation, curing)	No information	0.65	2.87	6.11	8.55
FR135_{1}	Thermal treatment (e.g drying, thermofixation, curing)	No information	0.27	4.69	14.30	24.1

Source: [ 50, TWG 2019 ]

### **3.5.5 Oil mist**

The emissions of oil mist are shown in Figure 3.65. The concentrations range from 0.2 mg/Nm<sup>3</sup> to 62.1 mg/Nm<sup>3</sup> and the mass flows range from 0.5 g/h to 932 g/h. According to the data collection, this parameter is monitored in Italy and the UK. The emission sources are reported to be thermal treatment associated with finishing and wool carbonising. Method MEL 14, a modified version of US EPA ‘*Method 0010: Modified method 5 sampling train*’, was reported to be used in Denmark for monitoring oil mist emissions [74, Danish EPA 2018].

### **3.5.6 Dust**

Dust emissions were reported for 180 emission points and are shown in Figure 3.66, Figure 3.67 and Figure 3.68. The concentrations range from 0.1 mg/Nm<sup>3</sup> to 112 mg/Nm<sup>3</sup> and the emission mass flows range from 0.03 g/h to 1 400 g/h.

Dust emissions were reported mainly for singeing, fabric production and thermal treatment (e.g. drying, curing and heat fixation).

Concerning singeing, as mentioned in Section 2.6.1.1.1, the fabric is combed under aspiration before singeing to eliminate the remaining dust and fibre but dust is nevertheless emitted to air.

A source of dust emissions associated with thermal treatment is possibly the textile material itself, as it is connected to direct heating (i.e. the flue-gas is in contact with the textile).

For example, emission points PT109\_{30}, PT109\_{31}, FR135\_{1}, PT109\_{30}, PT114\_{34} and PT109\_{29} reported a dust concentration range from 17.6 mg/Nm<sup>3</sup> to 45.9 mg/Nm<sup>3</sup> and a mass flow range from 14.4 g/h to 411 g/h, for processes associated with thermal treatment and using natural gas as a heating source.

Techniques applied to reduce emissions of dust to air have been reported for 27 emission points. They are generally wet scrubber (see description in Section 4.1.8.2), electrostatic precipitator (see Section 4.1.8.3) and cyclone (see Section 4.1.8.7). In those cases, the maximum concentration ranges from 0.1 mg/Nm<sup>3</sup> to 18 mg/Nm<sup>3</sup>. They are shown in Figure 3.66.

Absolute filters (see Section 4.1.8.8) and fabric filters (see Section 4.1.8.9) were also reported in four cases and the emission points equipped with these are connected to the weighing, handling or packaging of material.

Finally, other techniques such as self-cleaning filters or lint extraction systems were also reported to be used.

Dust emissions to air without abatement techniques are shown in Figure 3.67 and Figure 3.68. The maximal concentration ranges from 0.25 mg/Nm<sup>3</sup> to 87 mg/Nm<sup>3</sup>.

Figure 3.69 shows dust emission points to air without abatement techniques and with a maximum mass flow below 50 g/h from singeing and thermal treatments associated with pretreatment, dyeing, printing and finishing processes. The majority of the concentration values reported are below 10 mg/Nm<sup>3</sup>; only 3 out 90 emission points with a maximum mass flow below 50 g/h have a maximum concentration over 10 mg/Nm<sup>3</sup>.

In the case of emission points to air without abatement techniques and with a maximum mass flow above 50 g/h from singeing and thermal treatments associated with pretreatment, dyeing, printing and finishing processes, Figure 3.70 shows that 8 out of 34 emission points reported a maximum concentration below 10 mg/Nm<sup>3</sup>.

For processes other than singeing and thermal treatments associated with pretreatment, dyeing, printing and finishing, Figure 3.71 shows that the majority of emission points reported a maximum dust concentration value around 5 mg/Nm<sup>3</sup>.

Regarding the monitoring standards used, 112 out of 180 emissions points reported dust concentration values in accordance with the standard EN 13284-1, 27 emission points reported the concentration values in accordance with the standard EPA 5, and 24 did not report information about the monitoring standard used.

### 3.5.7 Ammonia (NH<sub>3</sub>)

The emissions of NH<sub>3</sub> are shown in Figure 3.72. The concentrations range from 0.1 mg/Nm<sup>3</sup> to 56.2 mg/Nm<sup>3</sup> and the mass flow varies between 0.04 g/h and 264 g/h.

It should be noted that ammonia is also continuously monitored in one case (BE013\_{01}), with an average concentration of 8.0 mg/Nm<sup>3</sup> and a maximal concentration of 56.2 mg/Nm<sup>3</sup>.

Plant BE013 carries out flame-retardance finishing of fabric with THPC (Tetrakis(hydroxymethyl)phosphonium chloride), which is subsequently cured using NH<sub>3</sub>. The air extracted from NH<sub>3</sub> curing is treated with water scrubbing and the emissions are reported to be 0 mg/Nm<sup>3</sup>. The air from the working area is extracted by hoods and sent directly to the atmosphere without treatment (which corresponds to the emission point BE013\_{01}).

According to the information reported, the processes associated with ammonia emissions are printing, coating and thermal treatment associated with finishing and with printing.

It should also be noted that Plant BE010 uses ammonium sulphamate for flame-retardance finishing, which could explain the level of NH<sub>3</sub> emissions (up to 16 mg/Nm<sup>3</sup> and mass flow of 264 g/h).

Wet scrubbing (see description in Section 4.1.8.2) is the technique used to reduce emissions of ammonia to air and was reported in four cases. In those cases, the maximal concentrations range from 3.1 mg/Nm<sup>3</sup> to 38.6 mg/Nm<sup>3</sup>.

In April 2020 the new monitoring standard for channelled emissions of NH<sub>3</sub> to air, EN ISO 21877:2019, was published. As the data collection period comprised the years 2016, 2017 and 2018, no emission points reported the concentration values in accordance with this new standard. Emission concentration values of NH<sub>3</sub> were collected from four countries:

- 11 out of 18 EPs from Italy reported NH<sub>3</sub> concentration values in accordance with the standard UNICHIM 632, and 4 did not report information about the monitoring standard used;
- 7 EPs from Germany reported NH<sub>3</sub> concentration values in accordance with emission factors;
- 2 out of 4 EPs from Belgium reported NH<sub>3</sub> concentration values in accordance with the standard SM 4500, and the other 2 emission points reported the use of dräger as the monitoring standard used;
- 1 EP from the United Kingdom, reported NH<sub>3</sub> concentration values in accordance with the standard EN 14791.

### 3.5.8 Waste gases from combustion processes

It is important to note that the information given in this section does not address emissions from combustion used to generate energy or steam as these emission sources are not within the scope of this document.



The emissions addressed in this section are emissions from thermal treatment equipment (e.g. stenters, dryers, heating chambers) in which the heat from the combustion of fuel is used to treat textile material or liquor/baths by direct contact of flue-gases or indirect conduction/radiation through a solid wall.

### 3.5.8.1 Nitrogen oxides (NO<sub>x</sub>)

The emissions of NO<sub>x</sub> are shown in Figure 3.73 and Figure 3.74. The concentrations range from 0.07 mg/Nm<sup>3</sup> to 238 mg/Nm<sup>3</sup>. The corresponding mass flows are generally low, up to 874 g/h, except for one emission point that is equipped with a thermal oxidation system. No techniques were reported for the abatement of NO<sub>x</sub> emissions to air.

According to the data collection, when the type of monitoring standard for NO<sub>x</sub> has been reported, the majority of the emission points reported NO<sub>x</sub> concentration values in accordance with the standard EN 14792.

### 3.5.8.2 Carbon monoxide (CO)

The emissions of CO are shown in Figure 3.75 and Figure 3.76 and are also generally low. The concentrations range from 0.025 mg/Nm<sup>3</sup> to 285 mg/Nm<sup>3</sup> and the mass flows from 0.3 g/h to 19 037 g/h. The main emission source which has been reported is thermal treatment. No techniques have been reported for the abatement of CO emissions to air.

According to the data collection, when the type of monitoring standard for CO has been reported, the majority of the emission points reported CO concentration values in accordance with the standard EN 15058.

### 3.5.8.3 Sulphur oxides (SO<sub>x</sub>)

The emissions of SO<sub>x</sub> are shown in Figure 3.77. Data were reported for only 12 emission points, 11 of them connected to thermal treatment and the last one to thermosol dyeing. The emissions are generally low: the concentrations range from 0.4 mg/Nm<sup>3</sup> to 28 mg/Nm<sup>3</sup> and the mass flows between 4.8 g/h and 433 g/h, the highest mass flow corresponding to the use of oil as fuel for thermal fixation. No techniques have been reported for the abatement of SO<sub>x</sub> emissions to air.

According to the data collection, when the type of monitoring standard for SO<sub>x</sub> has been reported, the majority of the emission points reported SO<sub>x</sub> concentration values in accordance with the standard EN 14791.

### 3.5.9 Odour

Some processes in the textile industry are often accompanied by odour emissions.

Substances with intense odour and typical ranges for odour concentrations are summarised in Table 3.15 and Table 3.16.

Table 3.15: Intensely odorous substances in the textile industry

Substance	Possible source
Epsilon-caprolactam	Heat-setting of polyamide 6 and polyamide 6 blends; Paste and powder coating with PA 6 and PA 6-copolymers
Paraffins, fatty alcohols, fatty acids, fatty acid esters (substances with less intensive odour, but high concentrations)	Heat-setting of grey textiles and inefficiently pre-washed textiles
Hydrocarbons	Printing, wetting agents, machine cleaning, coating
Aromatic compounds	Carriers
Acetic acid, formic acid	Various processes
Hydrogen sulphide, mercaptans	Sulphur dyeing
Sulphur derivatives	Reducing agents, hot acid cracking in wool scouring mills
Ammonia	Printing (e.g. from the use of urea), coating, non-woven processing
Acrylates	Printing (e.g. from the use of thickening agents), coating, non-woven processing
Formaldehyde	Easy-care finishing, finishing of non-woven fabrics, permanent flame retardants
Terpene (d limonene)	Solvents, machine cleaners
Styrene	SBR polymerisation, styrene addition to SBR compounds
4-Vinylcyclohexene (4-VCH)	SBR polymerisation (4-VCH is a dimer of butadiene that is formed during SBR polymerisation)
Butadiene	Monomer in SBR polymerisation
4-phenylcyclohexene (4-PCH)	SBR polymerisation (4-PCH is formed by reaction between styrene and butadiene)
Aldehydes	Singeing
Acroleine	Decomposition of glycerol
Phosphoric acid esters (esp. tributylphosphate)	Wetting agents, de-aeration agents
Phthalates	Levelling and dispersing agents
Amines (low molecular)	Various processes
Alcohols (octanol, butanol)	Wetting agents, antifoaming agents
<i>Source:</i> [ 5, UBA 2001 ]	

Table 3.16: Typical examples of odour concentrations in some textile processes

Substrate/Process	Range of odour concentration (OU <sub>E</sub> /Nm <sup>3</sup> )	Average odour concentration (OU <sub>E</sub> /Nm <sup>3</sup> )
<u>PA 6</u> Heat-setting grey fabric	2 000-4 500	2 500
<u>PA 6</u> Finishing of thermofixed and pre-washed fabrics	500-2 000	1 100
<u>PES</u> Heat-setting grey fabric	1 500-2 500	2 000
<u>PES</u> Finishing of thermofixed and pre-washed fabrics	500-1 500	800
<u>CO</u> Finishing	300-1 000	500
<u>Fibre blends</u> Heat setting	1 000-2 500	1 500
<u>Fibre blends</u> Finishing of thermofixed and pre-washed fabrics	500-2 000	1 200
Sulphur dyeing	NI	Up to 10 000
Singeing	NI	Up to 2 500
<u>Non-wovens</u> (monomer-containing binders)	NI	Up to 10 000
<u>Printing</u> (mansards) - pigment - vat dyes (2 steps) - disperse dyes - vat dyes (discharge)	NI	282 586 53 286
<u>Printing</u> (steamer) - pigment - disperse dyes - vat dyes (2 steps)	NI	670 608 633
<u>Drying carrier-dyed textiles</u> <sup>(1)</sup> - carrier: benzyl benzoate, phthalic acid ester - carrier: biphenyl, dimethyl phthalate - carrier: alkylphthalimide	NI	800-2 800 4 800 478
Drying of textiles without carriers	NI	4 790
NB: OU <sub>E</sub> : odour unit. NI: No information. (1) Data are based on fabric that has been dyed but not dried; drying and air emission measurements were carried out on a laboratory scale. Source: [ 5, UBA 2001 ]		

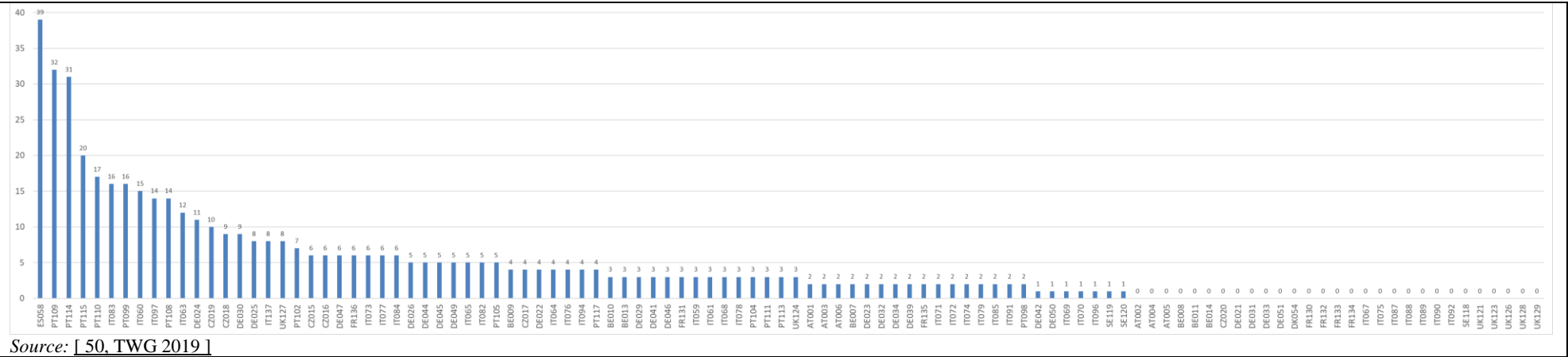
### 3.5.10 Figures with air emission levels

In the following figures, the average concentration is represented by a blue square and the minimum and maximum concentrations by error bars. Emission limit values (ELVs) are shown with a red line. In the box below the graph with the concentration values, the following contextual information is given: labels (identifier) of the emission point, the monitoring frequency, the total number of measurements reported over the 3 reporting years and an indication as to whether the monitoring standard is reported.

Regarding the number of measurements, when the type of sampling is continuous, it has been identified as continuous (C) instead of giving the total number of measurements.

The meanings of the acronyms used in the figures are as follows.

<b>Monitoring frequency</b>	<b>Abbreviation</b>
Continuous	C
4 times per year	4/y
Twice per year	2/y
Yearly	1/y
Once every 3 years	1/3y
Other	Ot
No information	NA



Source: [ 50, TWG 2019 ]

**Figure 3.52: Number of monitored points of emission to air by plant**

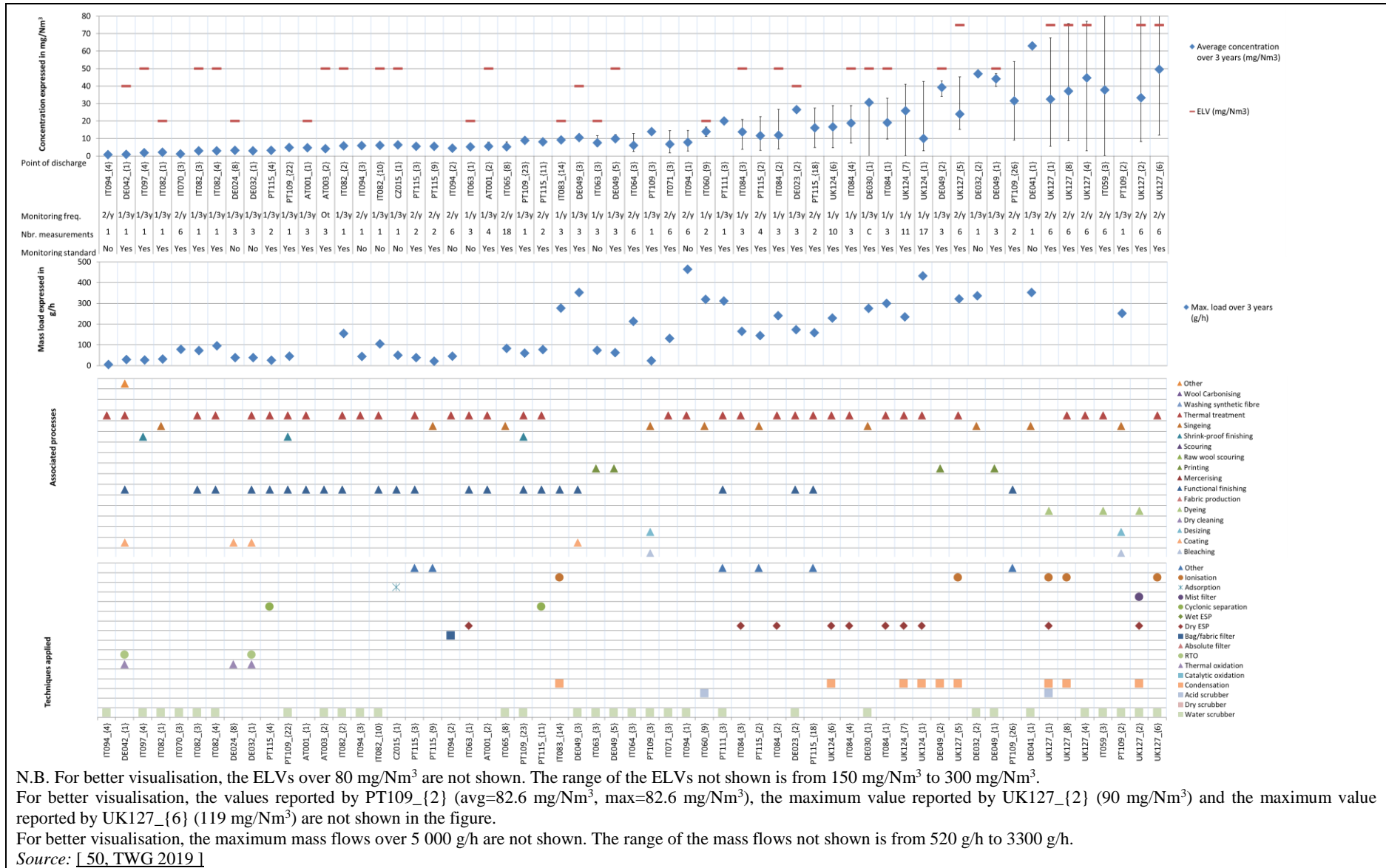
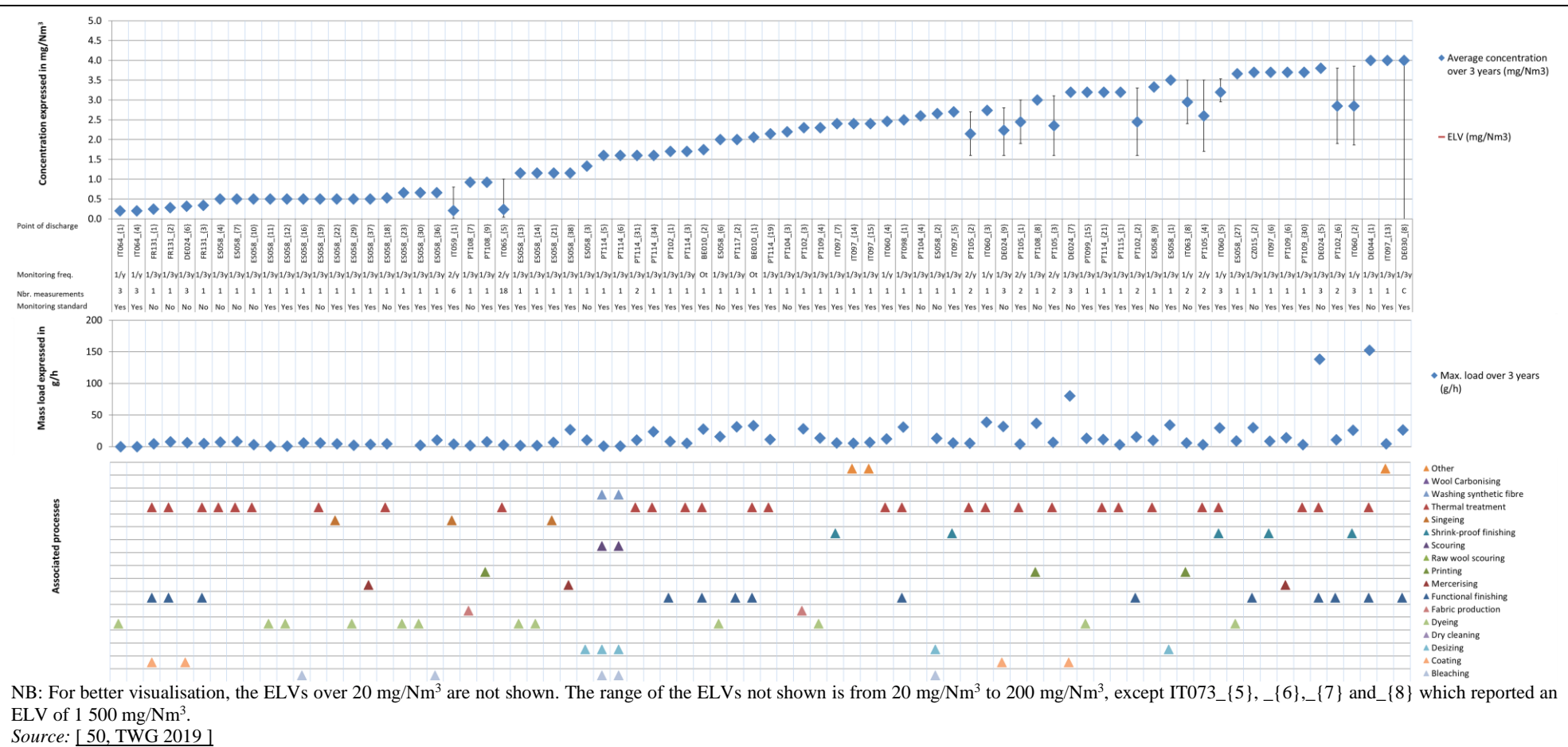


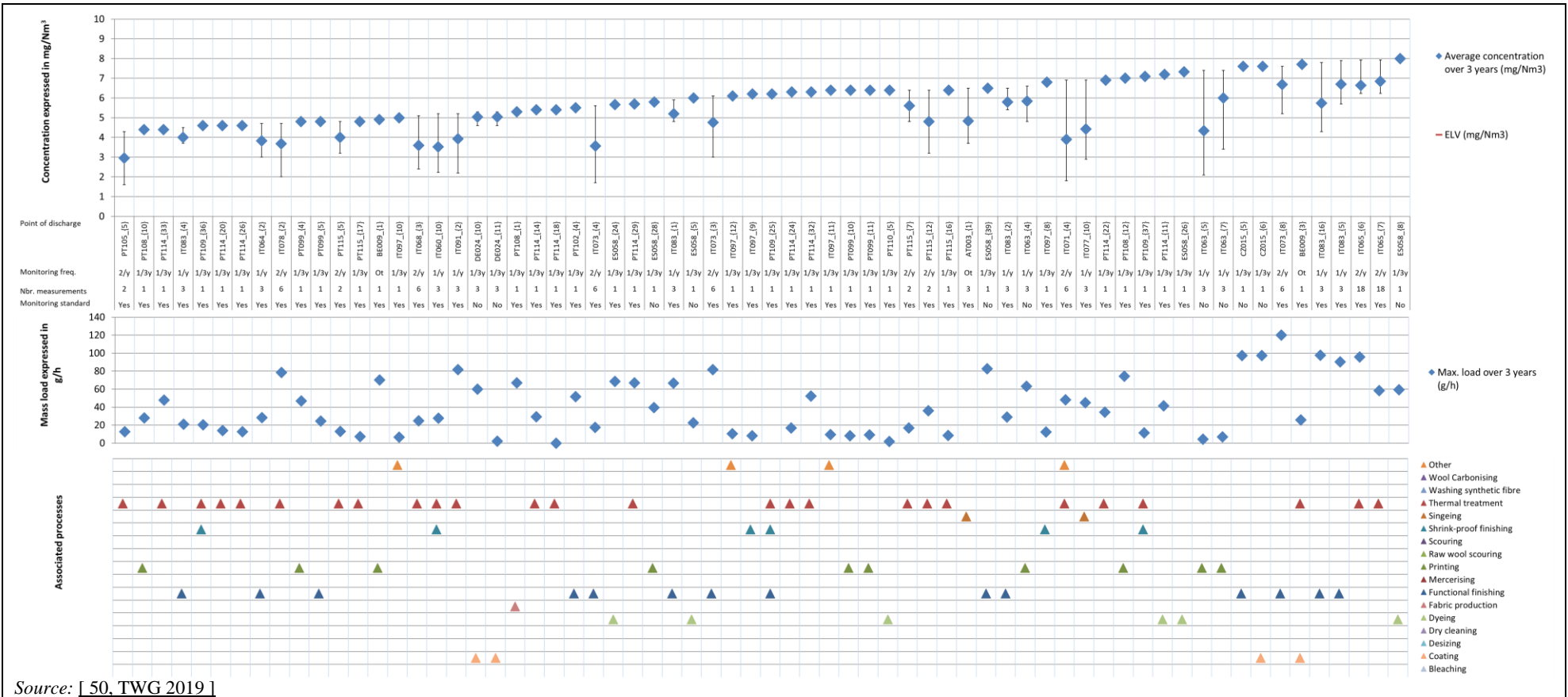
Figure 3.53: TVOC emissions to air with abatement techniques



NB: For better visualisation, the ELVs over 20 mg/Nm<sup>3</sup> are not shown. The range of the ELVs not shown is from 20 mg/Nm<sup>3</sup> to 200 mg/Nm<sup>3</sup>, except IT073\_{5}, \_{6}, \_{7} and \_{8} which reported an ELV of 1 500 mg/Nm<sup>3</sup>.

Source: [ 50, TWG 2019 ]

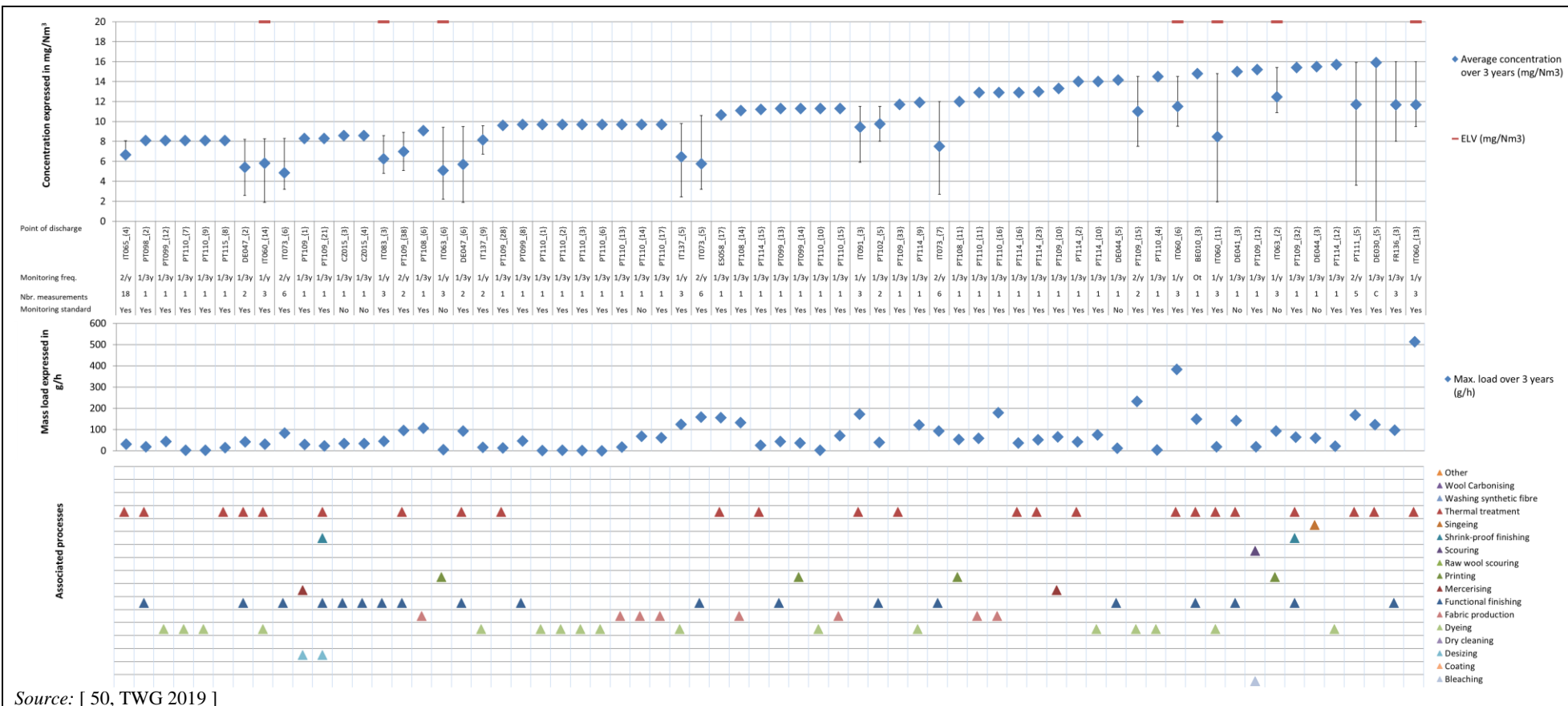
Figure 3.54: TVOC emissions to air without abatement techniques (maximum concentration range 0-4 mg/Nm<sup>3</sup>)



Source: [ 50, TWG 2019 ]

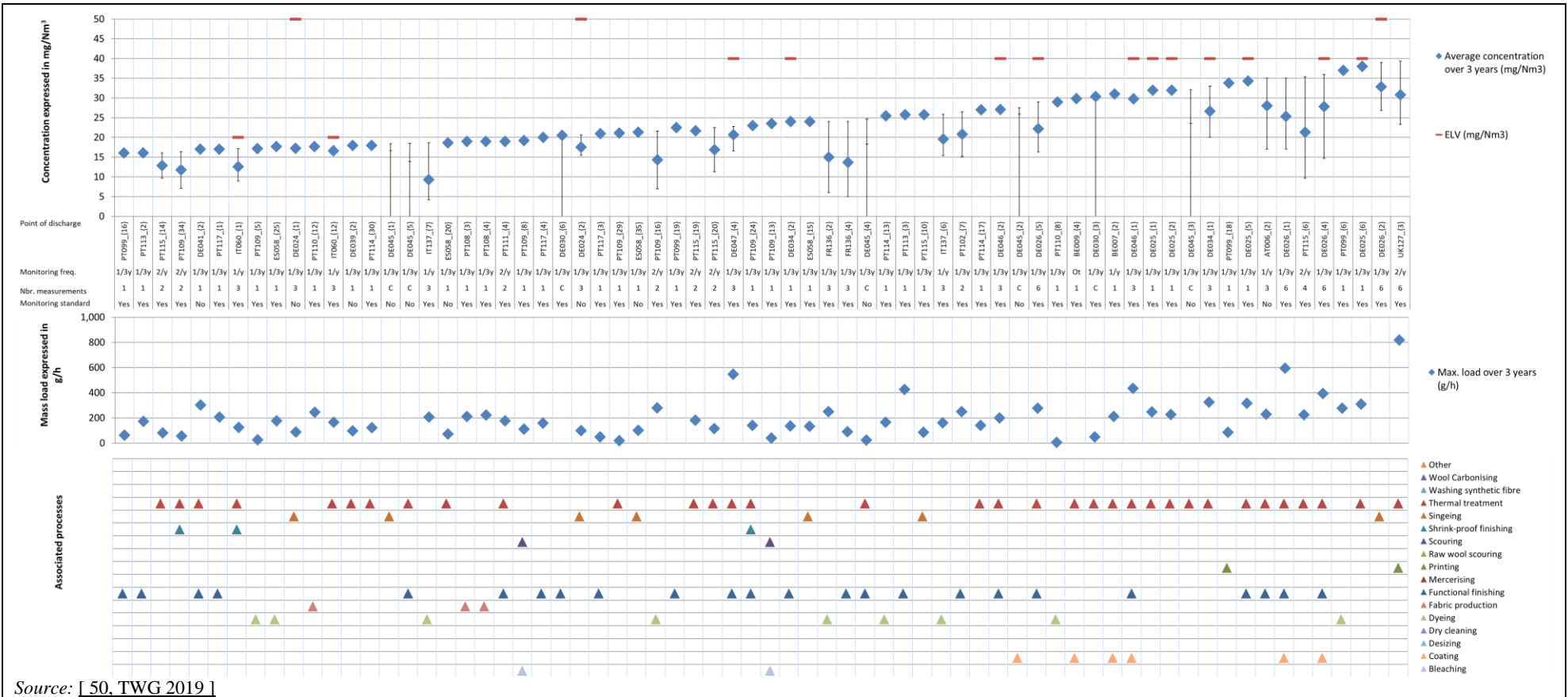
Figure 3.55: TVOC emissions to air without abatement techniques (maximum concentration range 4-8 mg/Nm<sup>3</sup>)





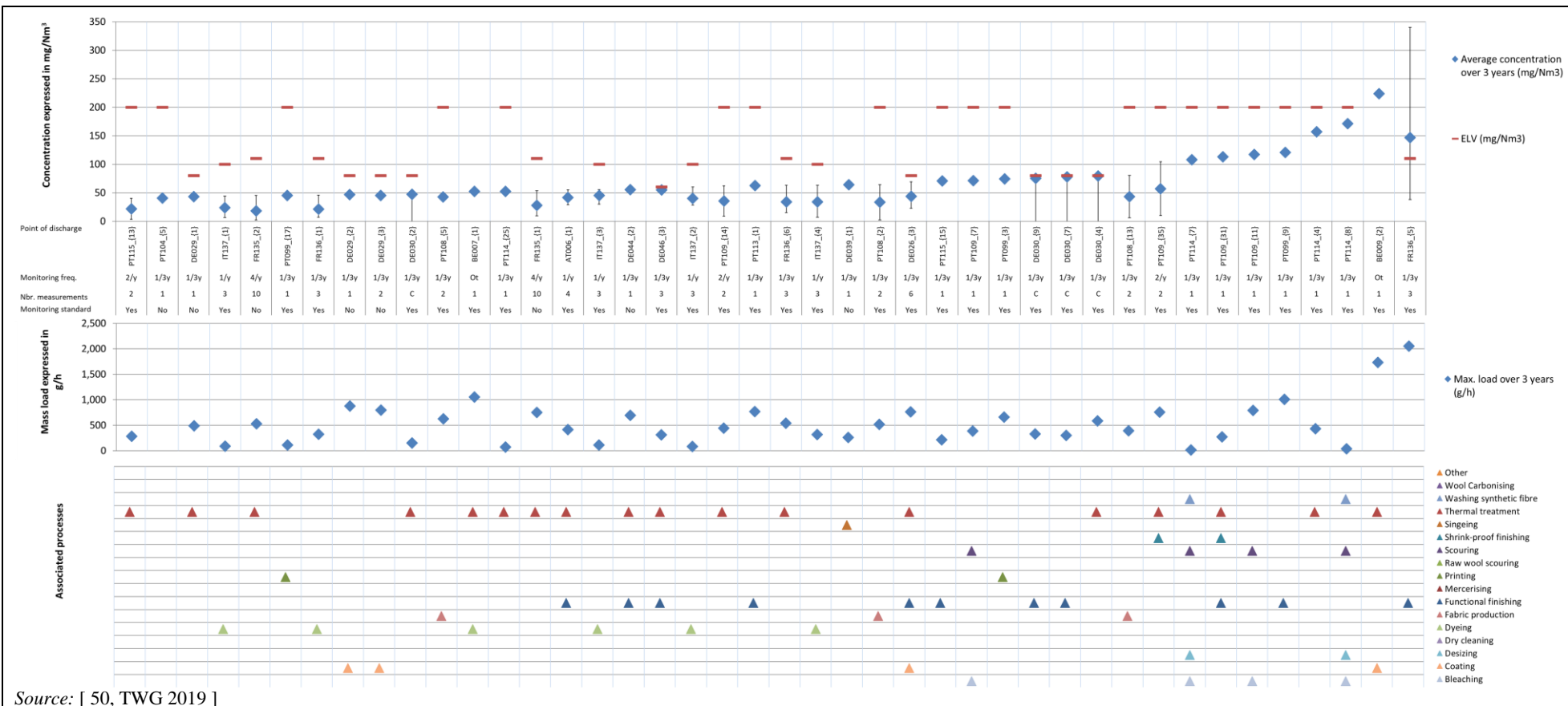
Source: [ 50, TWG 2019 ]

Figure 3.56: TVOC emissions to air without abatement techniques (maximum concentration range 8-16 mg/Nm<sup>3</sup>)



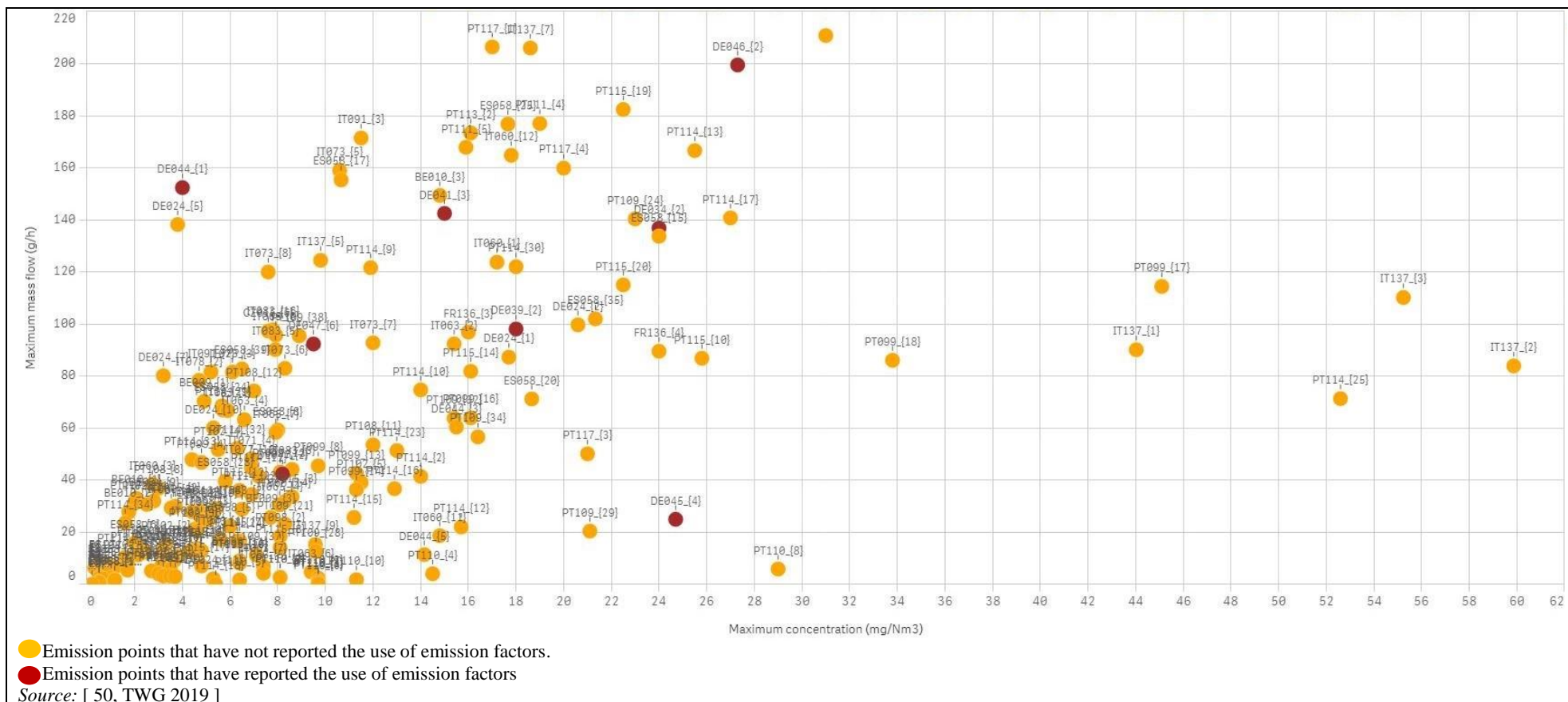
Source: [ 50, TWG 2019 ]

Figure 3.57: TVOC emissions to air without abatement techniques (maximum concentration range from 16-40 mg/Nm<sup>3</sup>)

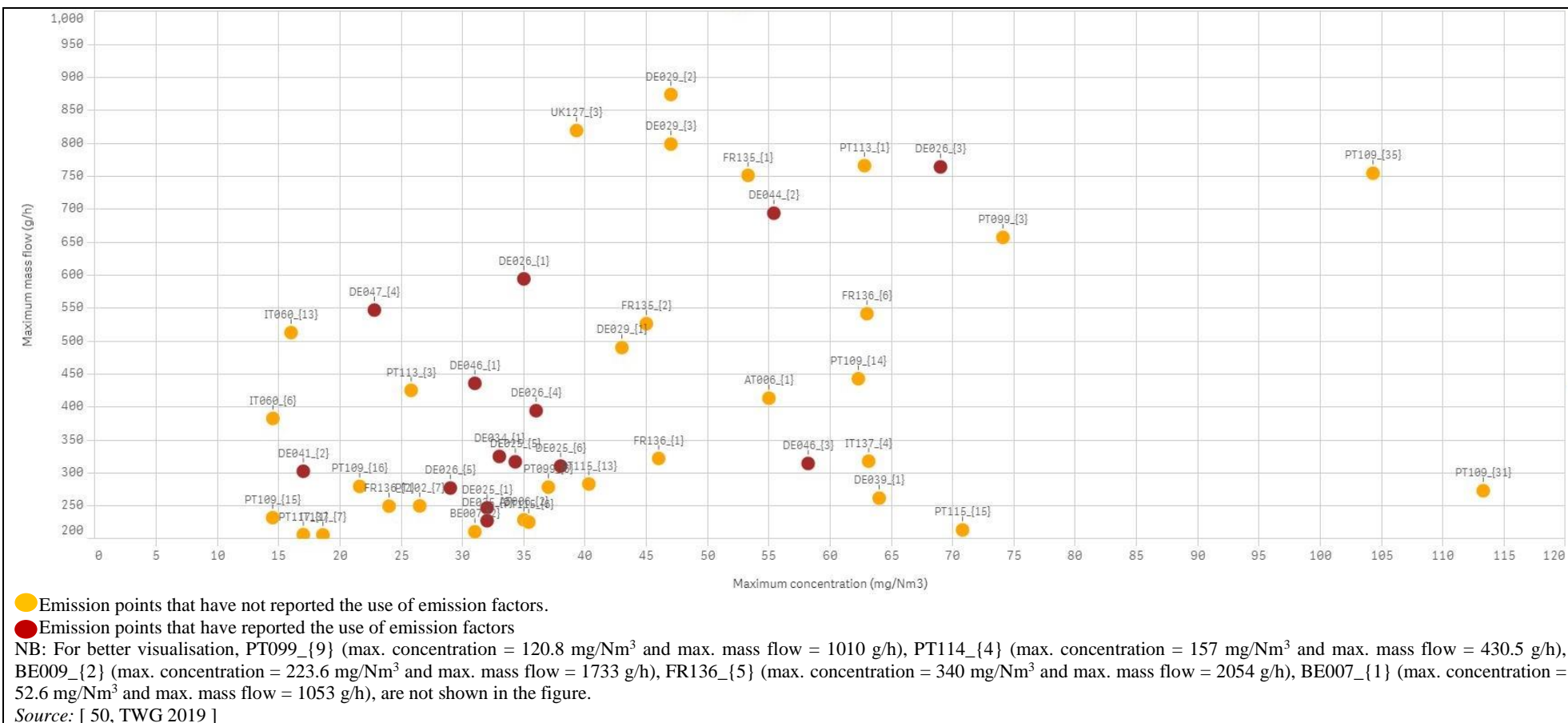


Source: [ 50, TWG 2019 ]

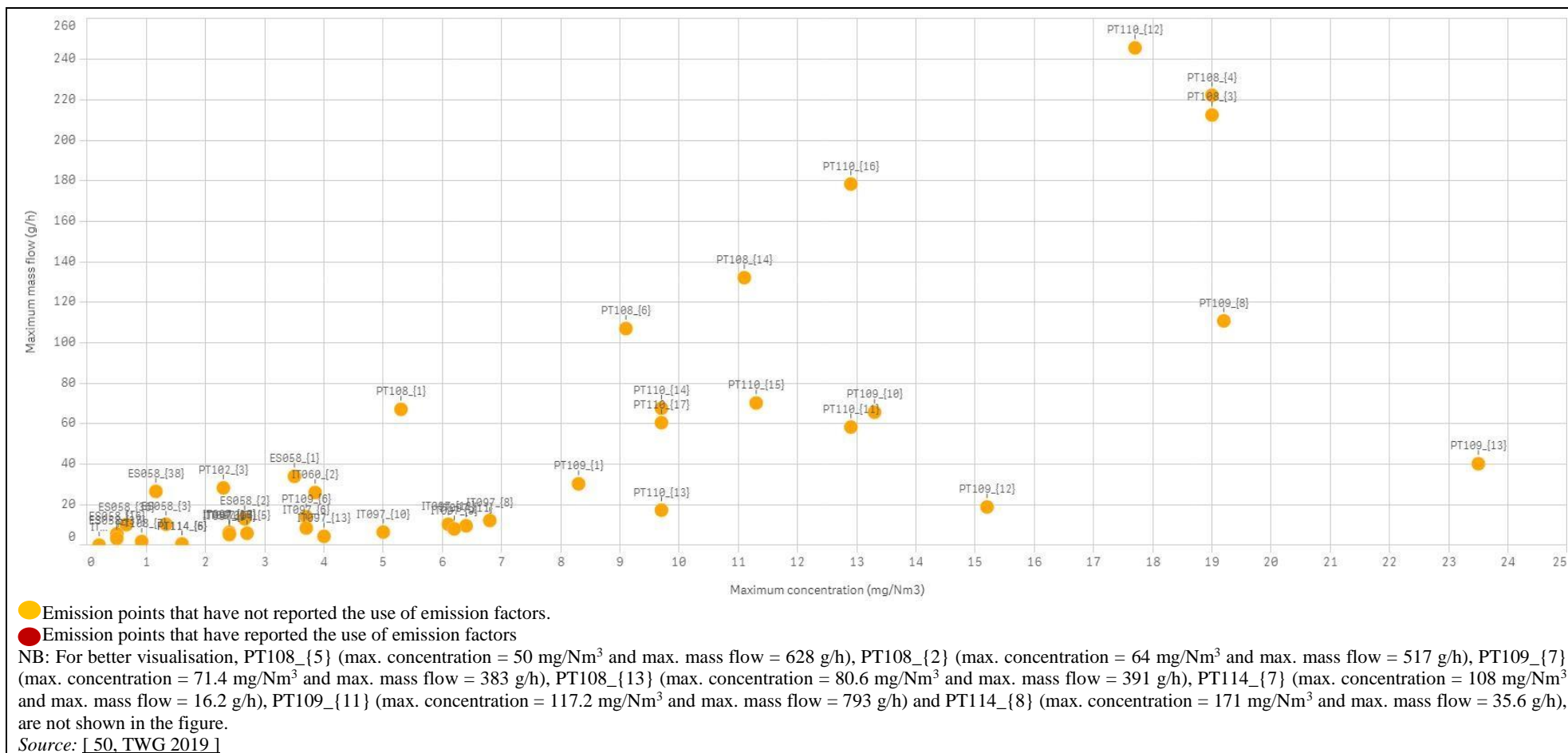
Figure 3.58: TVOC emissions to air without abatement techniques (maximum concentration values above 40 mg/Nm<sup>3</sup>)



**Figure 3.59: TVOC emissions to air from singeing and thermofixation or heat-setting as well as from coating, lamination, printing, dyeing and finishing (including thermal treatments associated with these processes), without abatement techniques, and a maximum mass flow equal to or below 200 g/h**



**Figure 3.60: TVOC emissions to air from singeing and thermofixation or heat-setting as well as from coating, lamination, printing, dyeing and finishing (including thermal treatments associated with these processes), without abatement techniques, and a maximum mass flow above 200 g/h**



**Figure 3.61: TVOC emissions to air from processes other than singeing and thermofixation or heat-setting as well as from coating, lamination, printing, dyeing and finishing (including thermal treatments associated with these processes), without abatement techniques**

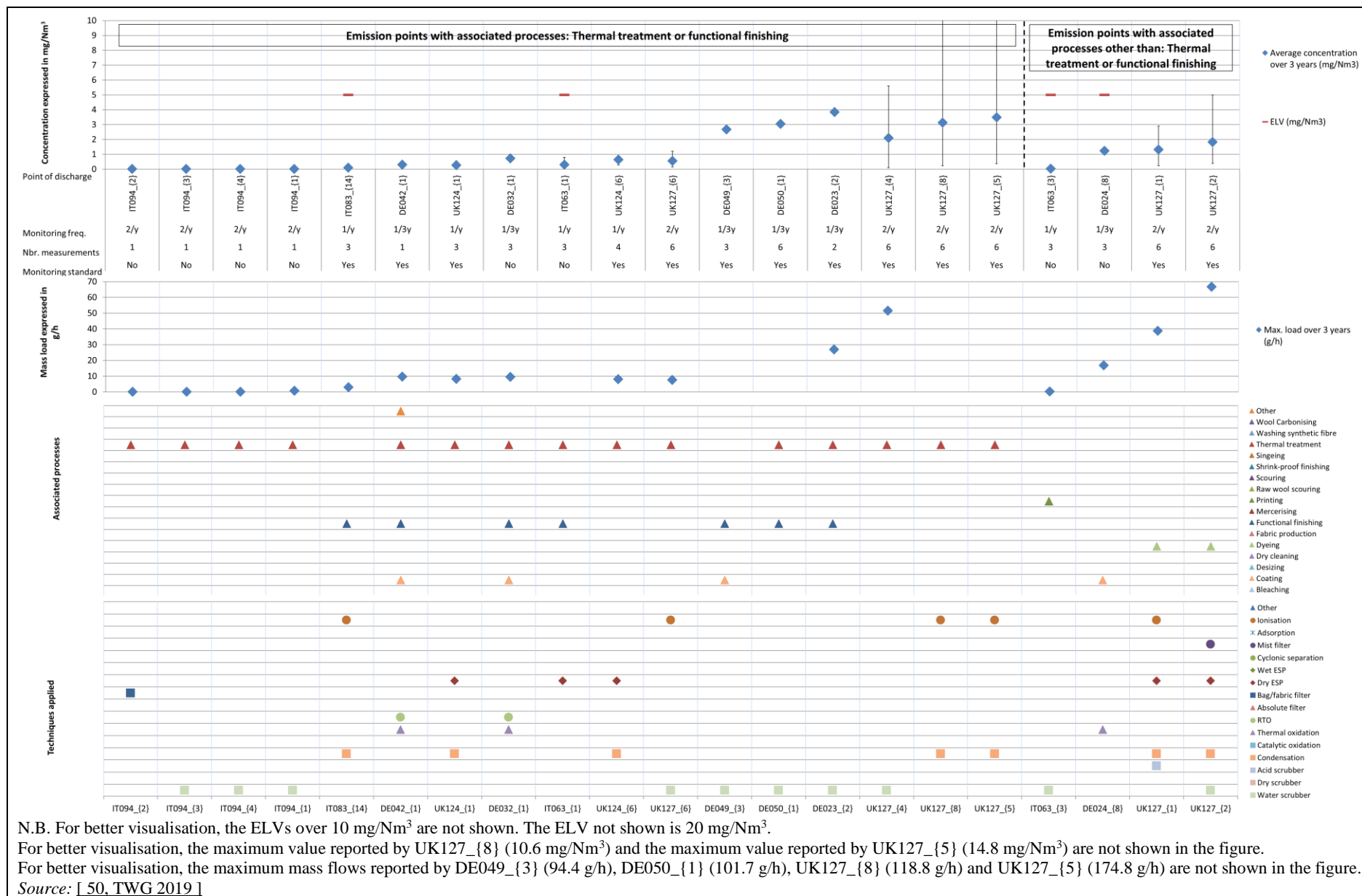


Figure 3.62: Formaldehyde emissions to air with abatement techniques

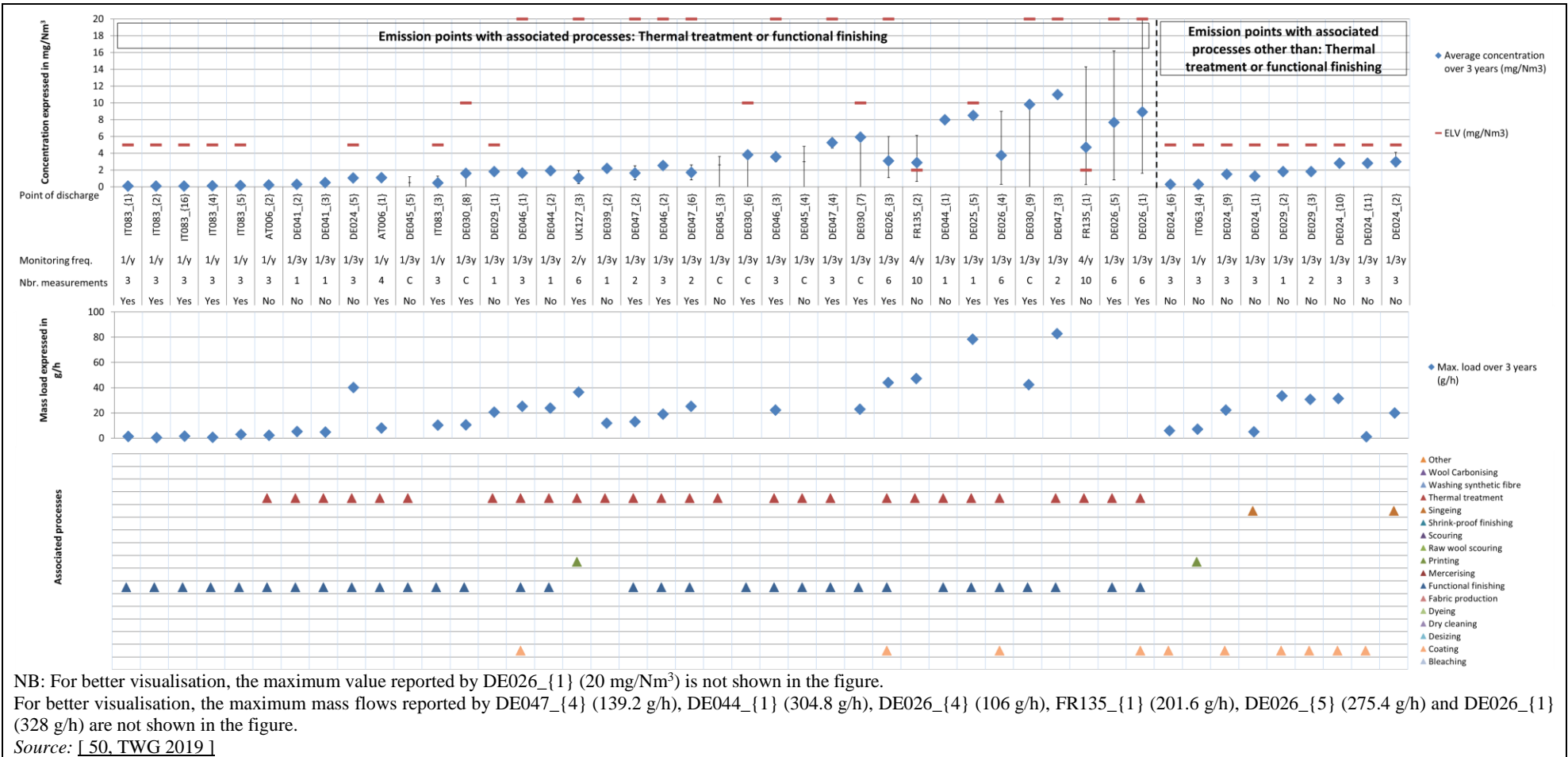


Figure 3.63: Formaldehyde emissions to air without abatement techniques



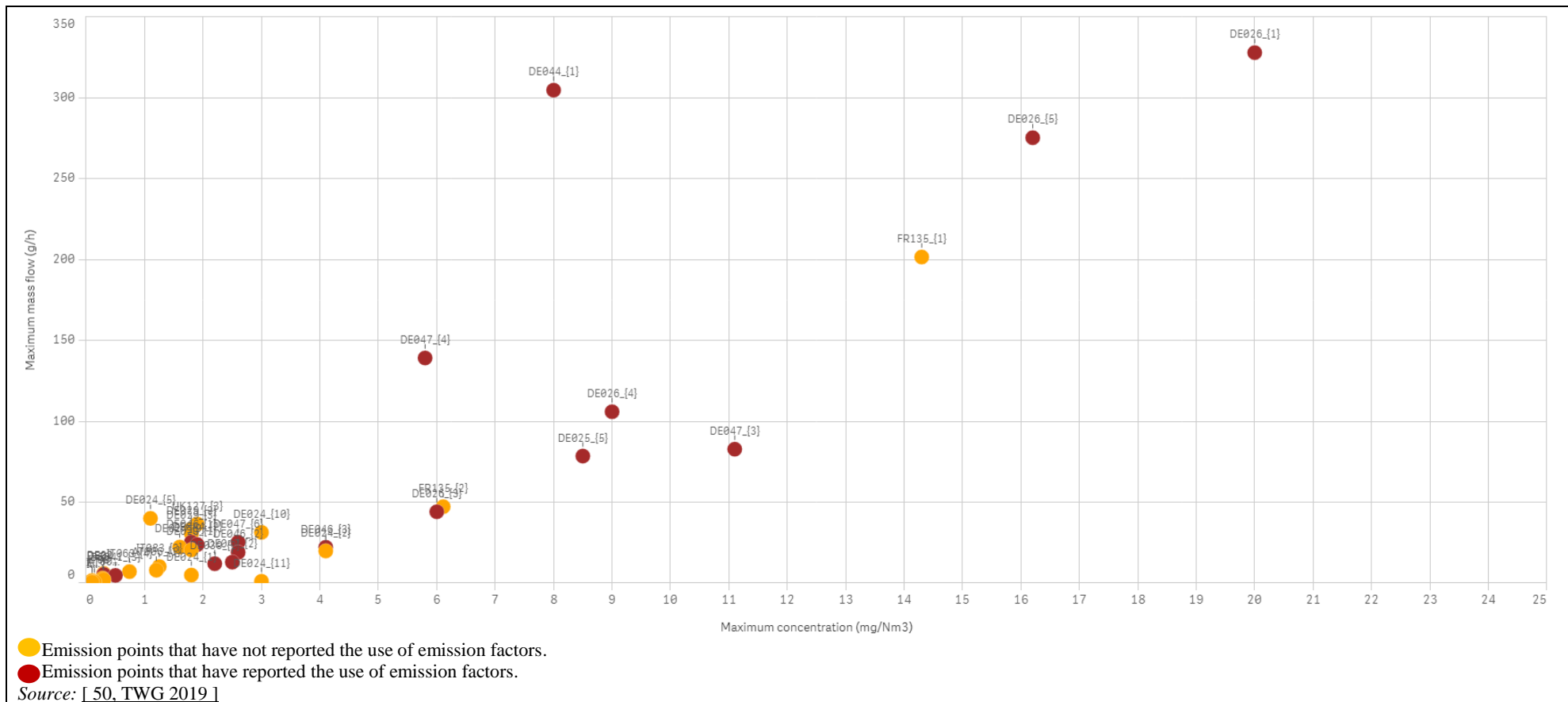


Figure 3.64: Formaldehyde emissions to air, without abatement techniques (correlation between maximum concentration and maximum mass flow values)

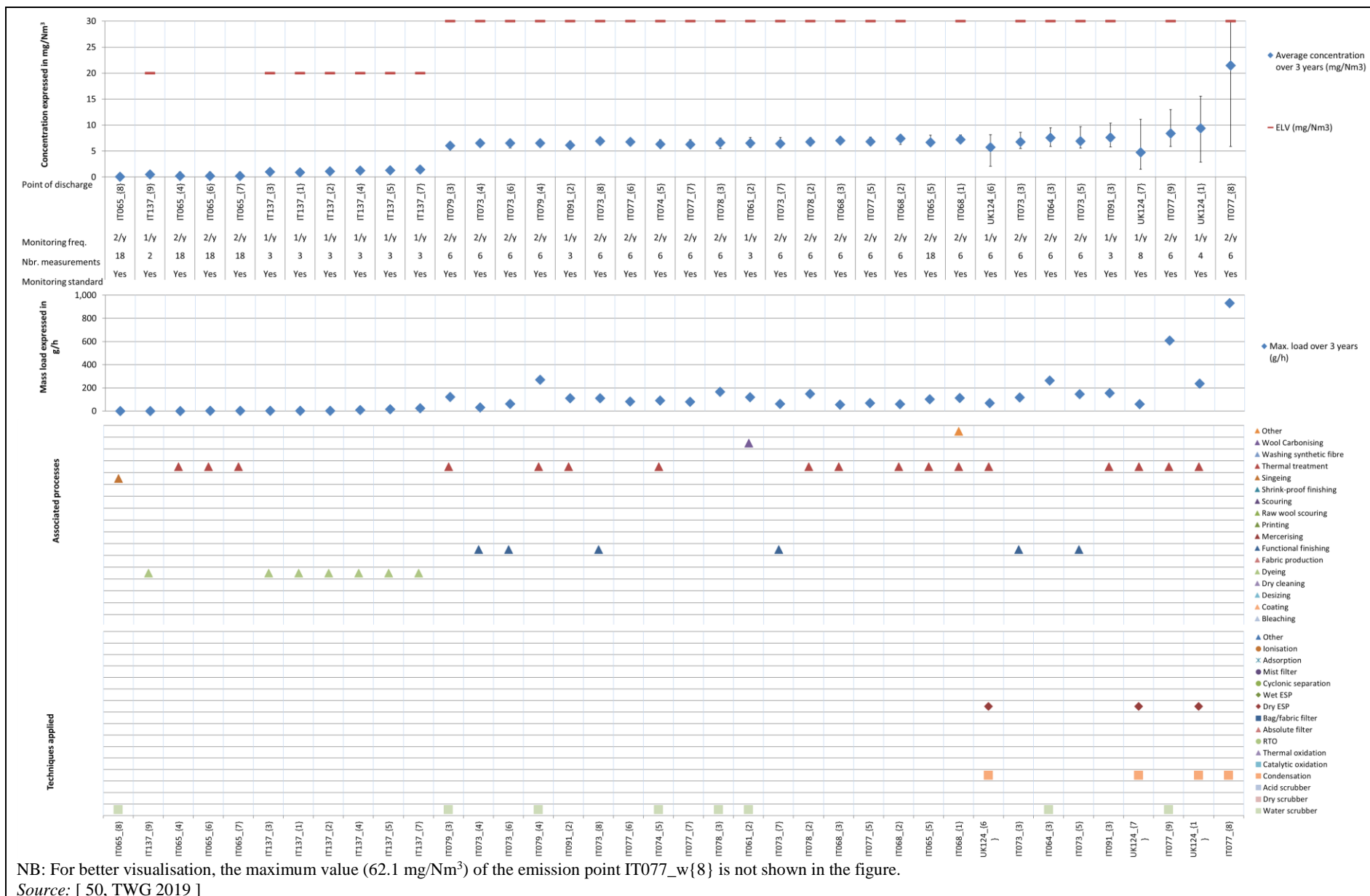


Figure 3.65: Oil mist emissions to air

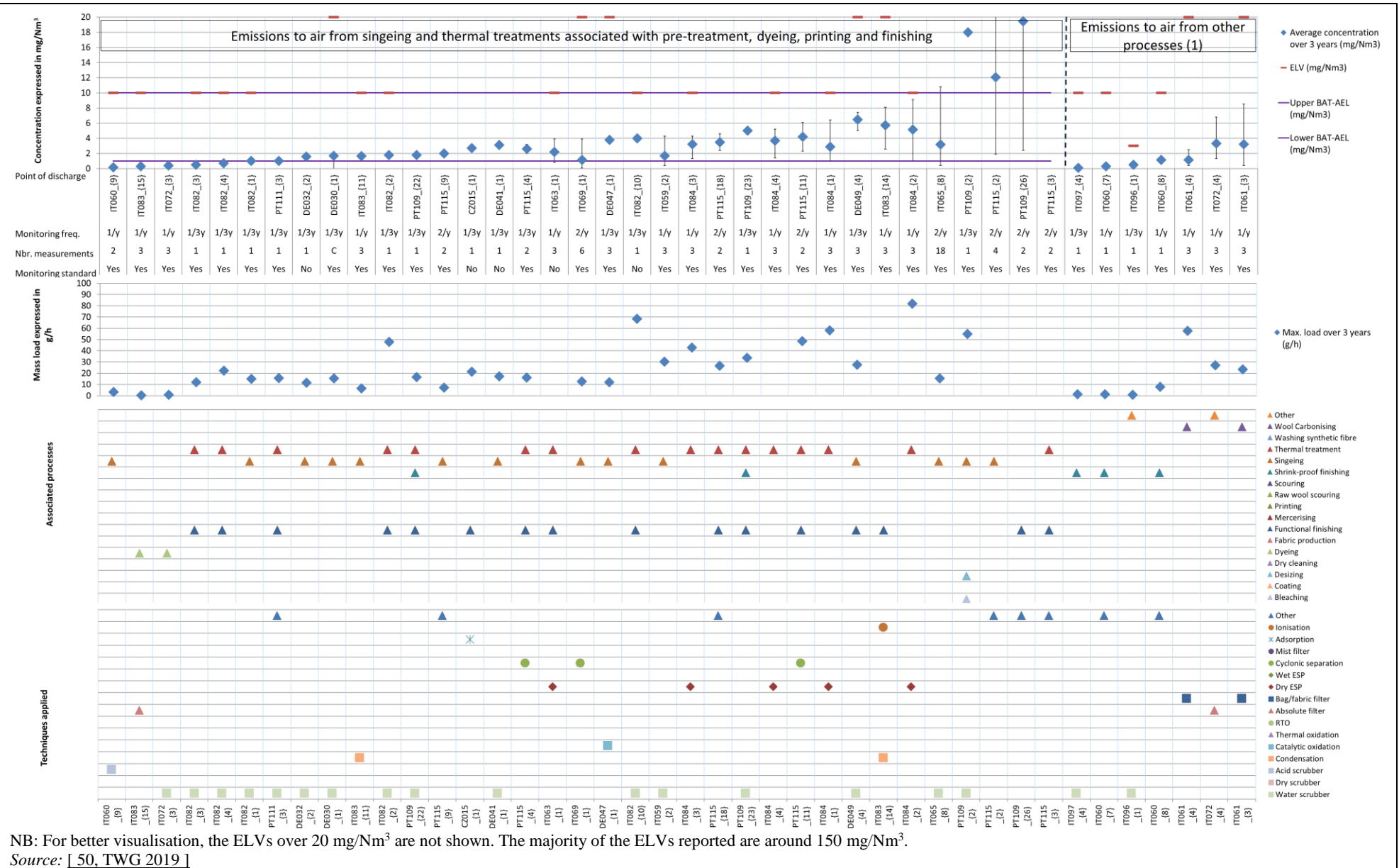


Figure 3.66: Dust emissions to air with abatement techniques

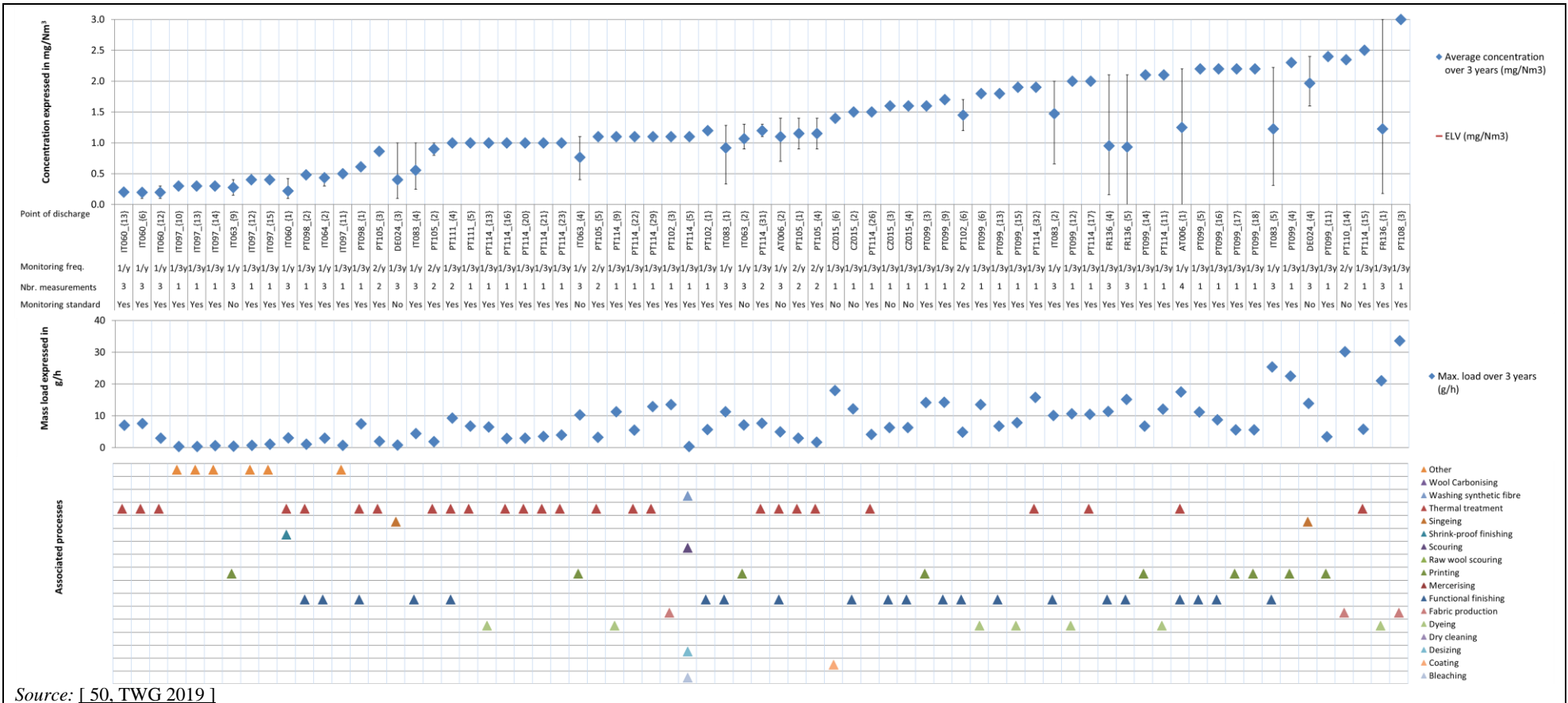


Figure 3.67: Dust emissions to air without abatement techniques (maximum concentration range 0-3 mg/Nm<sup>3</sup>)

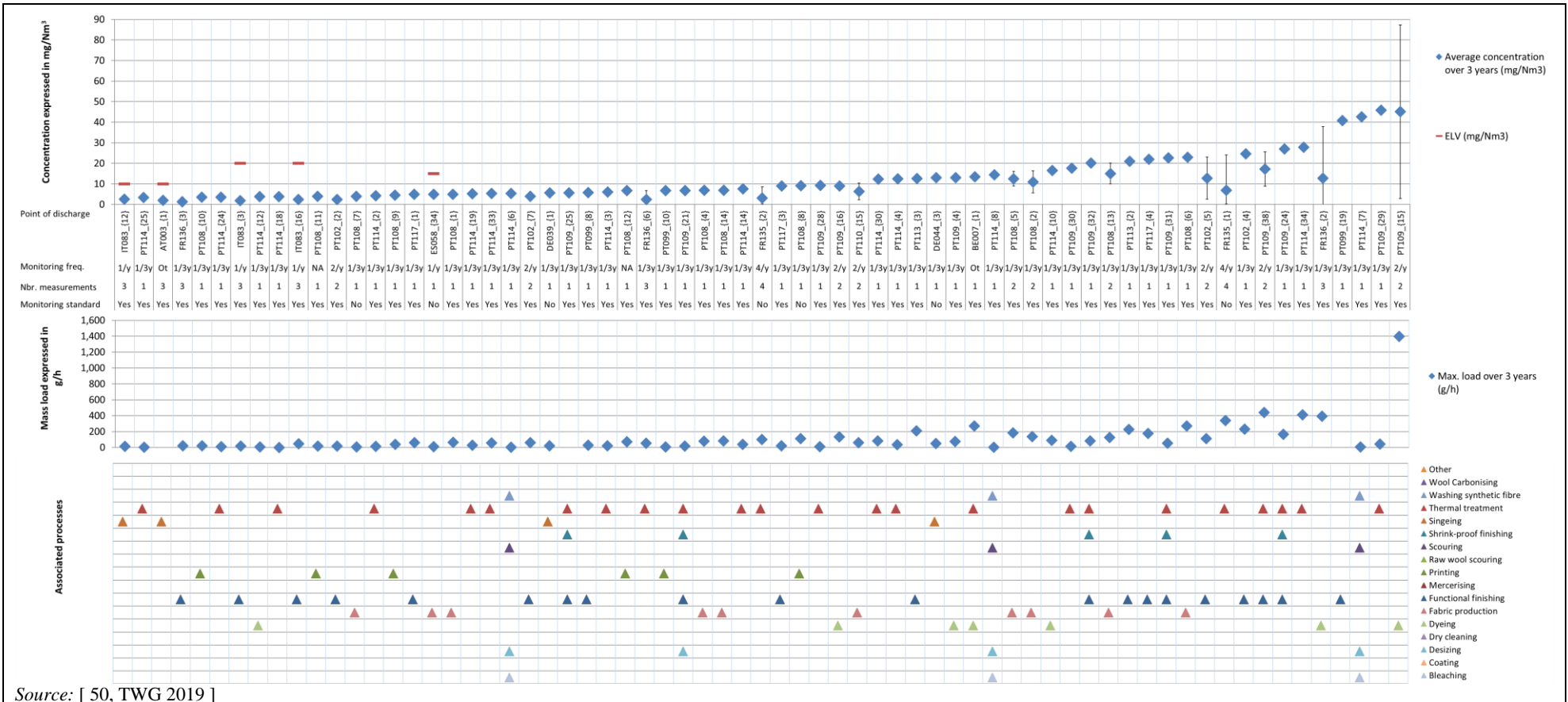
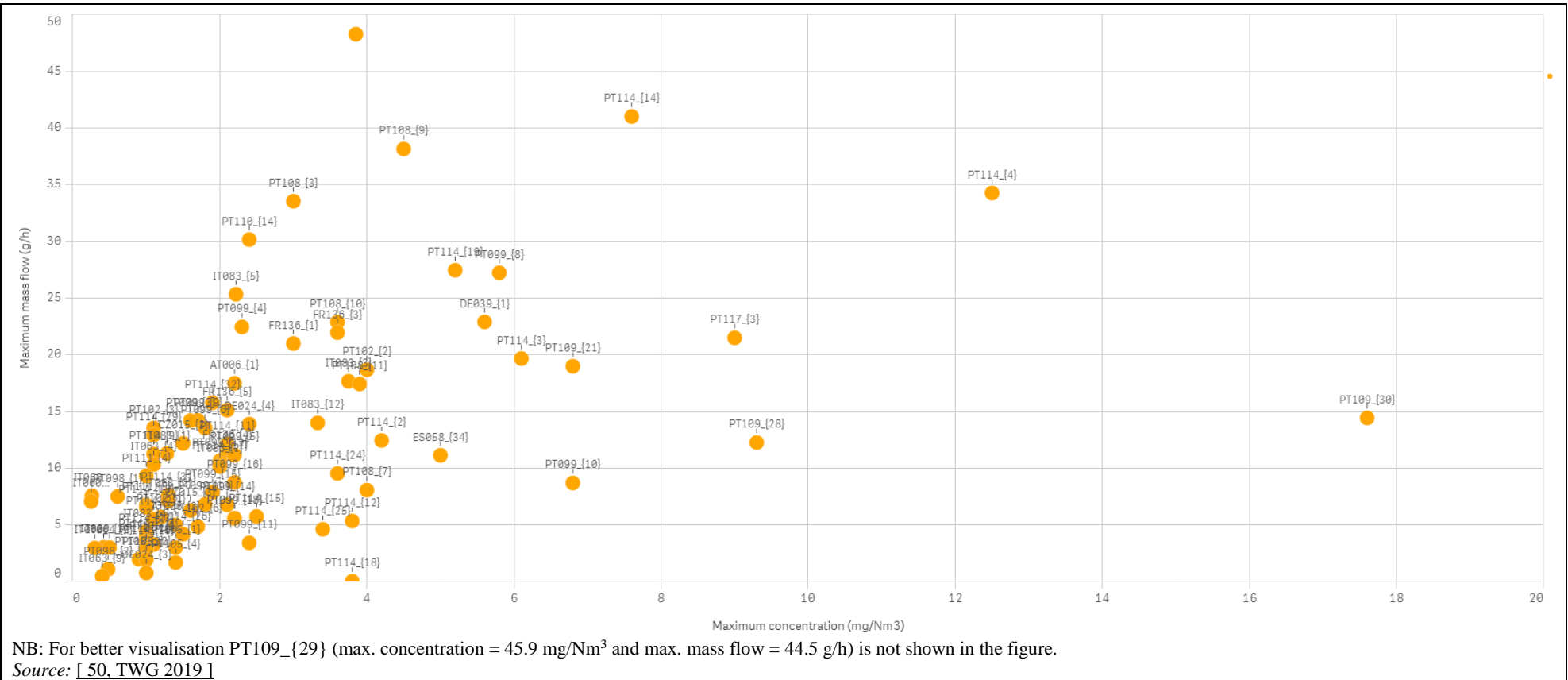
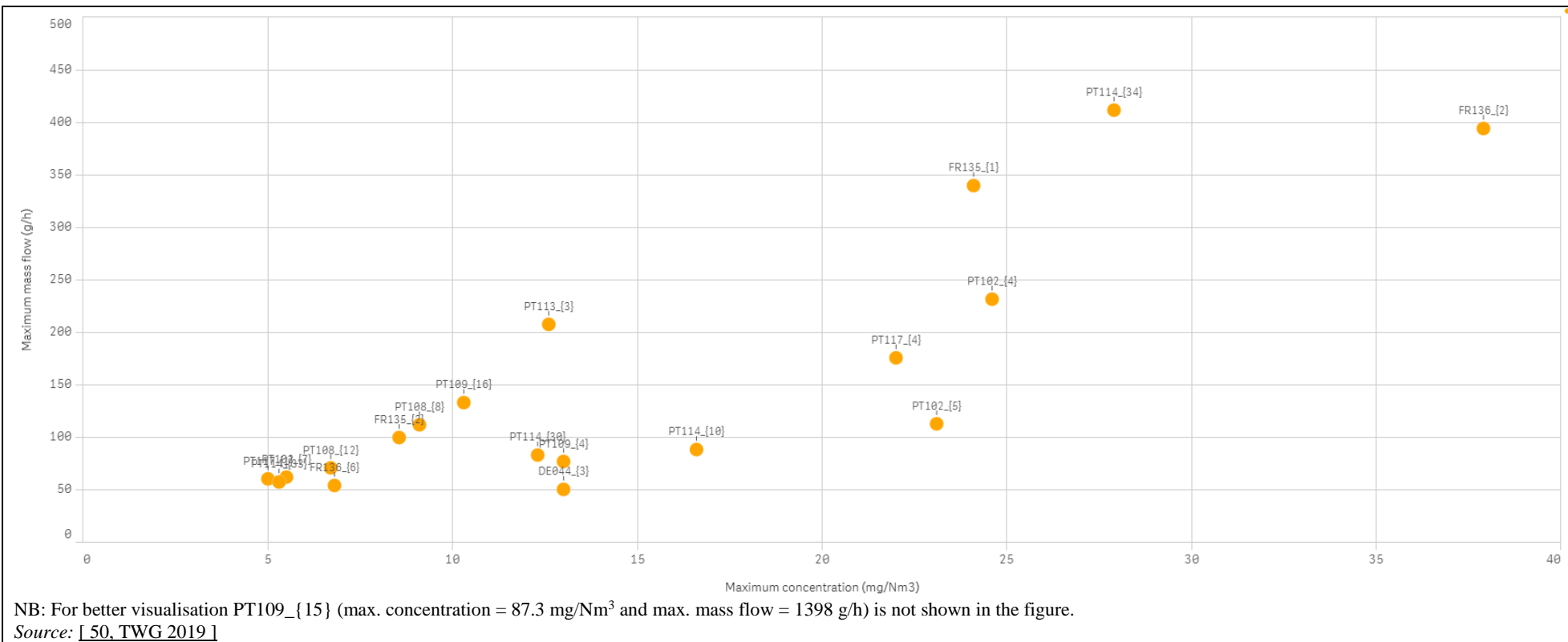


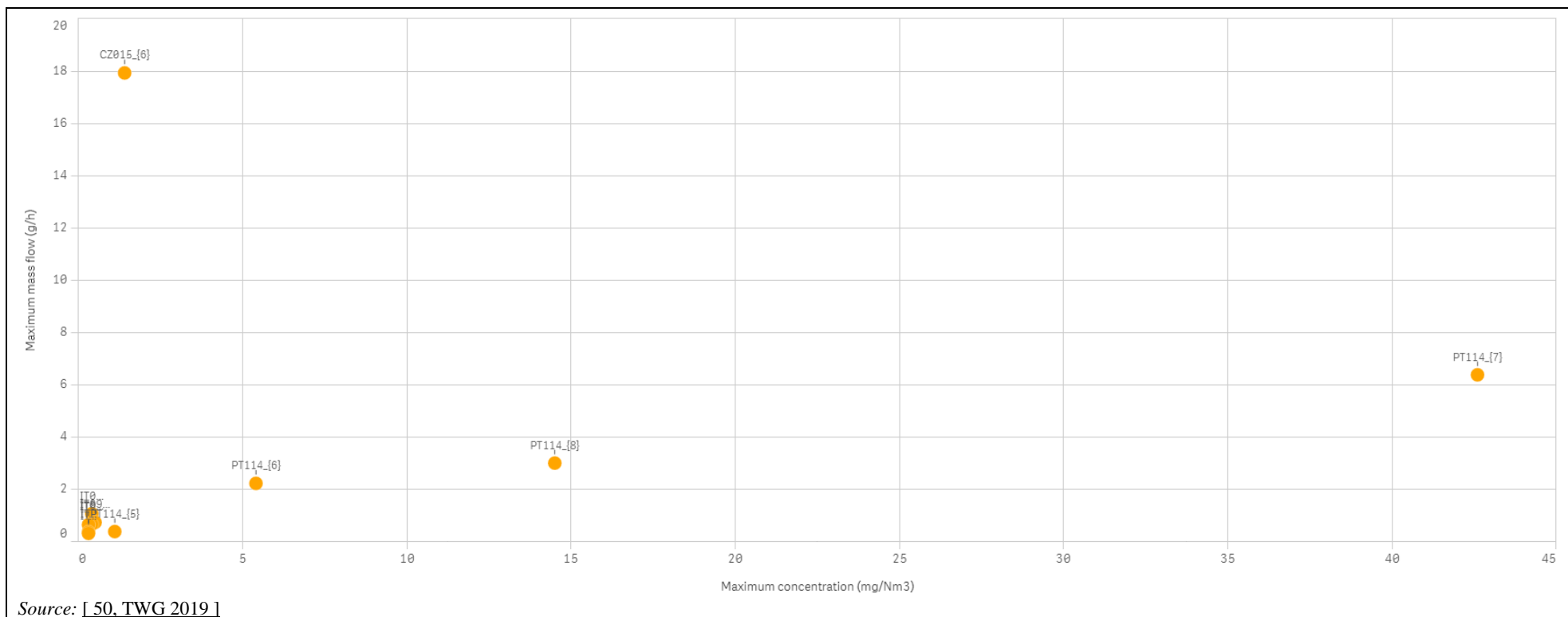
Figure 3.68: Dust emissions to air without abatement techniques (maximum concentration values above 3 mg/Nm<sup>3</sup>)



**Figure 3.69: Dust emissions to air from singeing and thermal treatments associated with pretreatment, dyeing, printing and finishing, without abatement techniques, and a maximum mass flow equal to or below 50 g/h**

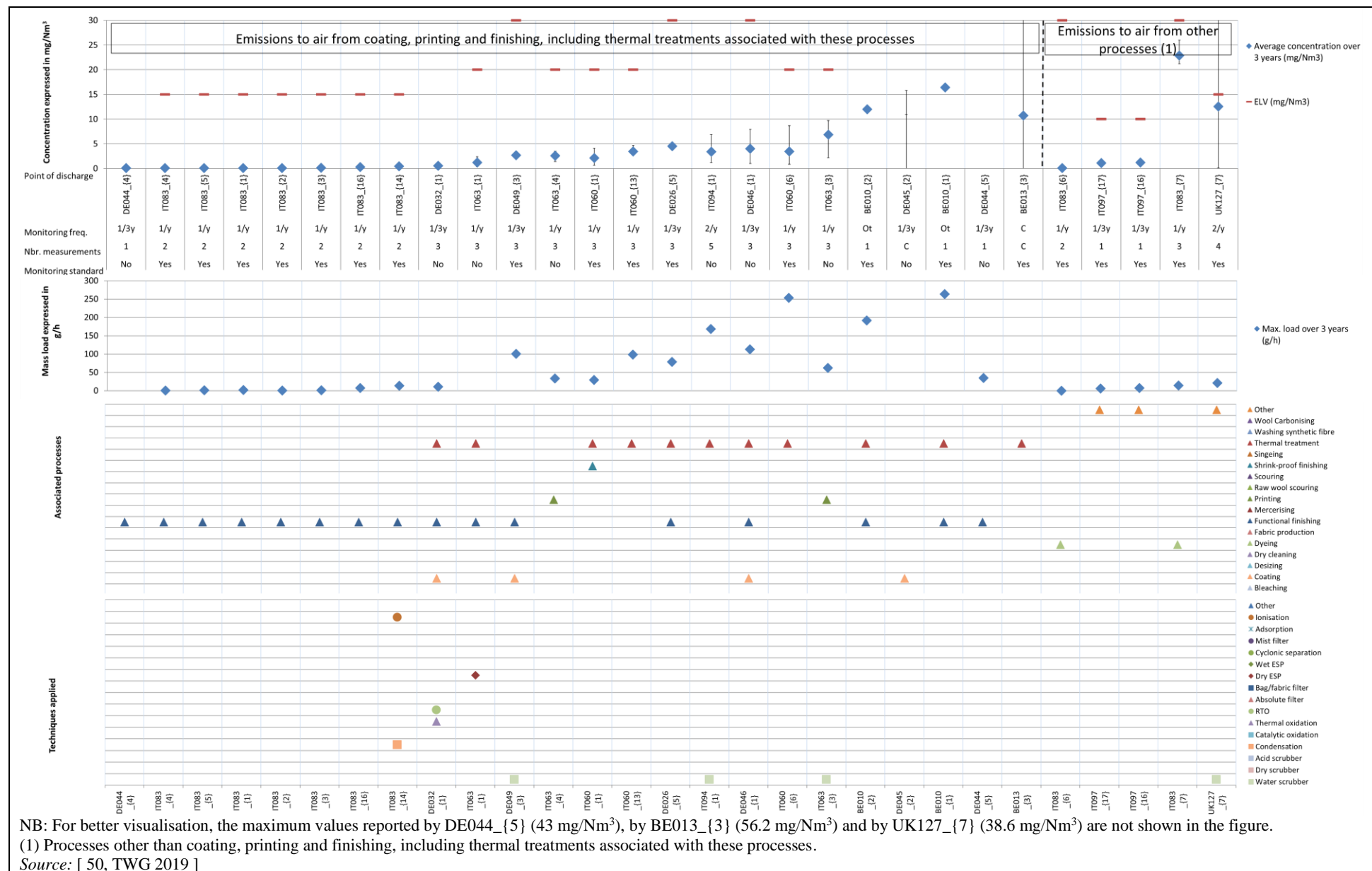


**Figure 3.70: Dust emissions to air emissions from singeing and thermal treatments associated with pretreatment, dyeing, printing and finishing, without abatement techniques, and a maximum mass flow above 50 g/h**



**Figure 3.71: Dust emissions to air emissions from processes other than singeing and thermal treatments associated with pretreatment, dyeing, printing and finishing, without abatement techniques**





NB: For better visualisation, the maximum values reported by DE044\_{5} (43 mg/Nm<sup>3</sup>), by BE013\_{3} (56.2 mg/Nm<sup>3</sup>) and by UK127\_{7} (38.6 mg/Nm<sup>3</sup>) are not shown in the figure.

(1) Processes other than coating, printing and finishing, including thermal treatments associated with these processes.

Source: [ 50, TWG 2019 ]

Figure 3.72: Ammonia emissions to air

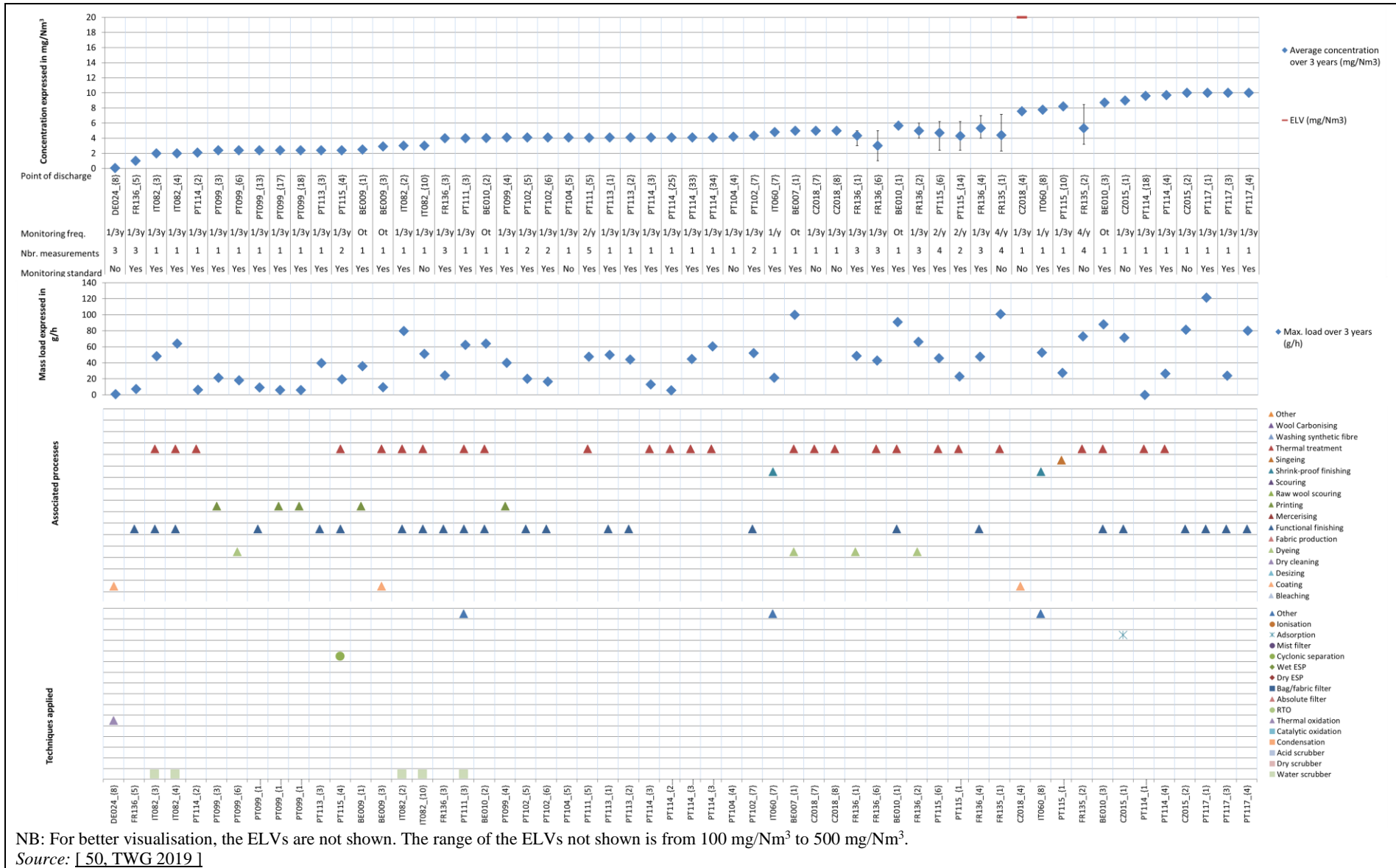


Figure 3.73: NOx emissions to air (Part 1 of 2)

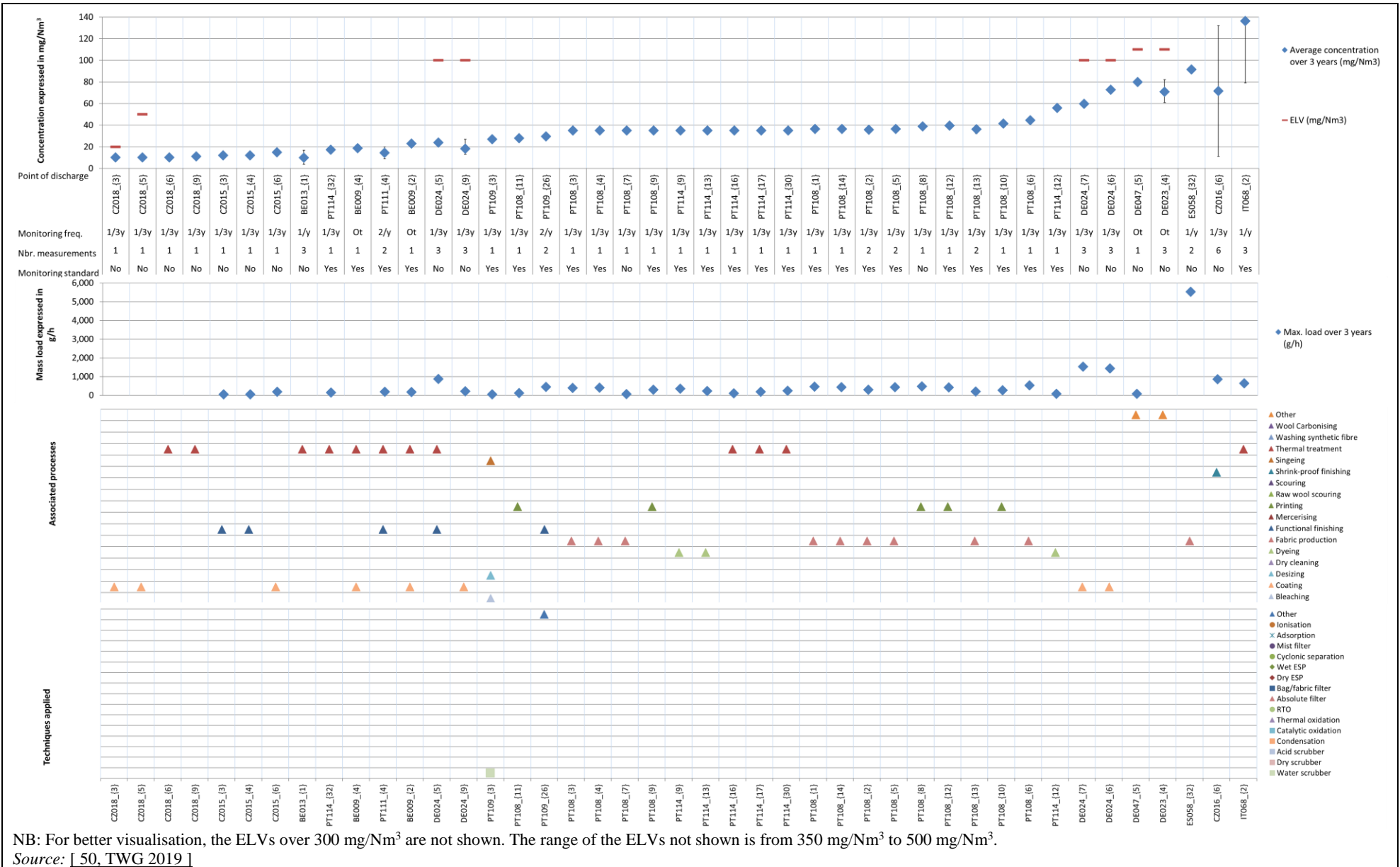
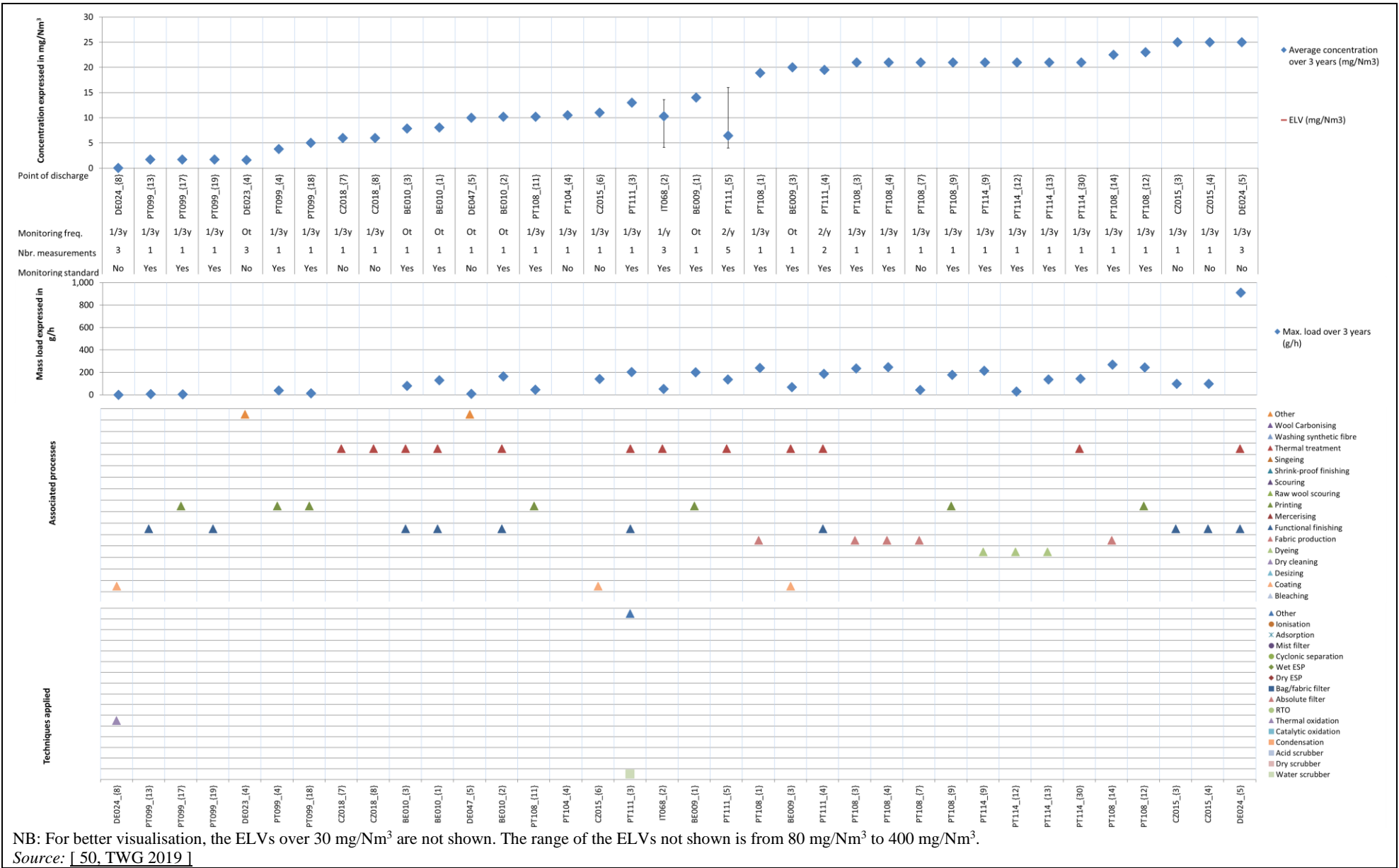


Figure 3.74: NO<sub>x</sub> emissions to air (Part 2 of 2)



NB: For better visualisation, the ELVs over 30 mg/Nm<sup>3</sup> are not shown. The range of the ELVs not shown is from 80 mg/Nm<sup>3</sup> to 400 mg/Nm<sup>3</sup>.  
 Source: [ 50, TWG 2019 ]

Figure 3.75: CO emissions to air (Part 1 of 2)

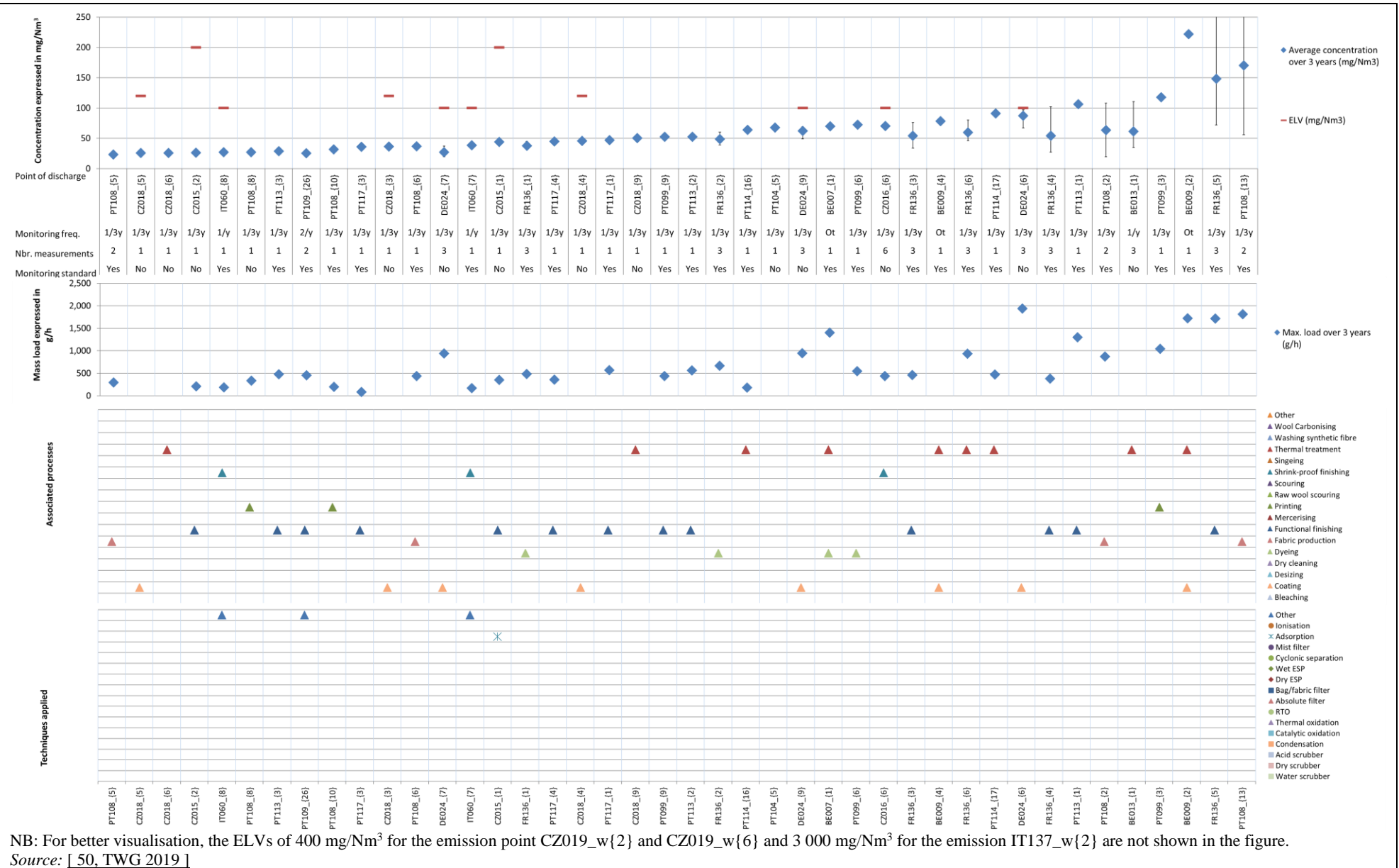


Figure 3.76: CO emissions to air (Part 2 of 2)

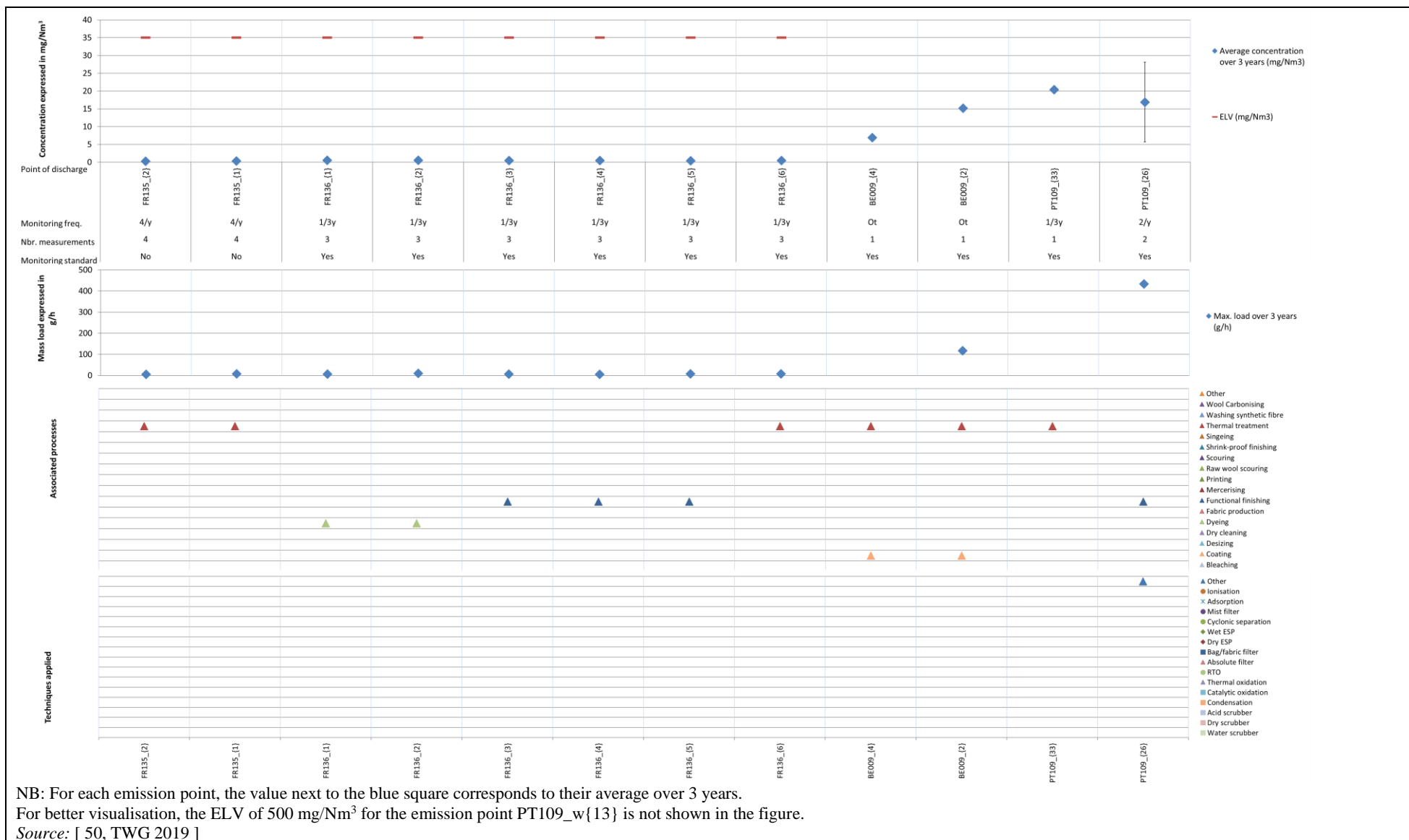


Figure 3.77: SO<sub>x</sub> emissions to air

## 3.6 Specific water and energy consumption

During the data collection, information was reported about the specific water consumption (i.e. cubic metre of water consumed per tonne of textile treated) or the specific energy consumption (i.e. kWh of energy consumed per tonne of textile treated). This information was reported at two levels of aggregation: at plant level (see Section 3.6.1) and, when relevant, at process level (see Section 3.6.2).

### 3.6.1 Consumption at plant level

#### 3.6.1.1 Specific water consumption

The specific water consumption at plant level is shown in Figure 3.80 and Figure 3.81. The upper part of each figure shows the average specific water consumption reported per plant and for the 3-year period (2016-2018). The second part in the middle shows the percentage of recycled/reused water for each year. The third part below shows the combination of candidate BATs reported in the data collection.

The specific water consumption at plant level sorted by the type of product is shown in Figure 3.82.

All the graphs are sorted by ascending order of average specific water consumption over the 3-year period.

#### 3.6.1.2 Specific energy consumption

The specific energy consumption at plant level is shown in Figure 3.83 and Figure 3.84.

The upper part of the figures shows the average specific energy consumption for the 3-year period (2016-2018). The second part shows the combination of candidate BAT reported in the questionnaires. The graph is sorted by ascending order of the average specific energy consumption.

Figure 3.85 and Figure 3.86 show the breakdown of the energy consumption by type of energy at plant level and consist of four parts. The first part shows the average specific energy consumption for the 3-year period (2016-2018). The second and third parts show the average specific electricity consumption and average specific heat consumption respectively. The last part shows the proportion of recovered heat in the heat consumed. The graph is sorted by ascending order of the average specific energy consumption.

### 3.6.2 Consumption at process level

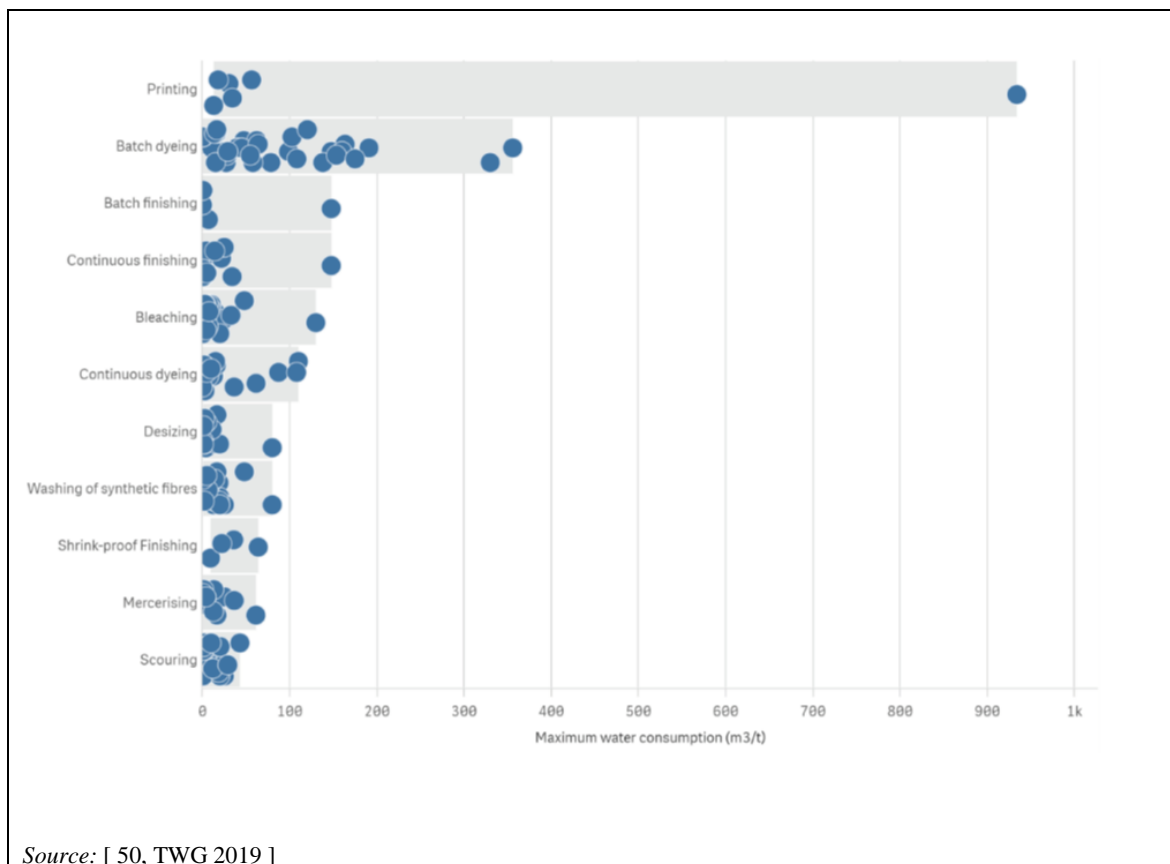
The specific water and energy consumption at the process level was considered confidential business information (CBI) by the TWG. In order to maintain the confidentiality of this information throughout the data assessment, the plant name is not mentioned in graphs and tables where the CBI is used but is replaced by randomly attributed CBI codes for each individual process.

The principles for presenting the data in this section are the same as for specific water and energy consumption at plant level (see Sections 3.6.1.1 and 3.6.1.2, respectively). However, as the data at process level are considered CBI, the following approach has been used to present the CBI data in this document:

- not to show in the graphs and tables any contextual information (e.g. process parameters or techniques applied) as this could give clues as to the plants' identities;
- to present CBI data for a given process only when at least 10 plants of the data collection carry out this process, as a smaller sample may also facilitate the identification of the plants concerned.

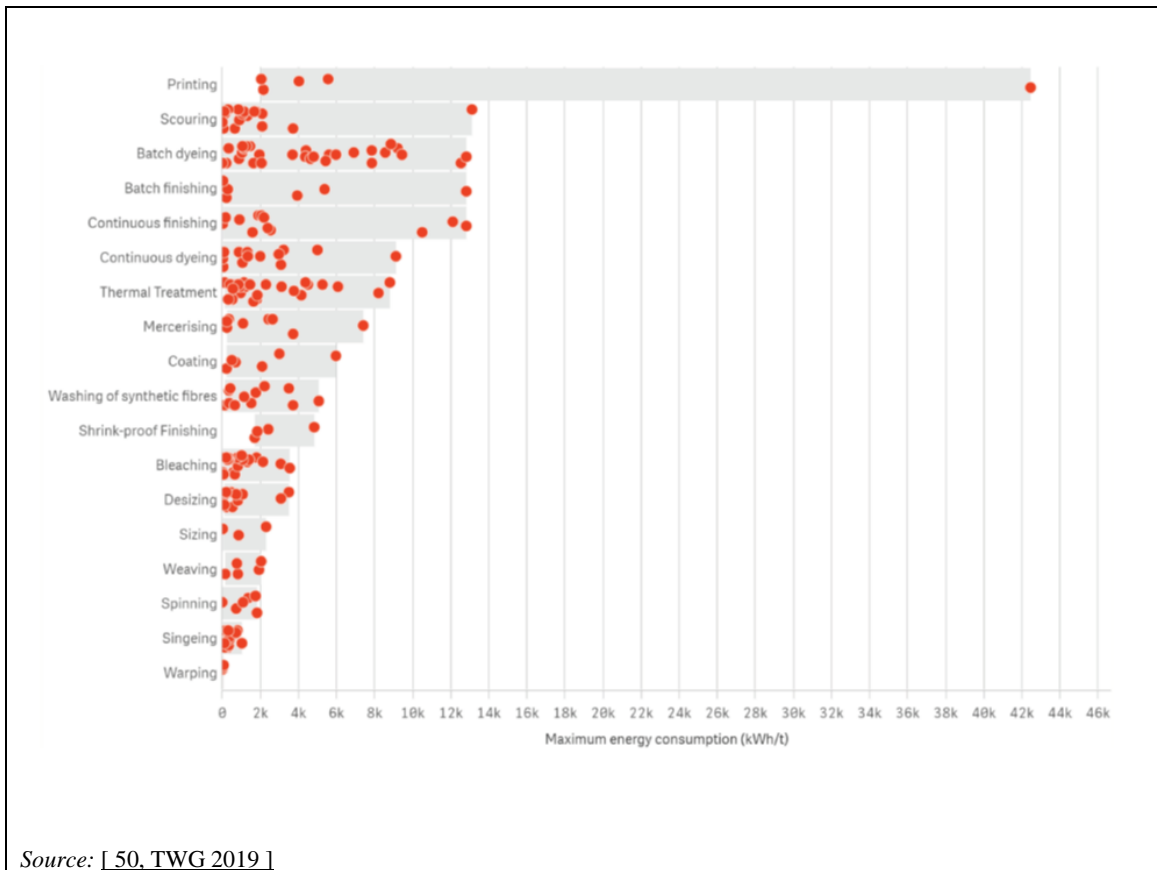
### 3.6.2.1 Overview

Figure 3.78 and Figure 3.79 show the distribution of specific water and energy consumption levels of the different processes carried out at the plants of the data collection, respectively. Some of the highest reported values are clearly outliers (e.g. surpassing the next highest value by several orders of magnitude), possibly due to mistakes in reporting the correct units.



**Figure 3.78: Specific water consumption of the different processes carried out at the plants**





Source: [ 50, TWG 2019 ]

**Figure 3.79: Specific energy consumption of the different processes carried out at the plants**

It is important to note that the reported values are yearly averages that reflect the average over a typical installation's production for a certain process in the reporting period (2016-2018). They are, therefore, the average of the consumption due to many different products, types of fibre and other operational parameters (e.g. auxiliary chemicals, temperature and time of holding in the process liquor or stenter/dryer).

Also important is the fact that the data were often reported agglomerating several processes or estimating/calculating (on an unknown basis) the consumption from the plant to the process level. Another important factor affecting particularly some of the lowest reported water consumption values was specific local technological circumstances, like common water management at large industrial sites (with many similar textile plants), where a high proportion of water recycling has been achieved (e.g. plants in the Prato district in Italy).

This section focuses in particular on the following processes:

- washing of synthetic fibres;
- singeing;
- desizing;
- mercerising;
- scouring;
- bleaching;
- batch and continuous dyeing;
- printing;
- batch and continuous finishing;
- coating;
- thermal treatment.

### 3.6.2.2 Washing of synthetic fibres

Figure 3.87 and Figure 3.88 show the specific water and energy consumption of washing of synthetic fibres, respectively. The specific water consumption ranges from 1 m<sup>3</sup>/t to 48 m<sup>3</sup>/t and the specific energy consumption from 129 kWh/t to 3 718 kWh/t.

### 3.6.2.3 Singeing

Figure 3.89 shows the specific energy consumption of singeing, which ranges from 25 kWh/t to 1 030 kWh/t.

### 3.6.2.4 Desizing

Figure 3.90 and Figure 3.91 show the specific water and energy consumption of desizing, respectively. The specific water consumption ranges from 1 m<sup>3</sup>/t to 22.2 m<sup>3</sup>/t and the specific energy consumption from 109 kWh/t to 3 500 kWh/t.

### 3.6.2.5 Mercerising

Figure 3.92 and Figure 3.93 show the specific water and energy consumption of mercerising, respectively. The specific water consumption ranges from 1 m<sup>3</sup>/t to 61 m<sup>3</sup>/t and the specific energy consumption from 243 kWh/t to 7 406 kWh/t.

### 3.6.2.6 Scouring

Figure 3.94 and Figure 3.95 show the specific water and energy consumption of scouring, respectively. The specific water consumption ranges from 1 m<sup>3</sup>/t to 43 m<sup>3</sup>/t and the specific energy consumption from 65.7 kWh/t to 13 117 kWh/t.

The range 1 m<sup>3</sup>/t to 43 m<sup>3</sup>/t corresponds to the specific water consumption of batch scouring, while the specific water consumption for continuous scouring ranges from 2 m<sup>3</sup>/t to 20 m<sup>3</sup>/t.

### 3.6.2.7 Bleaching

Figure 3.96 and Figure 3.97 show the specific water and energy consumption of bleaching, respectively. The specific water consumption ranges from 1 m<sup>3</sup>/t to 93.2 m<sup>3</sup>/t and the specific energy consumption from 29 kWh/t to 3 074 kWh/t.

The range 1 m<sup>3</sup>/t to 93.2 m<sup>3</sup>/t corresponds to the specific water consumption of batch bleaching, while the specific water consumption for continuous bleaching ranges from 1 m<sup>3</sup>/t to 32.7 m<sup>3</sup>/t.

In total, 13 plants reported using the technique of combined pretreatment of cotton (see Section 4.4.3). Figure 3.98 shows the specific water consumption reported by these plants for desizing, scouring and bleaching. The values range from 0 m<sup>3</sup>/t to 33 m<sup>3</sup>/t.

### 3.6.2.8 Dyeing

#### 3.6.2.8.1 Batch dyeing

Figure 3.99 and Figure 3.100 show the specific water and energy consumption of batch dyeing, respectively. The specific water consumption ranges from 0.4 m<sup>3</sup>/t to 330 m<sup>3</sup>/t and the specific energy consumption from 1 kWh/t to 12 820 kWh/t.

The range 0.4 m<sup>3</sup>/t to 175 m<sup>3</sup>/t corresponds to the specific water consumption of batch dyeing of fabrics (woven and knitted), while the specific water consumption for batch dyeing of loose fibre ranges from 14 m<sup>3</sup>/t to 191 m<sup>3</sup>/t and the specific water consumption for batch dyeing of yarns ranges from 3 m<sup>3</sup>/t to 330 m<sup>3</sup>/t.

#### 3.6.2.8.2 Continuous dyeing

Figure 3.101 and Figure 3.102 show the specific water and energy consumption of continuous dyeing, respectively. The specific water consumption ranges from 0.45 m<sup>3</sup>/t to 110 m<sup>3</sup>/t and the specific energy consumption from 40.9 kWh/t to 9 120 kWh/t.

### 3.6.2.9 Printing

Table 3.17 shows the specific water and energy consumption of printing. The specific water consumption ranges from 13 m<sup>3</sup>/t to 934 m<sup>3</sup>/t and the specific energy consumption from 2 050 kWh/t to 42 460 kWh/t.

### 3.6.2.10 Finishing

#### 3.6.2.10.1 Batch finishing

Little information has been collected about batch finishing in terms of water and energy consumption. The specific water consumption ranges from 0.03 m<sup>3</sup>/t to 148 m<sup>3</sup>/t and the specific energy consumption from 42 kWh/t to 12 818 kWh/t.

#### 3.6.2.10.2 Continuous finishing

Figure 3.103 and Figure 3.104 show the specific water and energy consumption of continuous dyeing, respectively. The specific water consumption ranges from 0 m<sup>3</sup>/t to 148 m<sup>3</sup>/t and the specific energy consumption from 29 kWh/t to 12 818 kWh/t.

### 3.6.2.11 Coating

Figure 3.105 shows the specific energy consumption of coating, which ranges from 228 kWh/t to 5 970 kWh/t.

### 3.6.2.12 Thermal treatment

Figure 3.106 shows the specific energy consumption of thermal treatment, which ranges from 120 kWh/t to 8 800 kWh/t.

Higher values may have included the energy consumption due to associated abatement techniques and/or recovery and recycling processes (e.g. for water, energy, chemicals).

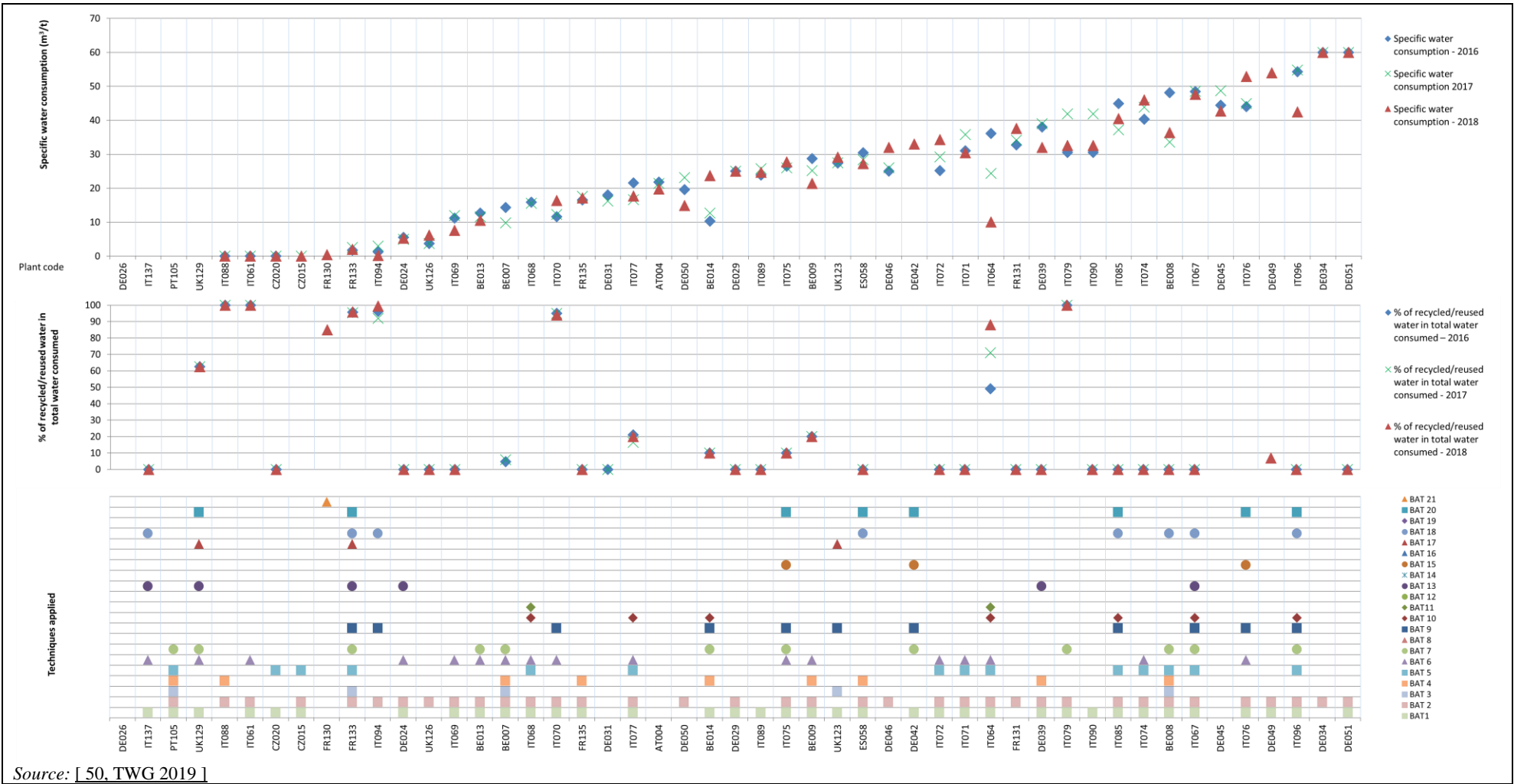
### 3.6.3 Figures and tables with water and energy consumption levels

The meanings of the acronyms used in Figure 3.80 and Figure 3.81 are as follows.

Acronym	Meaning
BAT1	Management and good housekeeping
BAT2	Optimising water consumption in textile operations
BAT3	Water reuse/recycling in batch dyeing processes
BAT4	Reduction of water consumption in cleaning operations
BAT5	Water and energy conservation in batch washing and rinsing
BAT6	Water and energy conservation in continuous washing and rinsing
BAT7	Procedures to avoid spillages and overfilling
BAT8	Adjustment of scheduling in production
BAT9	Automatic controllers of fill volume and liquor temperature
BAT10	Drain and fill method for rinsing
BAT11	Smart rinsing systems
BAT12	Overflow or 'flood' rinsing
BAT13	Automatic stop valves
BAT14	Counter-current washing
BAT15	Reduction of carry-over
BAT16	Dry cleaning of process baths before rinsing
BAT17	Reuse rinsing water
BAT18	Reuse cooling water
BAT19	Reuse cleaning water
BAT20	On-line monitoring
BAT21	Other

The meanings of the acronyms used in Figure 3.83 and Figure 3.84 are as follows.

<b>Acronym</b>	<b>Meaning</b>
BAT1	Management and good housekeeping
BAT2	Minimising energy consumption in wool scouring installations
BAT3	Minimisation of energy consumption of stenter frames
BAT4	Water and energy conservation in batch washing and rinsing
BAT5	Water and energy conservation in continuous washing and rinsing
BAT6	Heat recovery from waste water
BAT7	Heat recovery from waste gases
BAT8	Heat recovery from warm process water
BAT9	Optimisation of energy consumed by the compressed air system
BAT10	Combined Heat and Power
BAT11	On-line monitoring
BAT12	Other



Source: [ 50, TWG 2019 ]

Figure 3.80: Water consumption at plant level (Part 1 of 2)

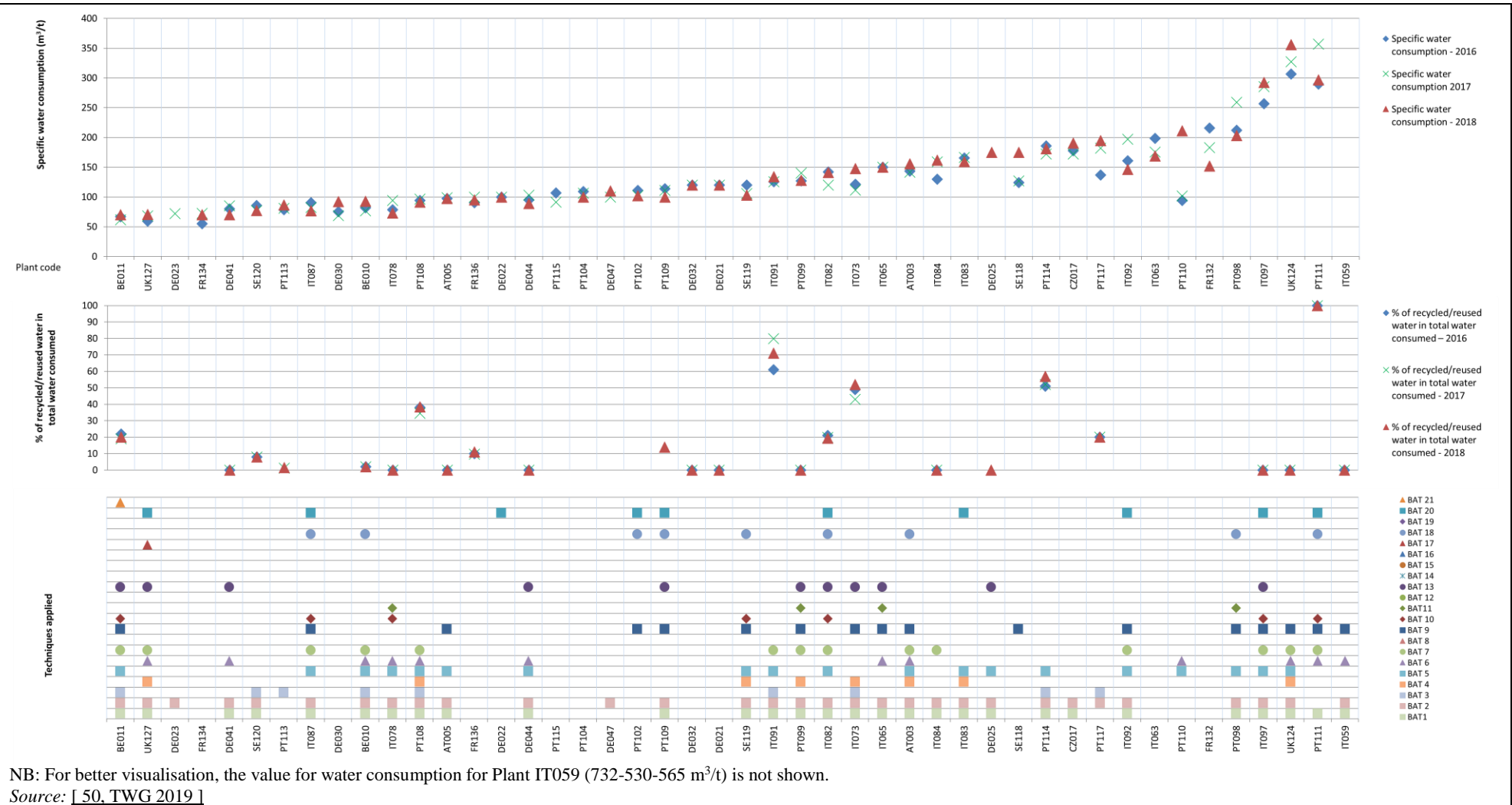


Figure 3.81: Water consumption at plant level (Part 2 of 2)

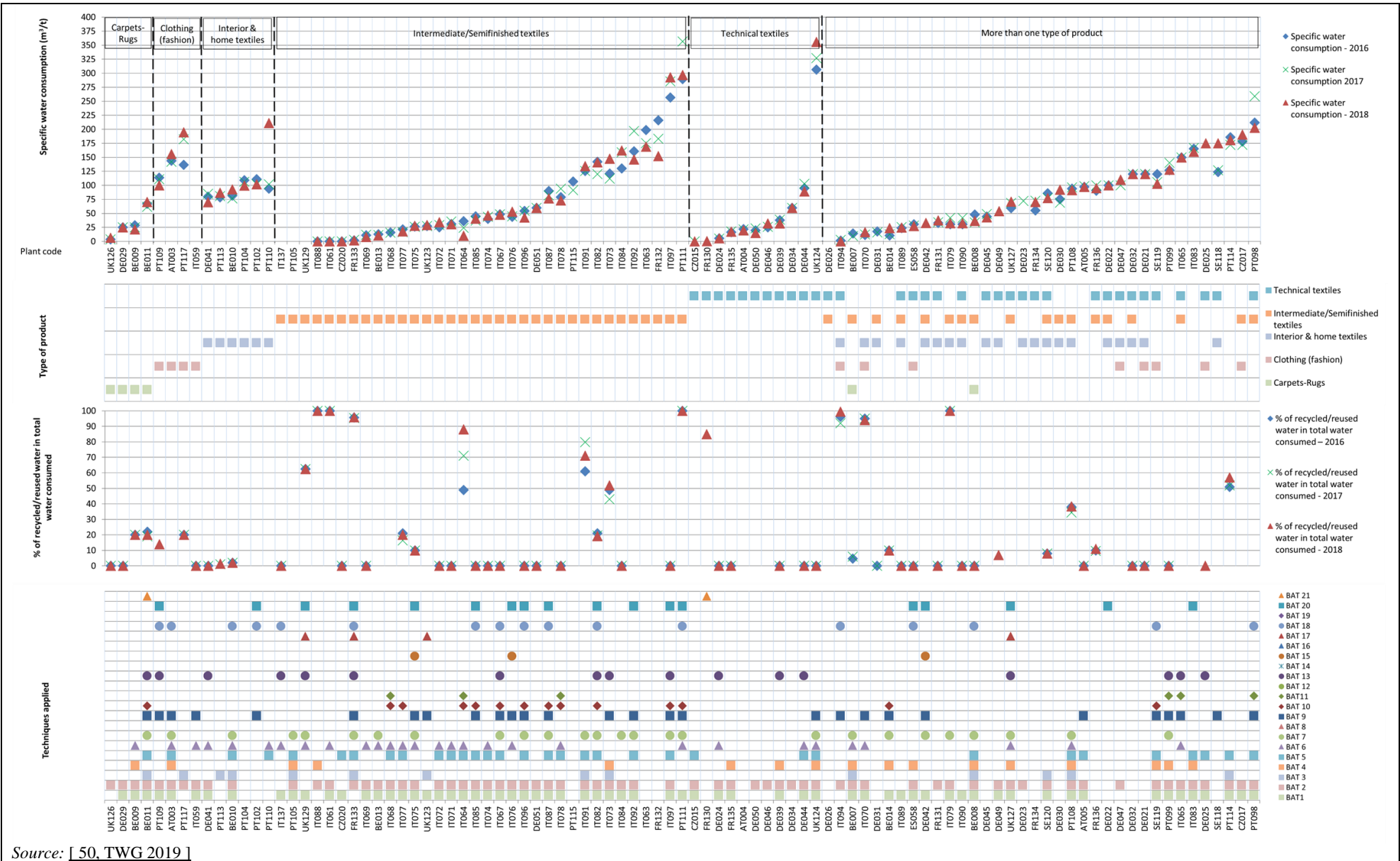
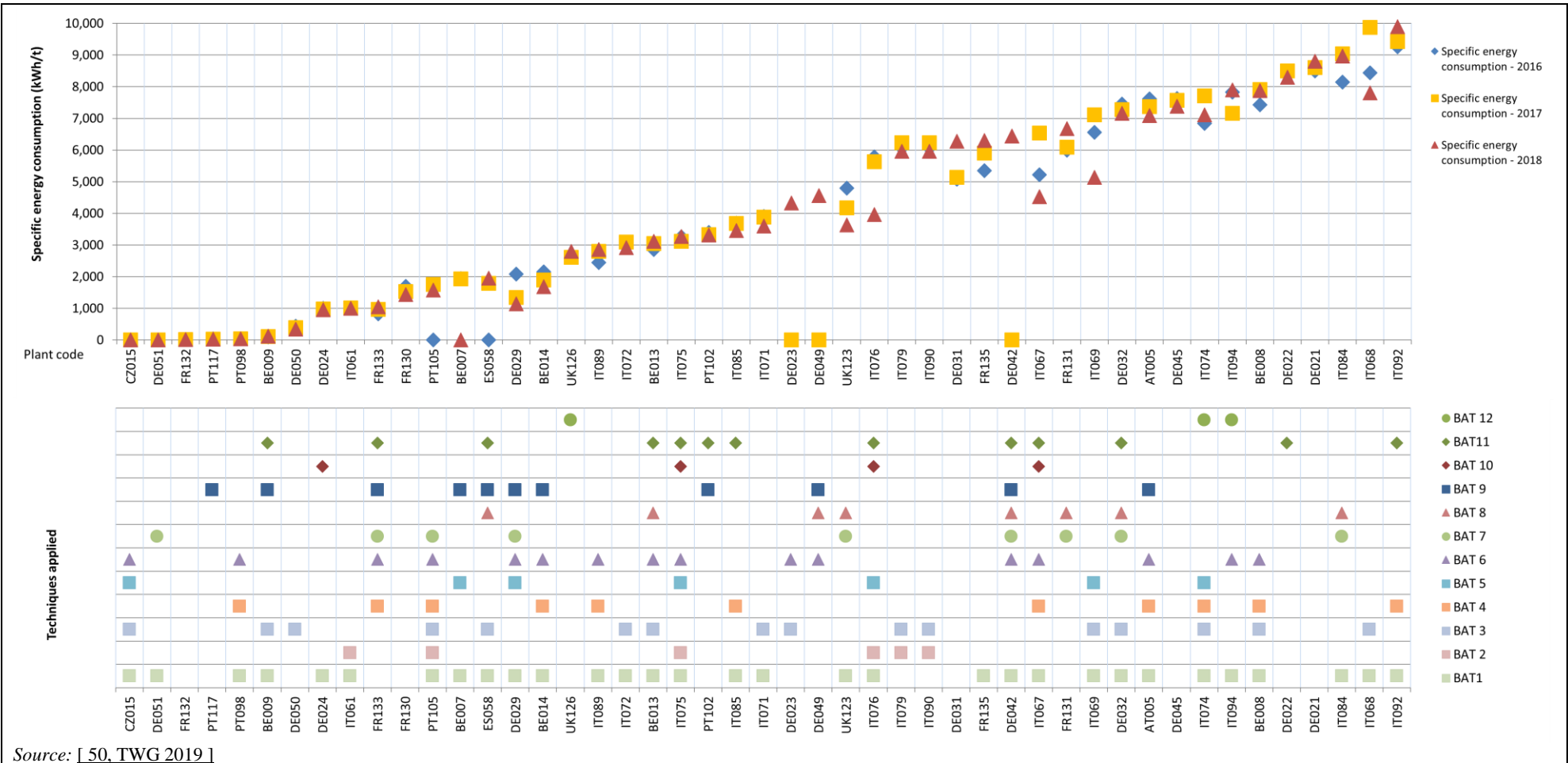


Figure 3.82: Water consumption at plant level sorted by type of product





Source: [ 50, TWG 2019 ]

Figure 3.83: Energy consumption at plant level (Part 1 of 2)

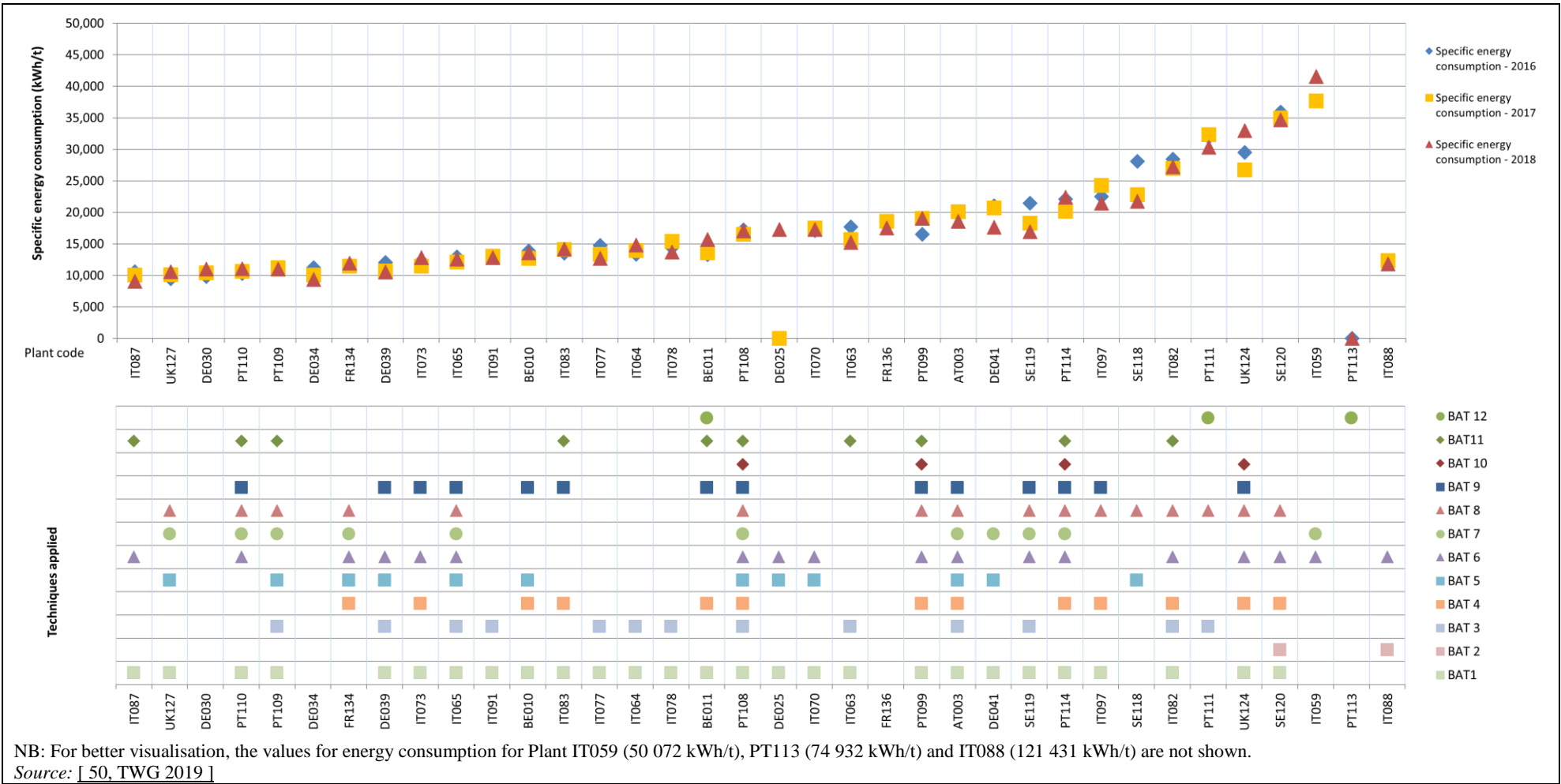
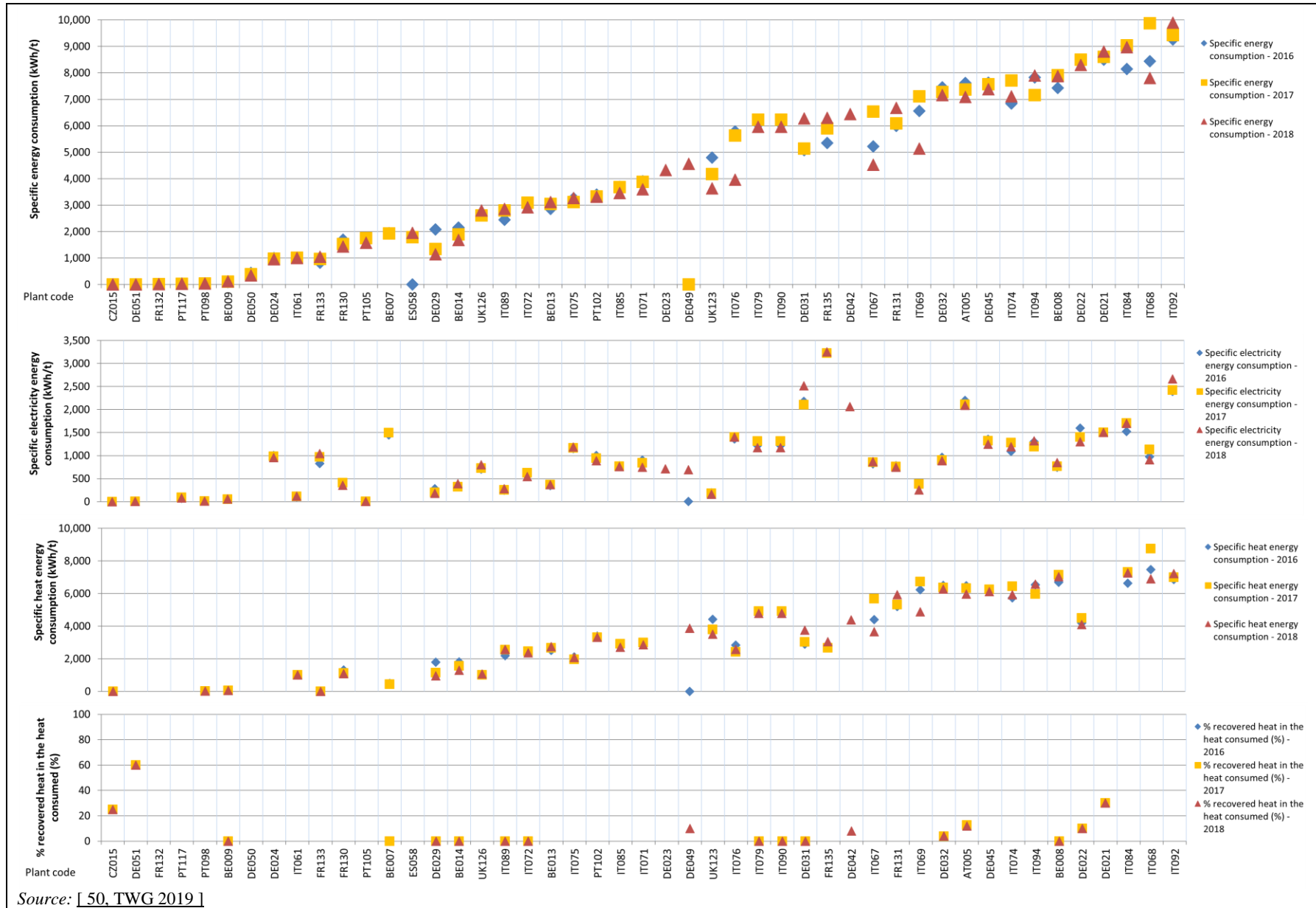


Figure 3.84: Energy consumption at plant level (Part 2 of 2)



Source: [ 50, TWG 2019 ]

Figure 3.85: Breakdown of the energy consumption at plant level (Part 1 of 2)

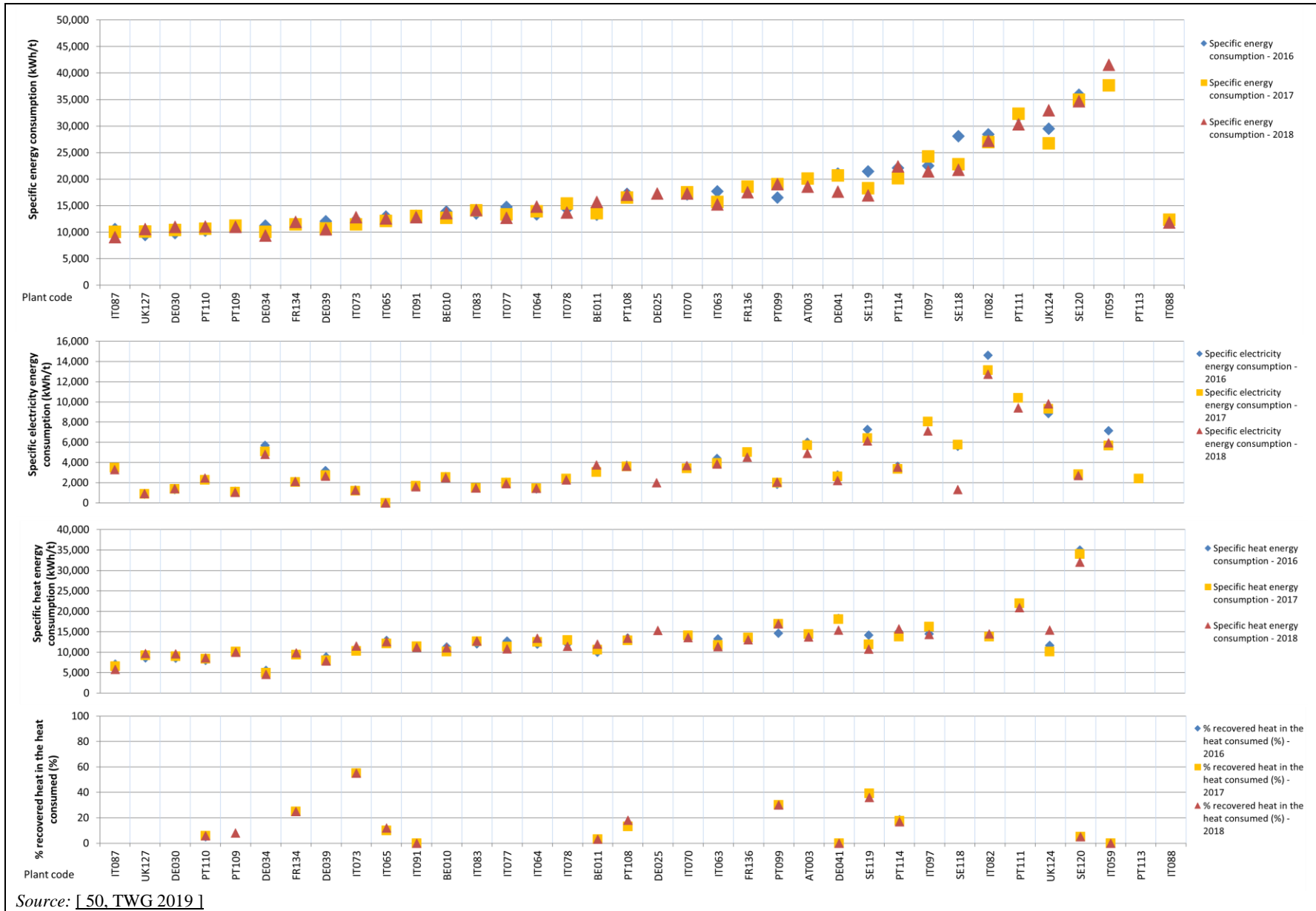


Figure 3.86: Breakdown of the energy consumption at plant level (Part 2 of 2)

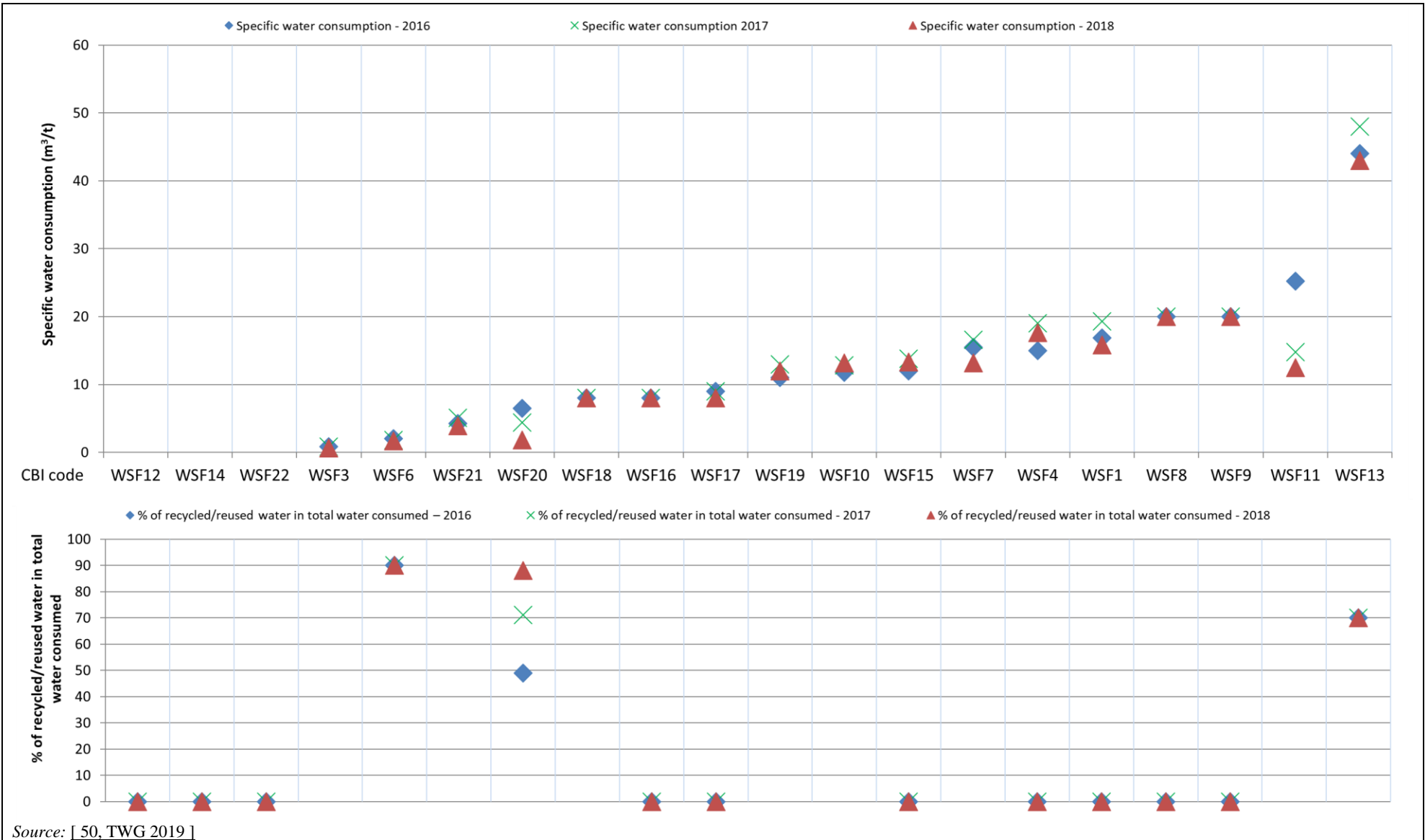


Figure 3.87: Specific water consumption of washing of synthetic fibres

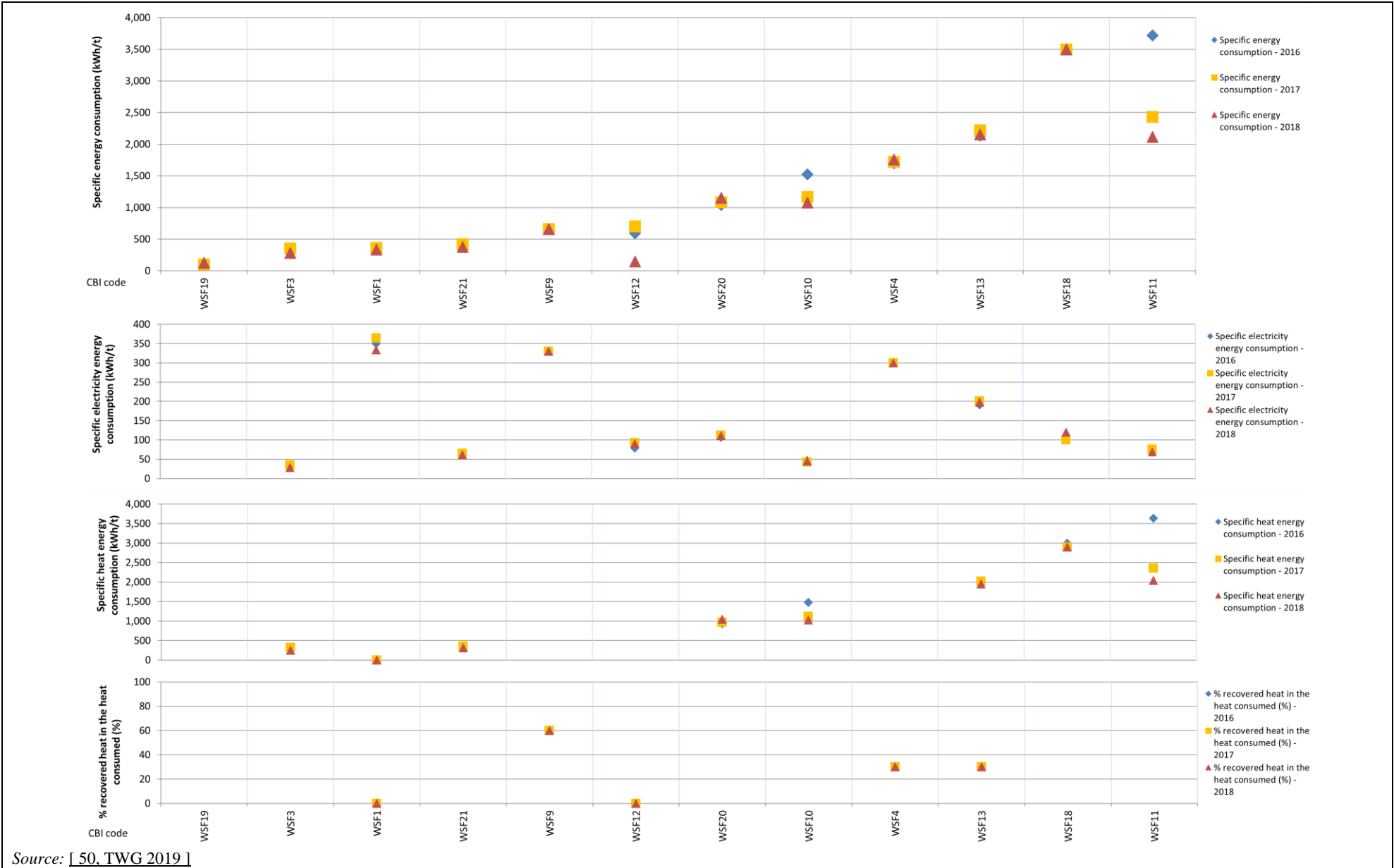
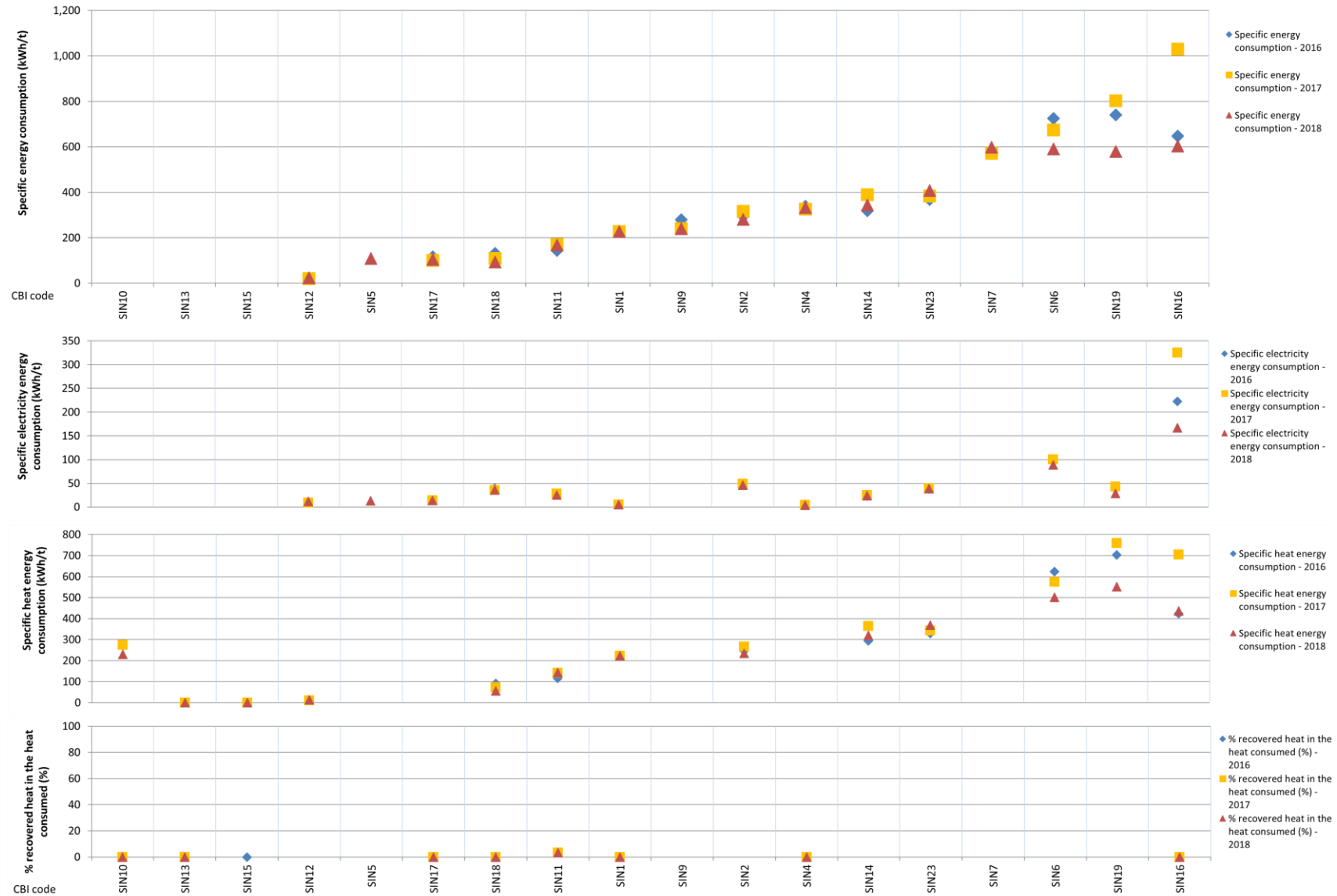


Figure 3.88: Specific energy consumption of washing of synthetic fibres



Source: [ 50, TWG 2019 ]

Figure 3.89: Specific energy consumption of singeing

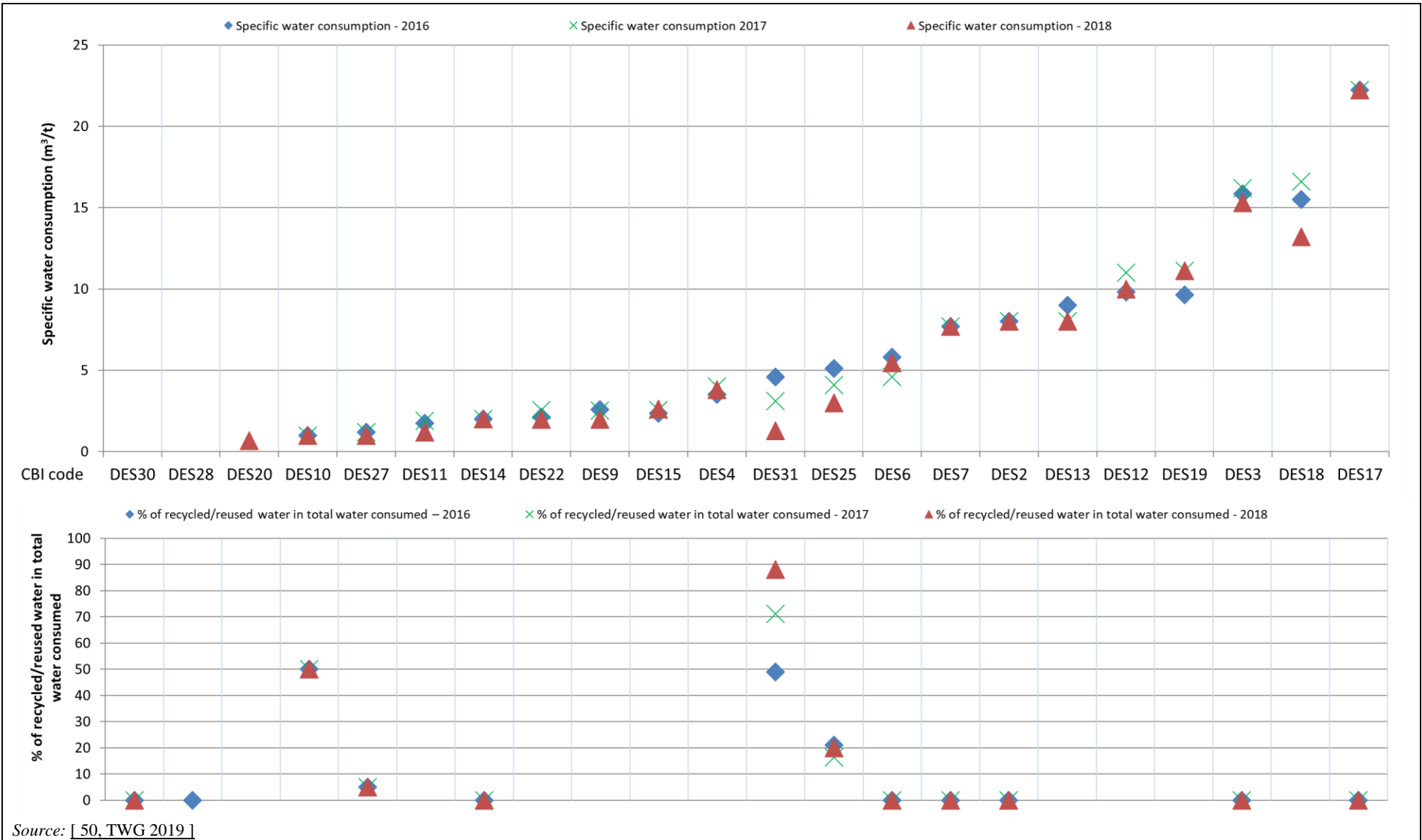


Figure 3.90: Specific water consumption of desizing



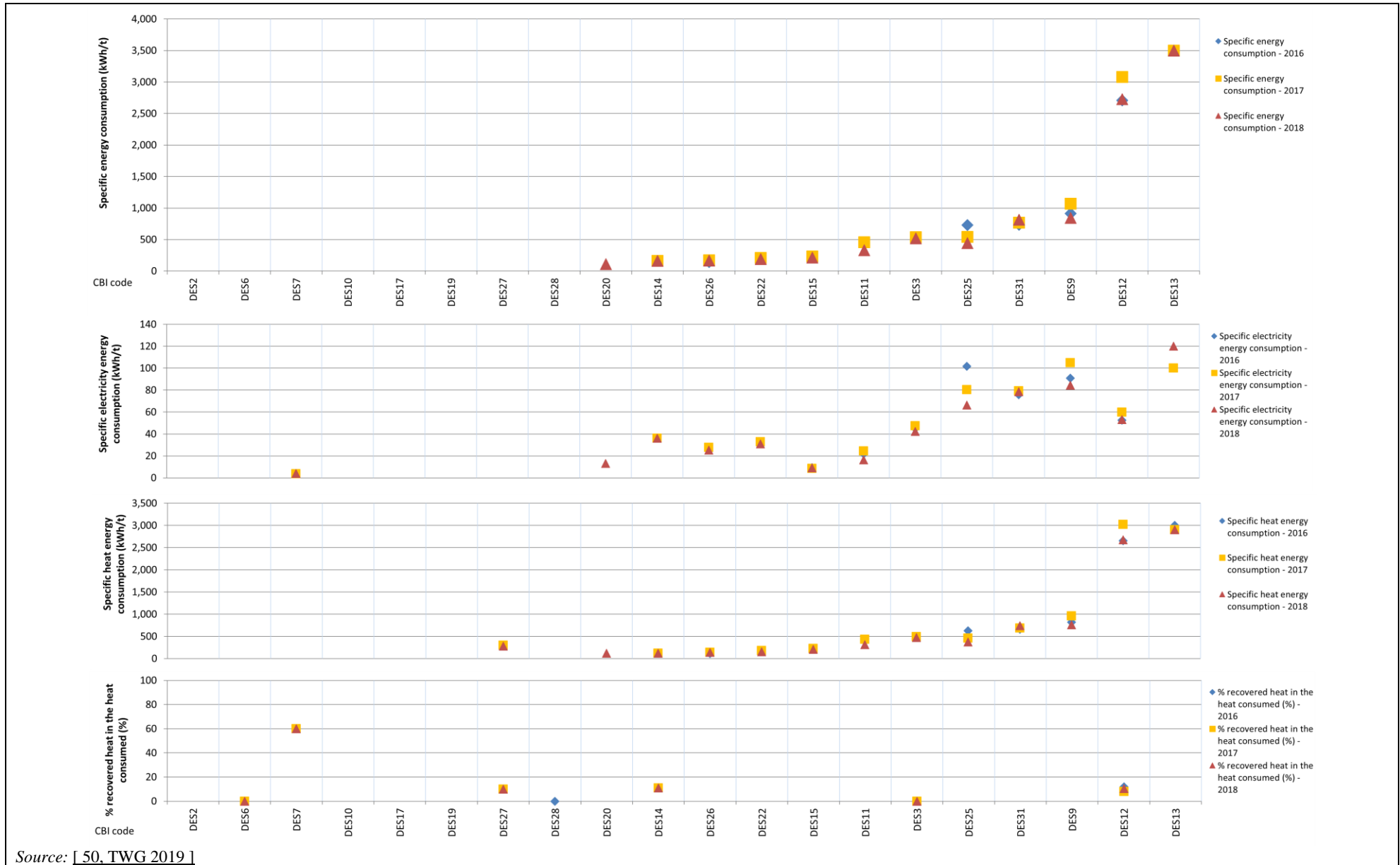


Figure 3.91: Specific energy consumption of desizing

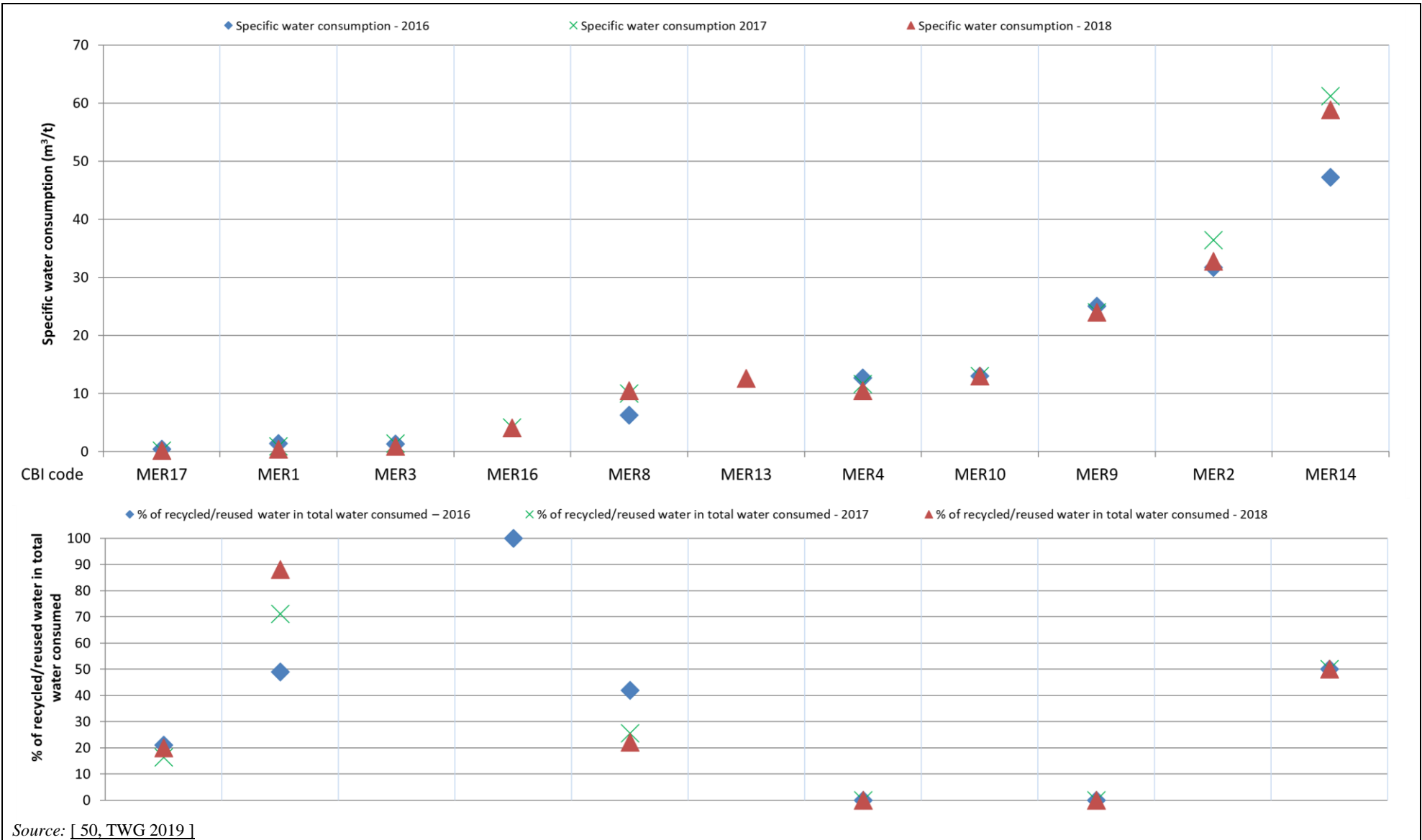


Figure 3.92: Specific water consumption of mercerising

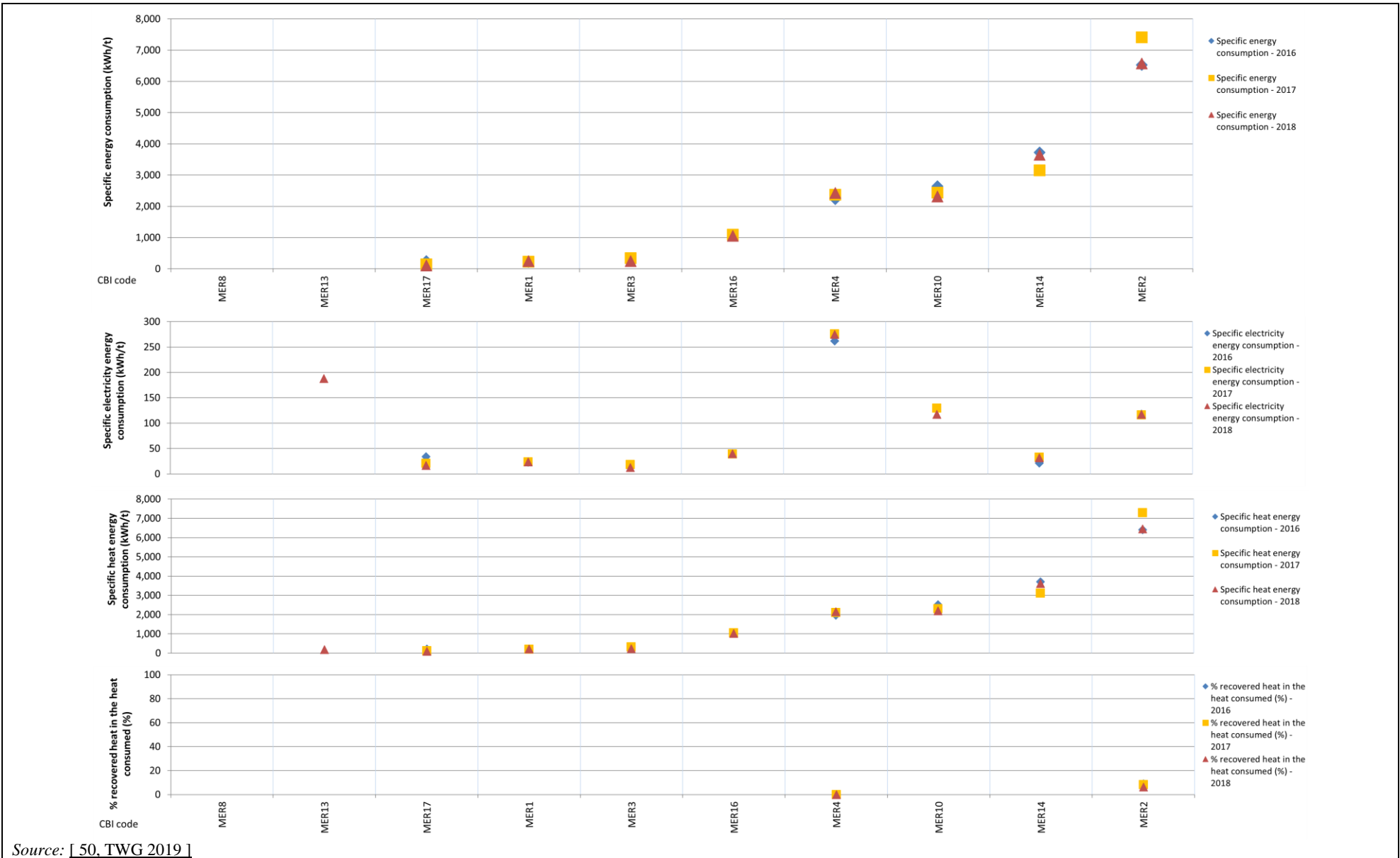


Figure 3.93: Specific energy consumption of mercerising

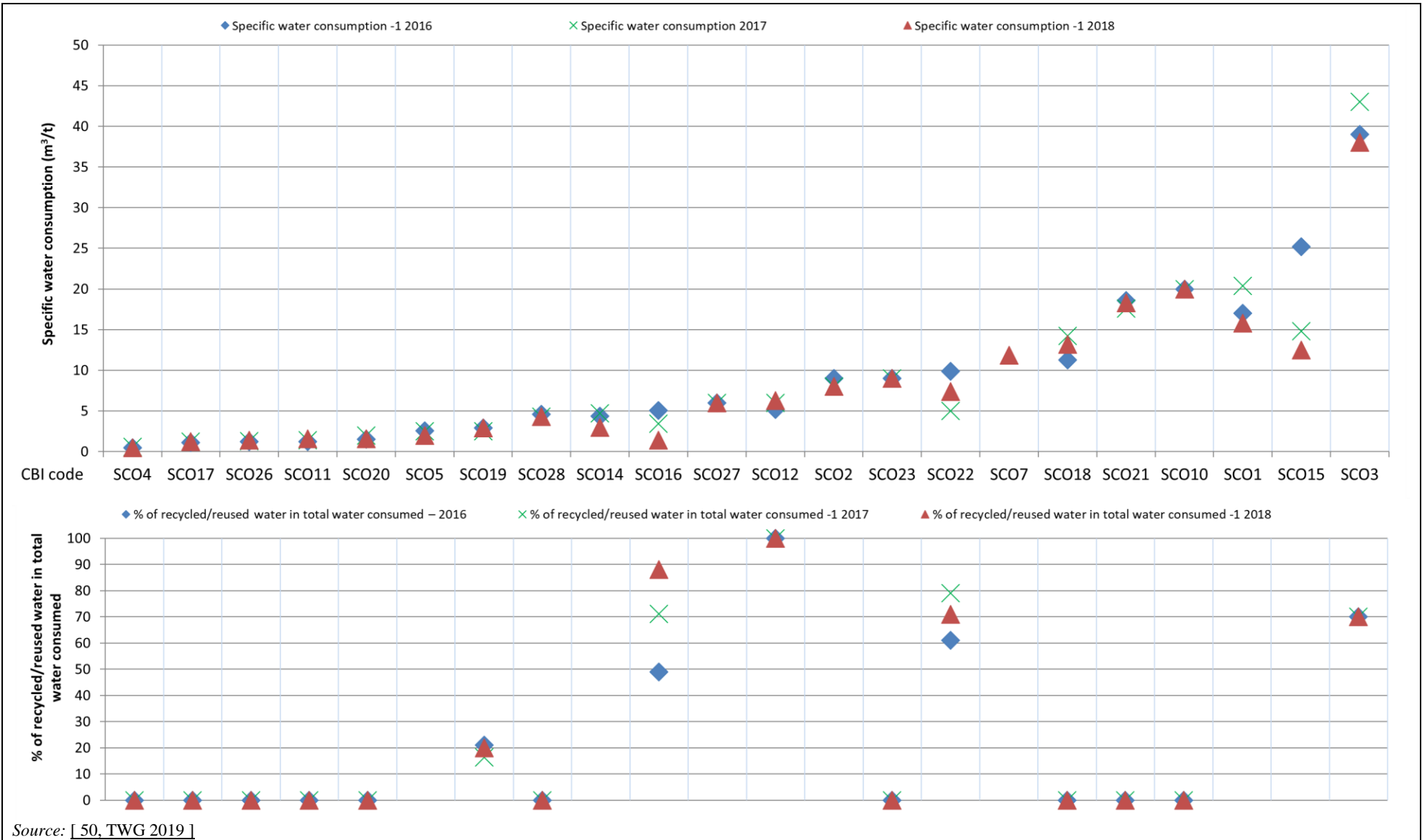


Figure 3.94: Specific water consumption of scouring

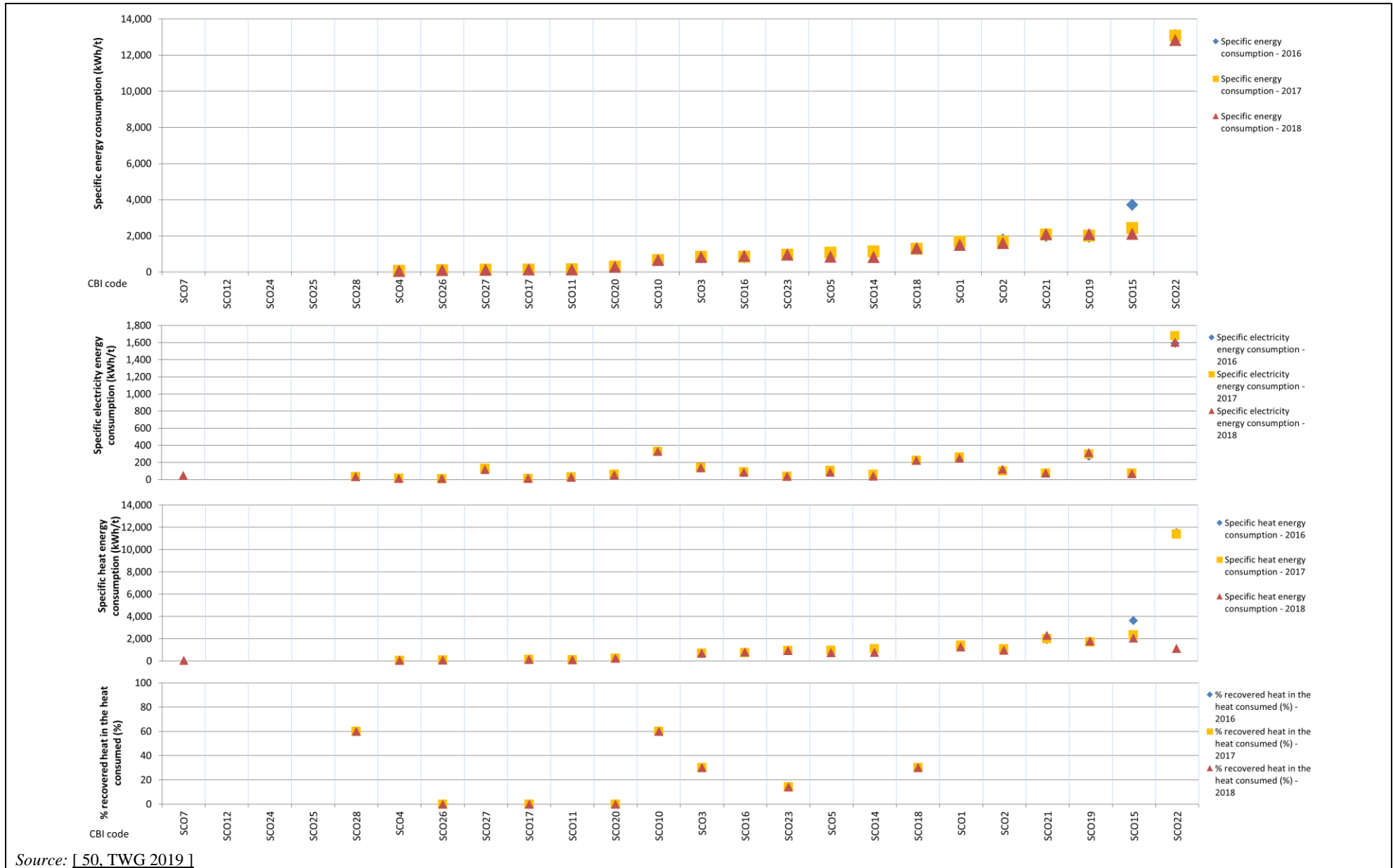


Figure 3.95: Specific energy consumption of scouring

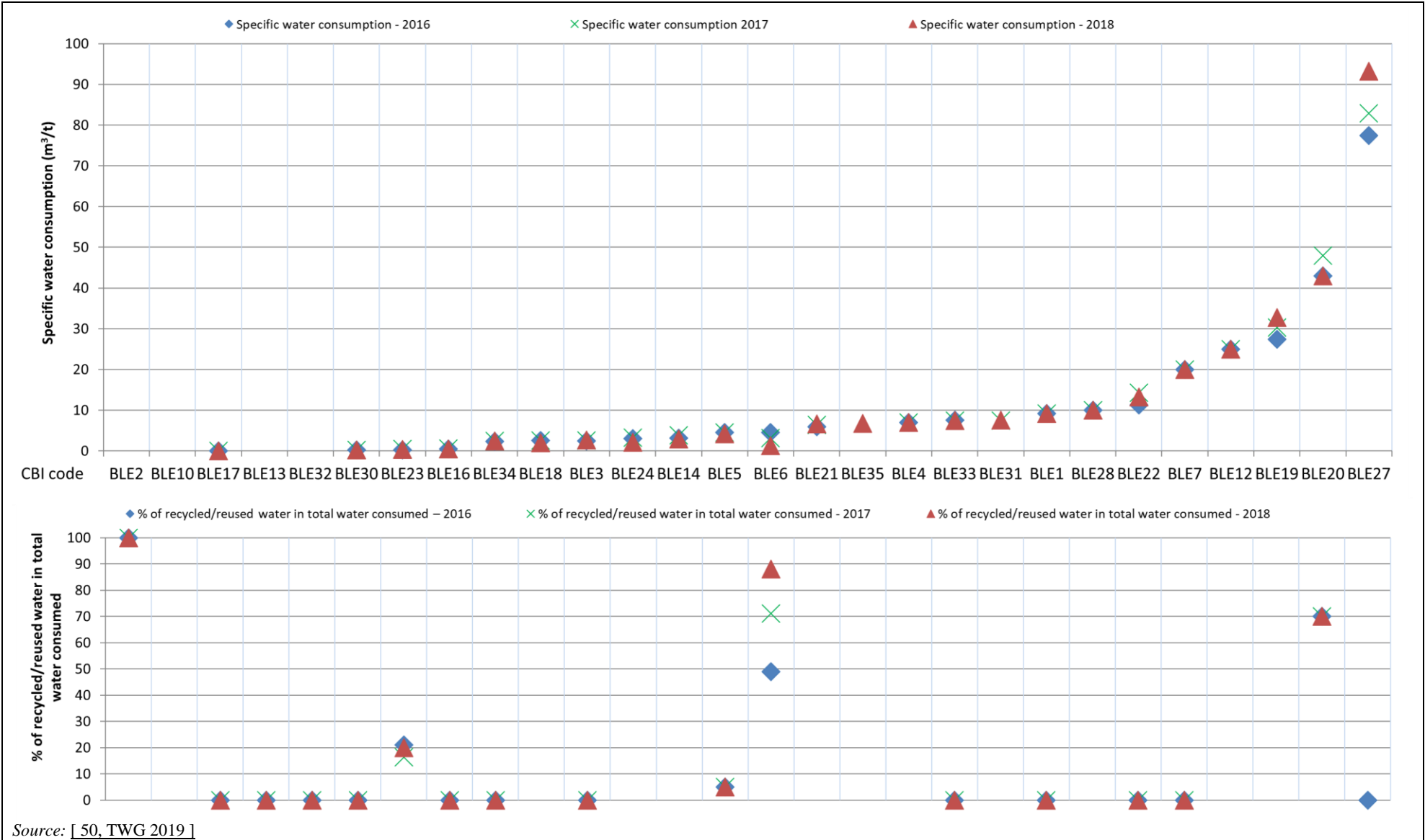
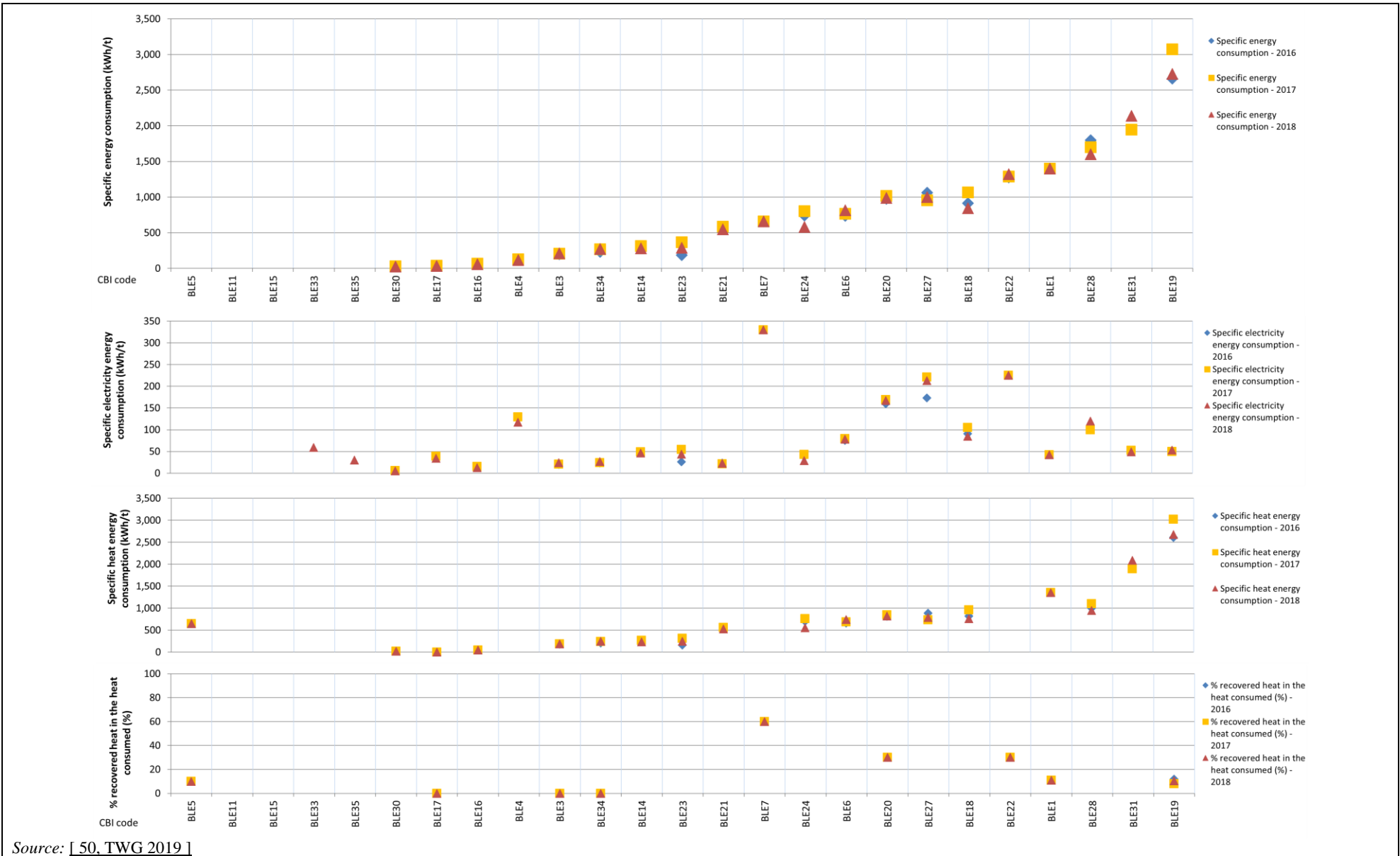


Figure 3.96: Specific water consumption of bleaching



Source: [ 50, TWG 2019 ]

Figure 3.97: Specific energy consumption of bleaching

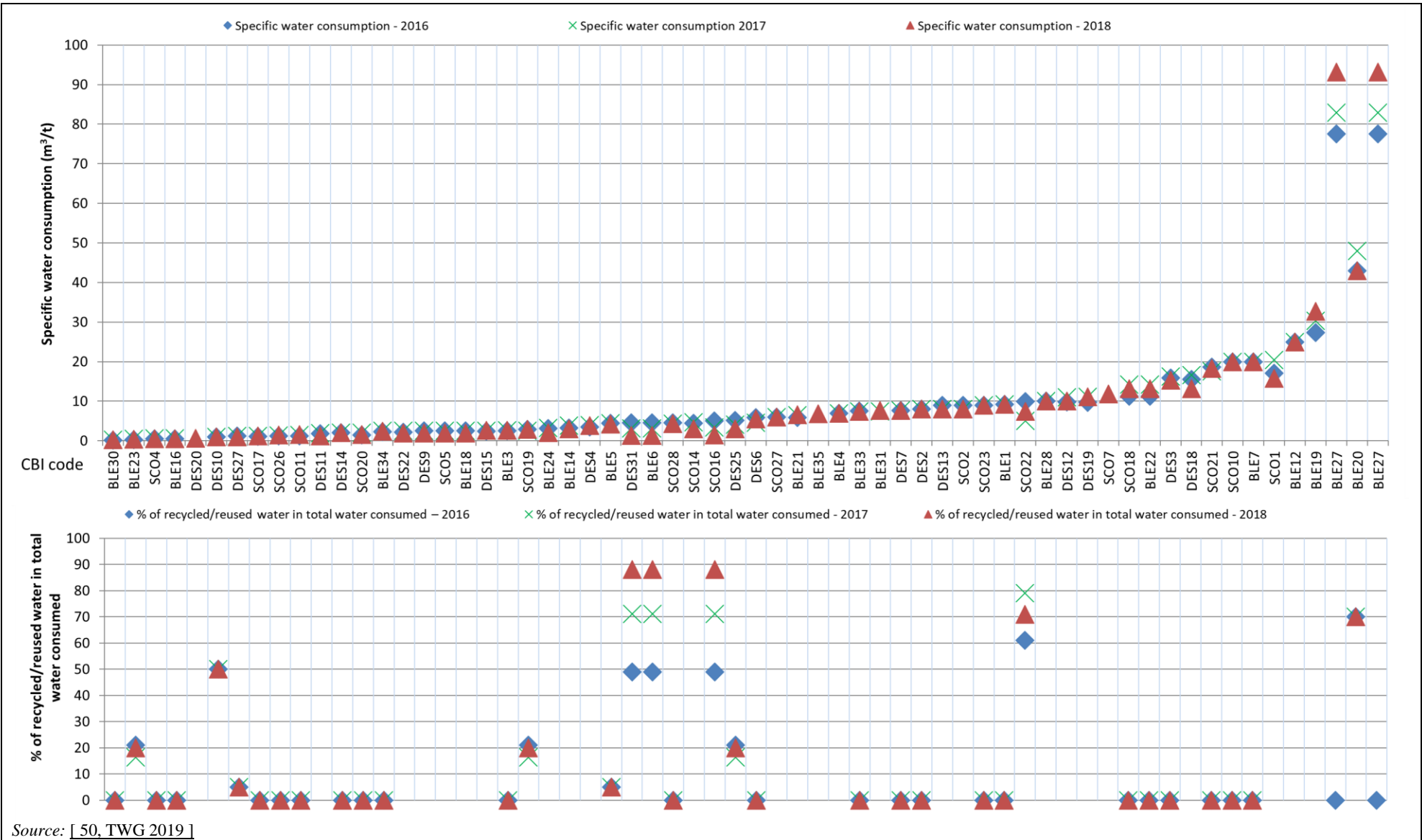


Figure 3.98: Specific energy consumption of combined pretreatment of cotton (see Section 4.4.3)



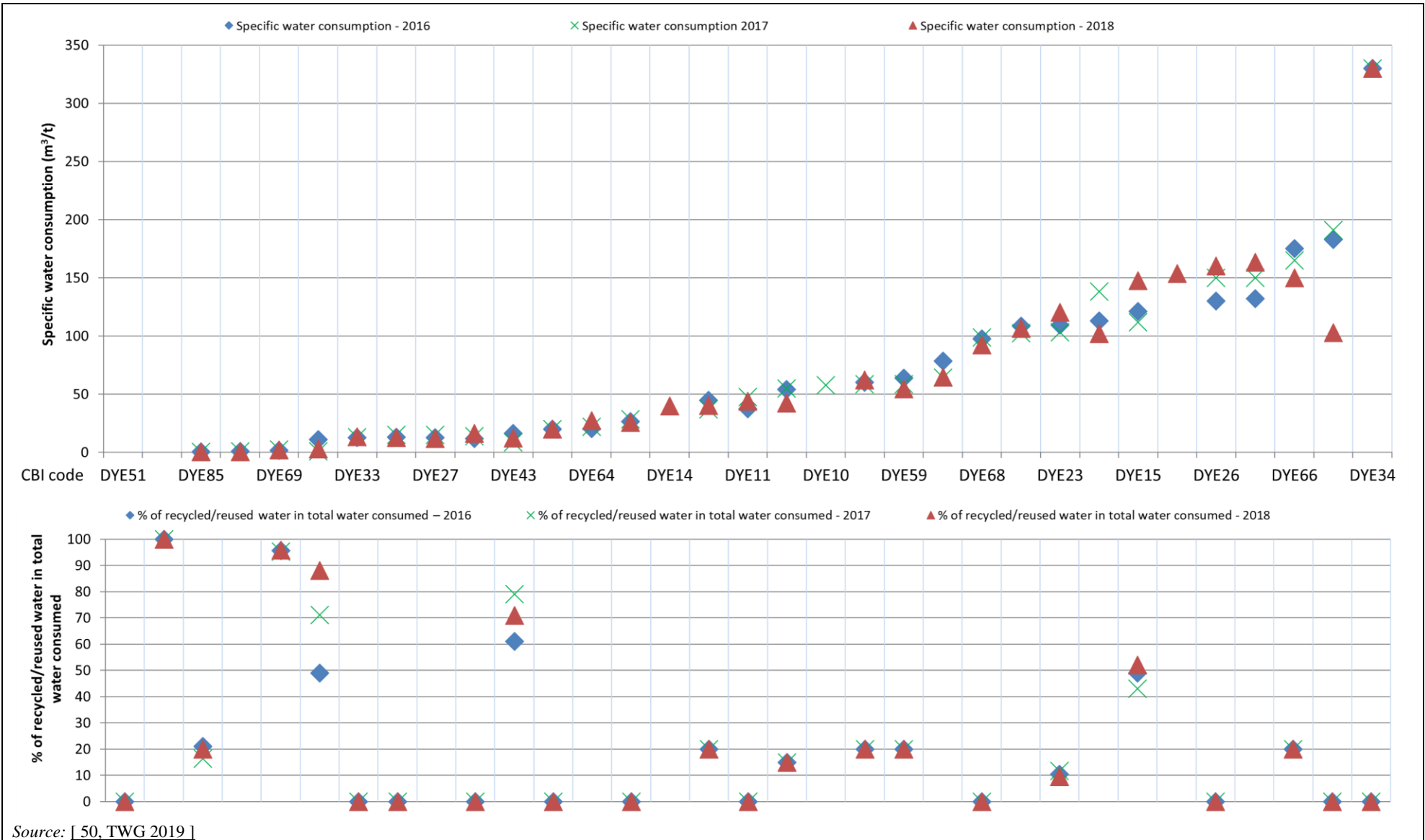
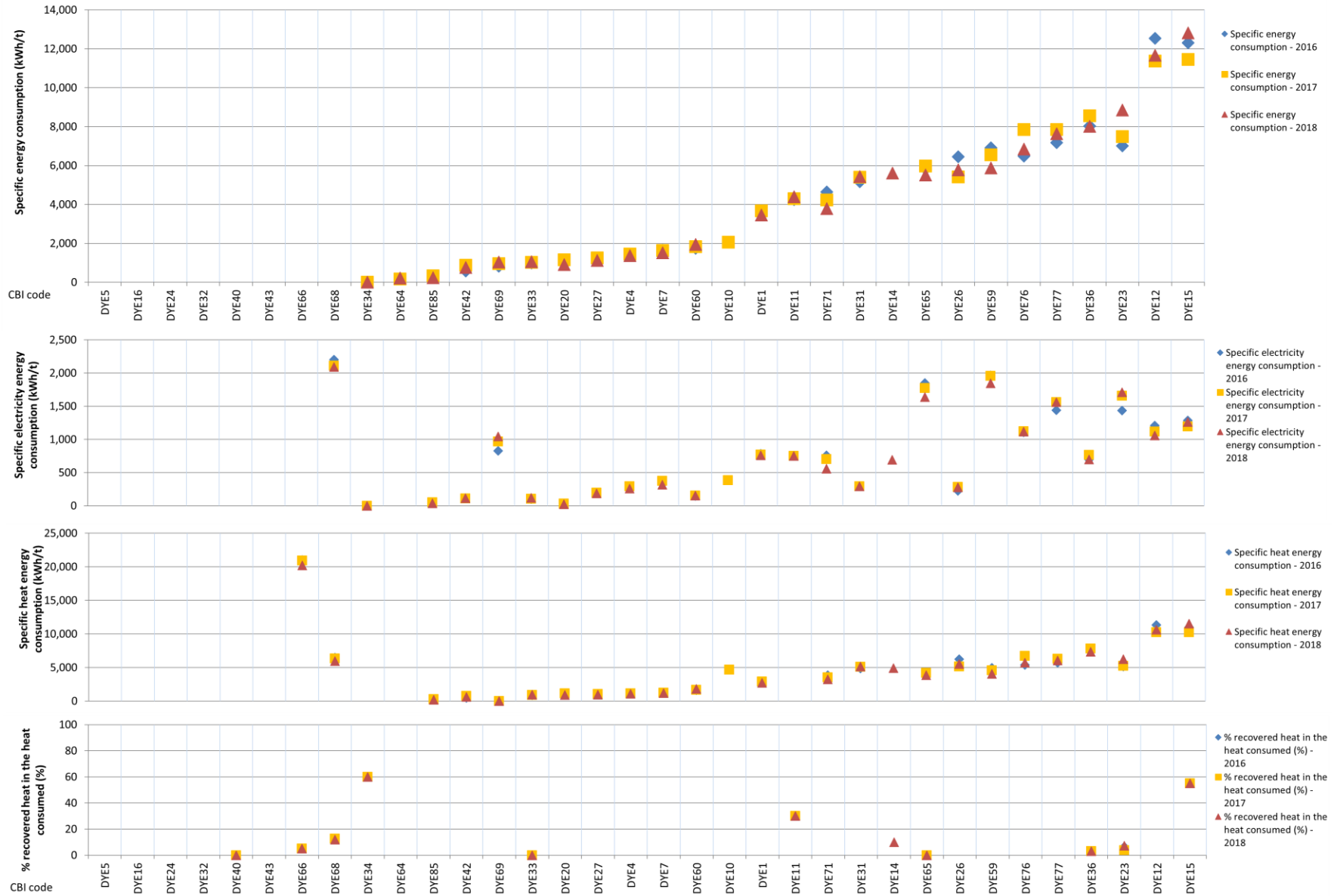


Figure 3.99: Specific water consumption of batch dyeing



Source: [ 50, TWG 2019 ]

Figure 3.100: Specific energy consumption of batch dyeing

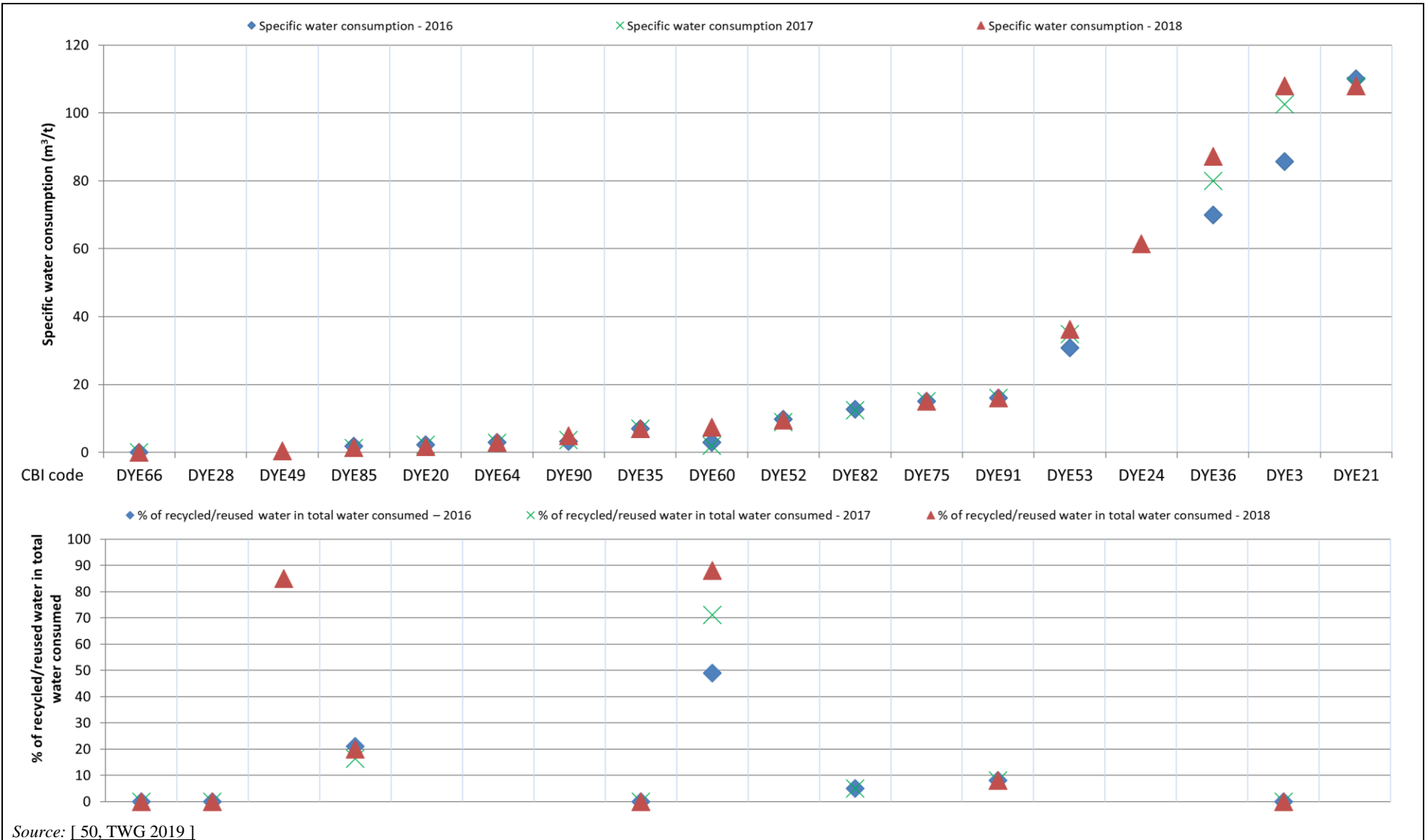


Figure 3.101: Specific water consumption of continuous dyeing



Source: [ 50, TWG 2019 ]

Figure 3.102: Specific energy consumption of continuous dyeing

Table 3.17: Specific water and energy consumption of printing

CBI code	Specific net (fresh) water consumption			Specific net energy consumption			Electricity consumption			Net heat consumption			Proportion of recycled/reused water in the total water consumed			Proportion of recovered heat in the heat consumed		
	m <sup>3</sup> /tonne of textiles processed						kWh/tonne of textiles processed						%					
	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018
PRI4	18.1	17.3	17.3	2 040	2 051	2 000	267	263	265	1 773	1788	1 735	32	25	25	4	3	6
PRI6	47	54.6	56.4	5 561	1 366	1 754	856	185	188	4 682	1169	1 560	0	0	0	30	30	30
PRI9	0	9.5	12.9	NI	NI	NI	0	182	217	NI	NI	2 606	NI	NI	NI	NI	NI	NI
PRI10	23.4	26.1	34.3	2164	2 053	2 101	195	192	219	1 969	1862	1 882	0	0	0	NI	NI	NI
PRI14	934	877	724	42 459	41 707	36 597	2 992	2 815	2 582	39 467	38892	34 015	NI	NI	NI	NI	NI	NI
PRI15	30.3	26.6	21.4	4 030	3 706	3 763	546	529	551	3 485	3178	3 213	20	20	20	0	0	0

NB: NI = No information.  
Source: [ 50, TWG 2019 ]

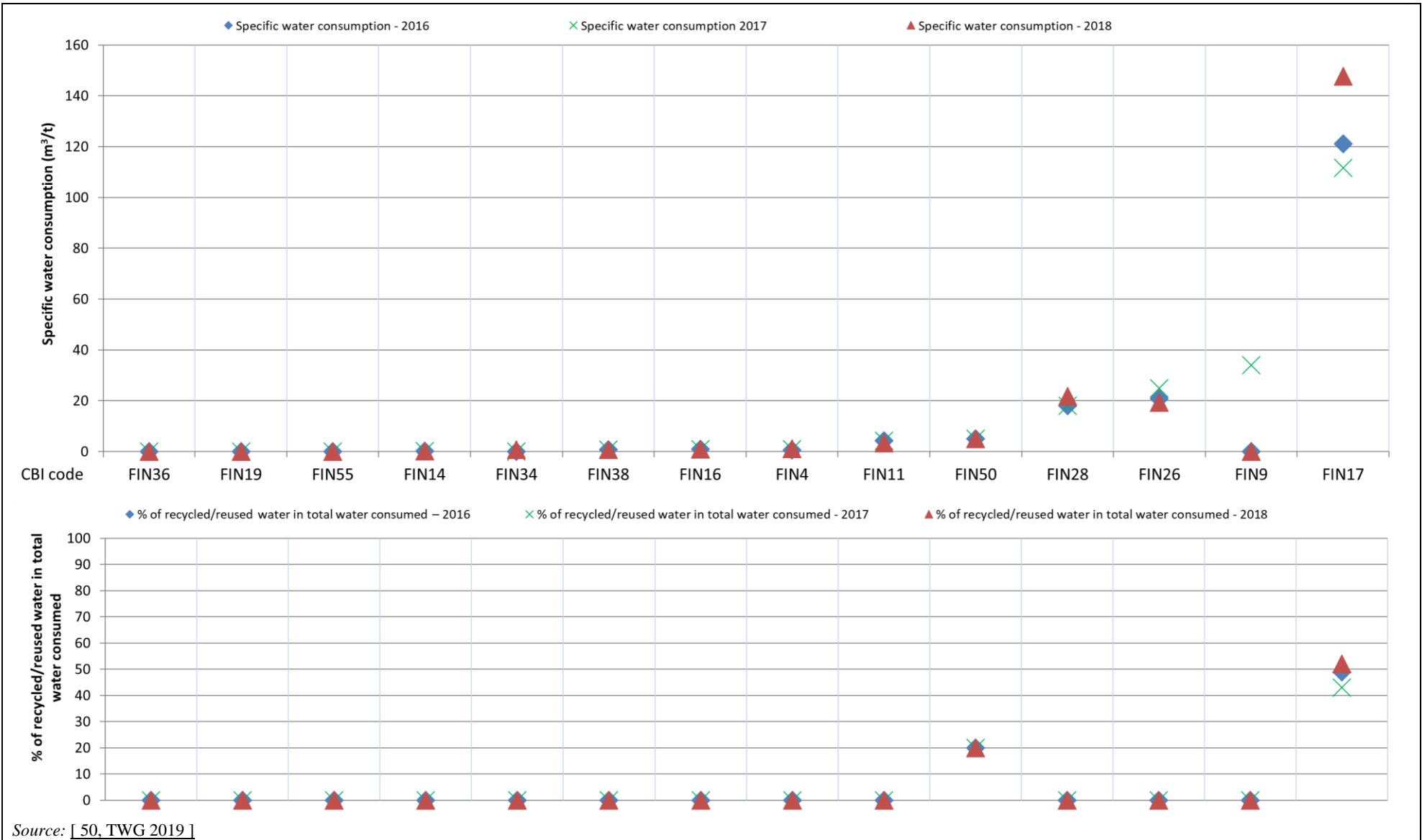


Figure 3.103: Specific water consumption of continuous finishing

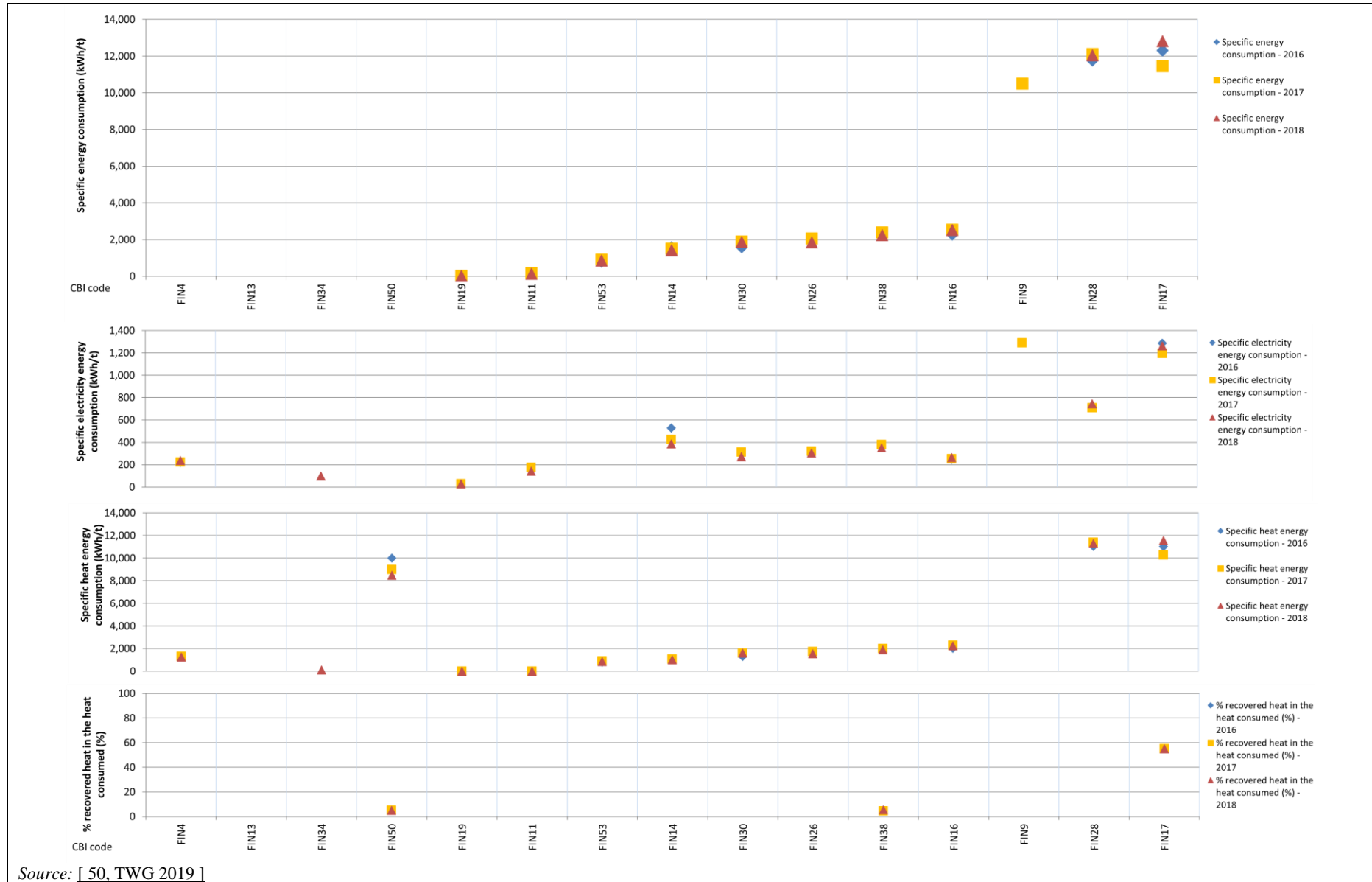


Figure 3.104: Specific energy consumption of continuous finishing

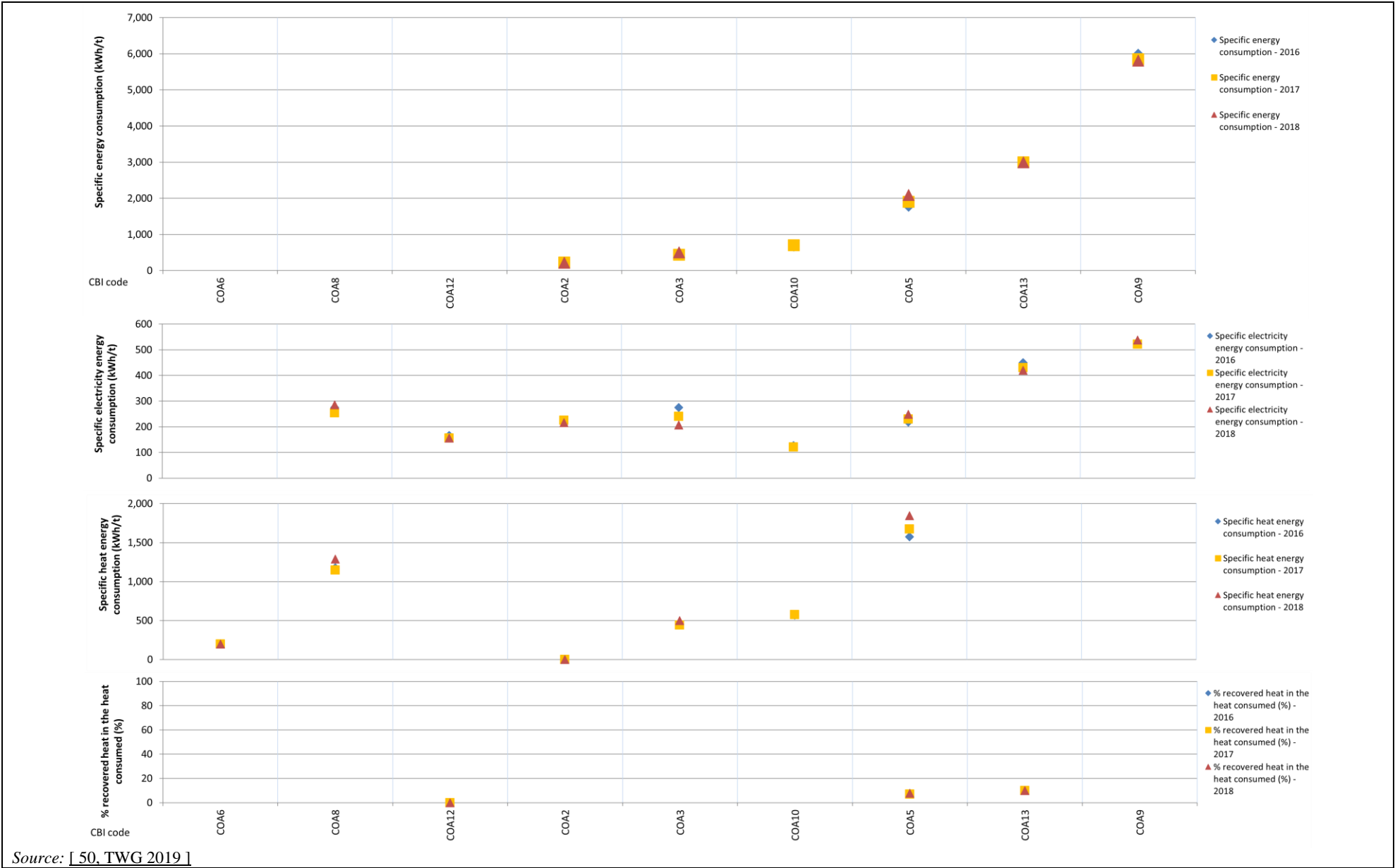


Figure 3.105: Specific energy consumption of coating



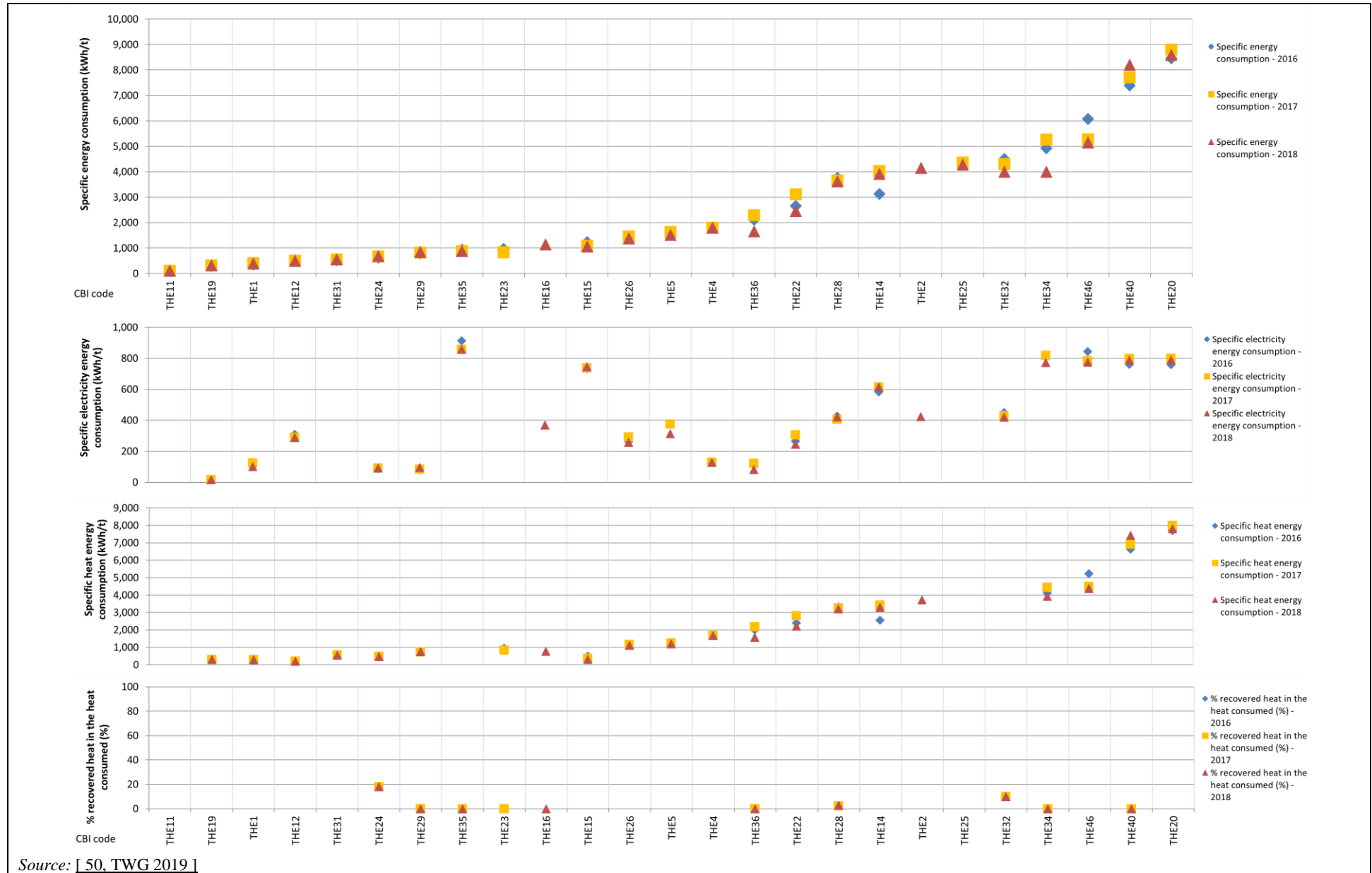


Figure 3.106: Specific energy consumption of thermal treatment

## 3.7 Waste generation and management

In textile finishing industries, many different solid and liquid wastes are generated and have to be disposed of. Some of them can be recycled or reused, whereas others are incinerated or landfilled. There are also some wastes which are treated in anaerobic digesters.

Generally speaking, little information was reported about the waste generated and recycled.

### 3.7.1 Raw wool scouring

Table 3.18 below contains the information reported by four plants about the recovery of grease and the amount of waste sent off site for recovery or disposal. All four plants use an integrated dirt removal and grease recovery loop.

Plants UK128 and UK129 are wholly or predominantly scourers of coarse wools, which contain lower percentages of grease in a more oxidised (less hydrophobic) form, which is more difficult to separate centrifugally.

**Table 3.18: Grease recovered and waste sent off site in raw wool scouring**

Plant code	Type of raw wool (fleece)	Specific amount of grease recovered (kg/t of raw wool)			Specific amount of waste with code 04 02 10 sent off site (kg/t of raw wool)		
		2016	2017	2018	2016	2017	2018
IT075	Extra/superfine	50	60	50	NI	NI	NI
IT076	Extra/superfine	60	50	50	NI	NI	NI
UK128	Coarse	10	11	13	4.3	7	9.3
UK129	Coarse	15	13.5	10.6	0	0	0

NB: NI = No information.  
Source: [50, TWG 2019]

### 3.7.2 Desizing

Only one plant (PT108) reported information about the percentage of sizing agent recovered during desizing. This percentage is reported to be 0 %.

### 3.7.3 Mercerising

In total, six plants reported information about the percentage of alkali recovered from mercerising (see Table 3.19 below).

Table 3.19: Alkali recovered from mercerising

Plant code	% of alkali recovered		
	2016	2017	2018
DE030	75	75	75
ES058	95	76	99
FR134	35	37	37
PT108	75	80	85
UK127	95	95	95

*Source: [ 50, TWG 2019 ]*

It should be noted that Plant BE013 reported a recovery rate of 99 % but this plant carries out a specific process using ammonia (see Section 2.6.1.1.3). Following mercerising, the ammonia is recovered by distillation.

### 3.7.4 Dyeing

In total, 14 plants reported data about the fate of spent dye baths and padding liquors, for a total of 63 data sets. This information is summarised in Figure 3.107, for each year for which information was reported.

In 46 instances (corresponding to 17 plants), no spent dye baths or padding liquor was reported as waste (i.e. sent off site for disposal and recovery). In those cases, the spent dye baths or padding liquor is mostly considered waste water.

In the 17 other instances (corresponding to 7 plants), spent dye baths or padding liquor were reported as waste and no waste water was reported. The case of Plant FR133 in particular is of note; all spent dye baths are said to be recycled with evaporation-concentration. The treatment sludge is the only remaining waste.

Spent dye baths or padding liquor are recycled in only three plants, including FR133 mentioned above.

In addition to the 14 plants that reported data, 6 plants reported that the spent dye bath is sent to waste water treatment.

### 3.7.5 Printing

Four plants reported data about the fate of printing residues (spent printing pigments and paste), for a total of 10 data sets. This information is summarised in Table 3.20.

Table 3.20: Printing residues

Plant code	Year	Description of waste	European List of Waste codes of printing residues sent off site (for disposal and recovery)	Printing residues sent off site (for disposal and recovery)	Printing residues recycled/reused	Printing residues treated as waste waters	Additional information
				t/t of textile treated	m <sup>3</sup> /t of textile treated		
DE025	2016	Paste residues	NI	0.01	0.01	0	
	2017		NI	0.01	0.01	0	
	2018		NI	0.01	0.01	0	
DE032	2016	AVV 16 10 03	NI	0.1024	0.1731	0	
	2017		NI	0.0762	0.1559	0	
	2018		NI	0.0992	0.1887	0	
DE049	2016	Residual paste	04 02 16*	0.02	0.026	0.009	
	2017		04 02 16*	0.02	0.03	0.009	
	2018		04 02 16*	0.02	0.03	0.009	
SE118	2016	Printing paste	04 02 17	NI	NI	NI	7 t waste
	2017		04 02 17	NI	NI	NI	10 t waste
	2018		04 02 17	NI	NI	NI	10 t waste
UK127	NI	NI	NI	NI	0.005	NI	Approximately 5kg/t. Acid dyes are reused on repeat print jobs
NB: NI = No information. Source: [ 50, TWG 2019 ]							

In two other cases (BE009 and FR131) printing paste residues are said to be treated as waste water and in one case (PT099) it is reported that no printing residues are produced.

### 3.7.6 Finishing

In total, 14 plants reported data about the fate of spent dye baths and padding liquors, for a total of 49 data sets. This information is summarised in Figure 3.108, for each year for which information was reported.

In 23 instances (corresponding to 8 plants), no spent finishing baths or padding liquor was reported as waste (i.e. sent off site for disposal and recovery). In those cases, the spent finishing baths or padding liquor are mostly considered waste water.

In 26 instances (corresponding to 10 plants), spent finishing baths or padding liquor were reported as waste and no waste water was reported (except in two cases).

Concerning waste water, Plant DE022 reported that waste water from some processes (like coating and finishing) is evaporated.

### 3.7.7 Leftover chemicals

Information about the specific amount of chemicals disposed of as waste at plant level was reported by 58 plants for a total of 177 data sets. The data are shown in Table 3.21, Table 3.22, Table 3.23 and Table 3.24 for the following European List of Waste Codes (EWCs):

- 04 02 16\*: dyestuffs and pigments containing hazardous substances;
- 04 02 17: dyestuffs and pigments other than those mentioned in 04 02 16;
- 16 03 03\*: inorganic wastes containing hazardous substances;
- 16 03 05\*: organic wastes containing hazardous substances.

**Table 3.21: Specific amount of waste (kg/t of textiles treated) – EWC 04 02 16\***

Plant code	2016	2017	2018
CZ017	0.03	0.36	0.10
DE025			0.21
DE042			11.00
DE049			20.00
IT059	0.20	0.33	
IT063		0.53	0.02
IT088		0.40	0.20
IT137	2.53		
PT110		0.24	0.25
UK124			15.63
<i>Source: [50, TWG 2019]</i>			

Table 3.22: Specific amount of waste (kg/t of textiles treated) – EWC 04 02 17

Plant code	2016	2017	2018	Additional information
DE025			0.71	
DE029	10.00	10.00	10.00	
DE042			1.00	
DE045	0.00	3541.00	12650.00	In 2018 disposal of old chemicals
SE118	21.00	23.70	37.90	
UK124		426.22	267.83	Effluent with high pollutant load that cannot be treated by on-site WWTP.
UK126	5.24	7.89	5.00	These leftover dyes are mainly diluted dyestuff used in the print dyeing process. The actual dyestuff content is less than 3 % by weight; it is a water-based formula that makes up the other 97 %. The calculation is therefore based on 1 kg = 1 l. Dyestuff powder is not disposed of. The actual quantities are far lower than data inputted allow. The corresponding years are all below 9 kg of waste per tonne of textiles.
<i>Source:</i> [ 50, TWG 2019 ]				

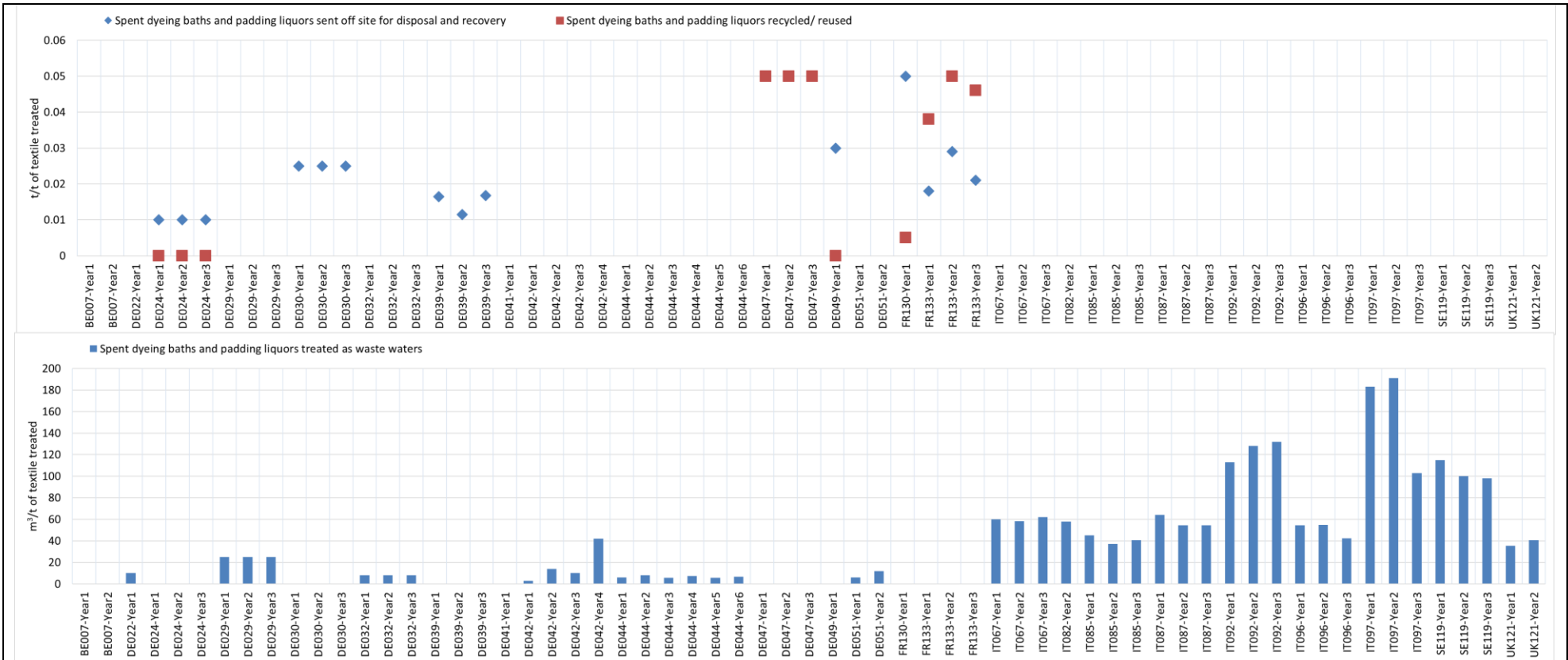
Table 3.23: Specific amount of waste (kg/t of textiles treated) – EWC 16 03 03\*

Plant code	2016	2017	2018	Additional information
IT088		0.16	0.2	
PT114	0.04	0.06	0.16	
UK121		10		2018 column is 2015 data.
UK124	1.30		1.26	
<i>Source:</i> [ 50, TWG 2019 ]				

Table 3.24: Specific amount of waste (kg/t of textiles treated) – EWC 16 03 05\*

<b>Plant code</b>	<b>2016</b>	<b>2017</b>	<b>2018</b>	<b>Additional information</b>
FR136	4.80	0.09		
IT063	0.05	0.13	0.02	
IT067		0.50		Occasional waste
PT109		0.02	0.07	
UK124		6.55		
<i>Source:</i> [ 50, TWG 2019 ]				

### 3.7.8 Figures on waste generation and management



Source: [ 50, TWG 2019 ]

Figure 3.107: Fate of spent dye baths and padding liquors



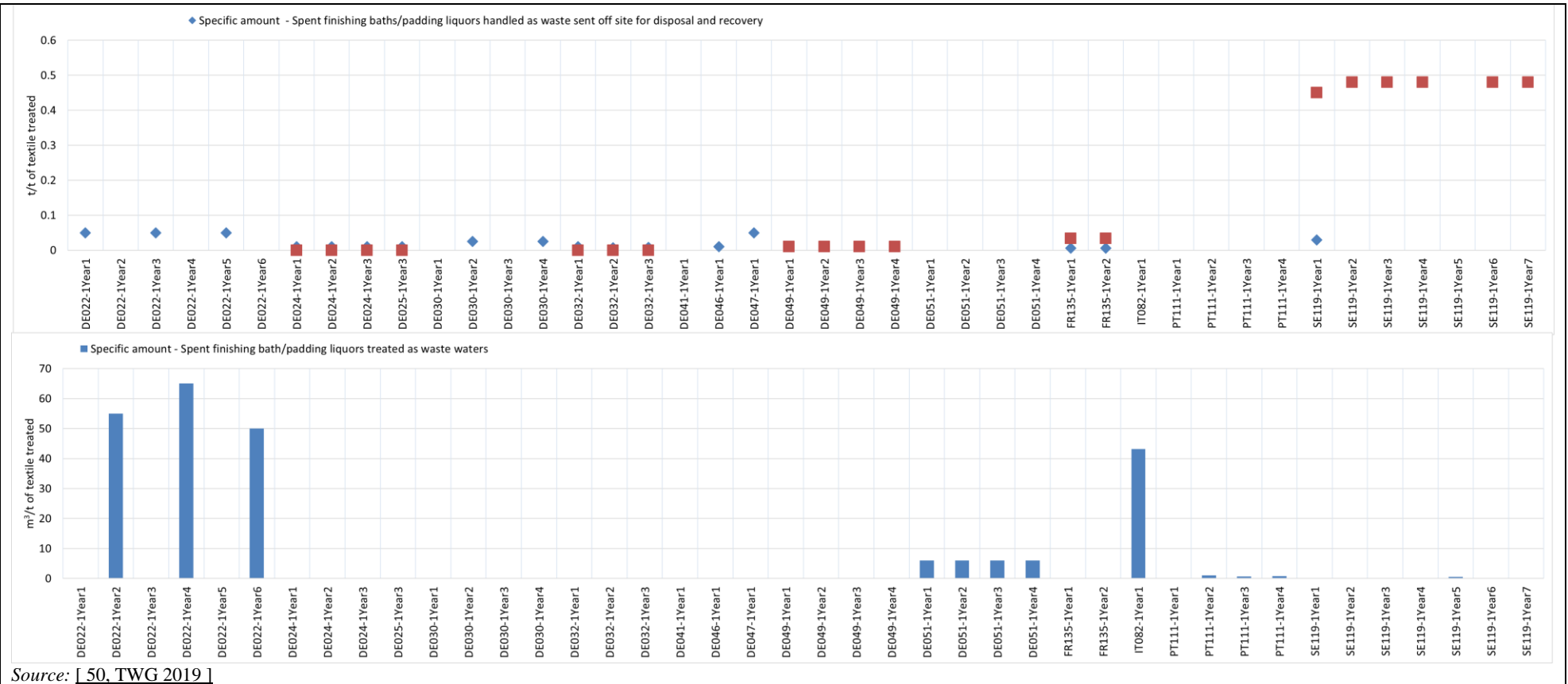


Figure 3.108: Fate of spent finishing baths and padding liquors

## 4 TECHNIQUES TO CONSIDER IN THE DETERMINATION OF BAT

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

It covers environmental management systems as well as process-integrated 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. 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 4.1 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 does 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 4.1: Information for each technique**

Heading within the sections	Type of information included
Description	A brief description of the technique with a view to being used in the BAT conclusions.
Technical description	A more detailed and yet concise technical description using, as appropriate, chemical or other equations, pictures, diagrams and flow charts.
Achieved environmental benefits	The <b>main</b> potential environmental benefits to be gained through implementing the technique (including reduced consumption of energy; reduced emissions to water, air and land; raw material savings; as well as production yield increases, reduced waste, etc.).
Environmental performance and operational data	<p>Actual and <b>plant-specific</b> performance data (including emission levels, consumption levels – of raw materials, water, energy – and amounts of residues/wastes generated) from well-performing installations/plants (with respect to the environment taken as a whole) applying the technique accompanied by the relevant contextual information.</p> <p>Any other useful information on the following items:</p> <ol style="list-style-type: none"> <li>1. how to design, operate, maintain, control and decommission the technique;</li> <li>2. emission monitoring issues related to the use of the technique;</li> <li>3. sensitivity and durability of the technique;</li> <li>4. issues regarding accident prevention.</li> </ol> <p>Links between inputs (e.g. nature and quantity of raw material and fuel, energy, water) and outputs (emissions, residues/wastes, products) are highlighted, in particular where relevant to enhancing an understanding of different environmental impacts and their interaction, for example where trade-offs have been made between different outputs such that certain</p>

	<p>environmental performance levels cannot be achieved at the same time.</p> <p>Emission and consumption data are qualified as far as possible with details of relevant operating conditions (e.g. percentage of full capacity, fuel composition, bypassing of the (abatement) technique, inclusion or exclusion of other than normal operating conditions, reference conditions), sampling and analytical methods, and statistical presentation (e.g. short- and long-term averages, maxima, ranges and distributions).</p> <p>Information is included on conditions/circumstances hampering the use of the (abatement) technique at full capacity and/or necessitating full or partial bypassing of the (abatement) technique and measures taken to restore full (abatement) capacity.</p>
Cross-media effects	<p>Relevant negative effects on the environment due to implementing the technique, allowing a comparison between techniques in order to assess the impact on the environment as a whole. This may include issues such as:</p> <ul style="list-style-type: none"> <li>• consumption and nature of raw materials and water;</li> <li>• energy consumption and contribution to climate change;</li> <li>• stratospheric ozone depletion potential;</li> <li>• photochemical ozone creation potential;</li> <li>• acidification resulting from emissions to air;</li> <li>• presence of particulate matter in ambient air (including microparticles and metals);</li> <li>• eutrophication of land and waters resulting from emissions to air or water;</li> <li>• oxygen depletion potential in water;</li> <li>• persistent/toxic/bioaccumulable components (including metals);</li> <li>• generation of residues/waste;</li> <li>• limitation of the ability to reuse or recycle residues/waste;</li> <li>• generation of noise and/or odour;</li> <li>• increased risk of accidents.</li> </ul> <p>The Reference Document on Economics and Cross-media Effects (ECM) should be taken into account.</p>
Technical considerations relevant to applicability	<p>It is indicated whether the technique can be applied throughout the sector. Otherwise, the main general technical restrictions on the use of the technique within the sector are indicated. These may be:</p> <ul style="list-style-type: none"> <li>• an indication of the type of plants or processes within the sector to which the technique cannot be applied;</li> <li>• constraints to implementation in certain generic cases, considering, e.g.: <ul style="list-style-type: none"> <li>○ whether it concerns a new or an existing plant, taking into account factors involved in retrofitting (e.g. space availability) and interactions with techniques already installed;</li> <li>○ plant size, capacity or load factor;</li> <li>○ quantity, type or quality of product manufactured;</li> <li>○ type of fuel or raw material used;</li> <li>○ animal welfare;</li> <li>○ climatic conditions.</li> </ul> </li> </ul> <p>These restrictions are indicated together with the reasons for them.</p> <p>These restrictions are not meant to be a list of the possible local conditions that could affect the applicability of the technique for an individual plant.</p>
Economics	<p>Information on the costs (capital/investment, operating and maintenance costs including details on how they have been calculated/estimated) and any possible savings (e.g. reduced raw material or energy consumption, waste charges, reduced payback time compared to other techniques), or revenues or other benefits including details on how these have been calculated/estimated.</p>

	<p>Cost data are preferably given in euros (EUR). If a conversion is made from another currency, the data in the original currency and the year when the data were collected are indicated. The price/cost of the equipment or service is accompanied by the year it was purchased.</p> <p>Information on the market for the sector is given in order to put costs of techniques into context.</p> <p>Information relevant to both newly built, retrofitted and existing plants is included. This should allow assessment, where possible, of the economic viability of the technique for the sector concerned.</p> <p>Information on the cost-effectiveness of the technique (e.g. in EUR per mass of pollutant abated) and related assumptions for its calculation can be reported.</p> <p>The Reference Document on Economics and Cross-media Effects (ECM) and the Reference Report on Monitoring of Emissions to Air and Water from IED Installations (ROM) are taken into account with regard to economic aspects and monitoring costs, respectively.</p>
Driving force for implementation	<p>Where applicable, specific local conditions, requirements (e.g. legislation, safety measures) or non-environmental triggers (e.g. increased yield, improved product quality, economic incentives – e.g. subsidies, tax breaks) which have driven or stimulated the implementation of the technique to date are provided.</p> <p>This subsection should be very short and use a list of bullet points.</p>
Example plants	<p>Reference to a plant(s) where the technique has been implemented and from which information has been collected and used in writing the section. An indication of the degree to which the technique is in use in the EU or worldwide.</p>
Reference literature	<p>Literature or other reference material (e.g. books, reports, studies) that was used in writing the section and that contains more detailed information on the technique. When the reference material consists of many pages, reference will be made to the relevant page(s) or section(s).</p>

## 4.1 General techniques

### 4.1.1 General management techniques

#### 4.1.1.1 Environmental management system (EMS)

##### Description

A formal system to demonstrate compliance with environmental objectives.

##### Technical description

The Industrial Emissions 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 4.1).

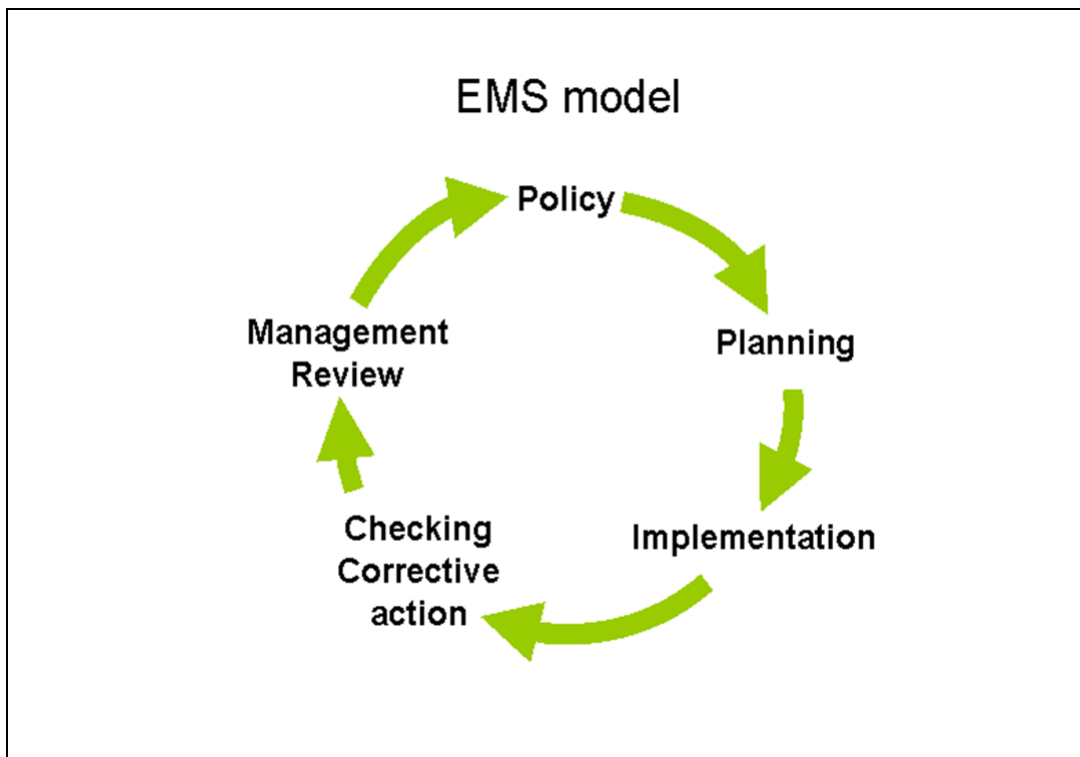


Figure 4.1: Continuous improvement in an EMS model

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 14001:2015, 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 IED only regulates installations.

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 [ 73, Brinkmann et al. 2018 ];
- 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 the textile industry, it is also important to incorporate the following potential features in the EMS:

- xxi. an inventory of input and output streams (see Section 4.1.1.2);
- xxii. an OTNOC management plan (see Section 4.1.1.4);
- xxiii. a water efficiency plan (see Section 4.1.3.1);
- xxiv. an energy efficiency plan (see Section 4.1.4.1);
- xxv. a raw materials management plan (see Section 4.1.5.1);
- xxvi. a chemicals management system (see Section 4.1.6.1);
- xxvii. a waste management plan (see Section 4.1.9.1).

### **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.

### **Environmental performance and operational data**

Concerning the maintenance programmes, particular attention should be paid to the following areas:

- the most significant components of the machinery like pumps, valves, level switches and pressure and flow regulators are checked;
- verifications are conducted to detect potential leaks from broken and leaking pipes, drums, pumps and valves, not only in the water system but also from the oil heat transfer and chemical dispensing systems in particular;
- regular cleaning and checking of filters;
- calibration of measuring equipment, such as chemical measuring and dispensing devices, thermometers;
- thermal treatment units (e.g. stenters) are cleaned and maintained regularly (at least once a year) This includes cleaning deposits from the exhaust gas ducts and from the intake system of the burner air inlet.

### **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 [[75, 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. In total, 58 plants from the data collection apply an EMS.

### Reference literature

[ 76, EU 2009 ], [ 77, COM 2016 ], [ 78, COM 2010 ], [ 79, ISO 1996 ], [ 80, CEN 2015 ], [ 81, bluesign 2018 ]

#### 4.1.1.2 Input/output streams inventory

##### Description

The compilation of relevant basic data on input and output streams of resources (e.g. inputs like materials, energy and water and outputs like waste gases, waste waters, wastes, energy losses, etc.). Basic data for streams include information on environmentally important characteristics, like presence of hazardous substances, their toxicity, composition and quantities. These data are used in mass balances, efficiency plans and for monitoring of emissions.

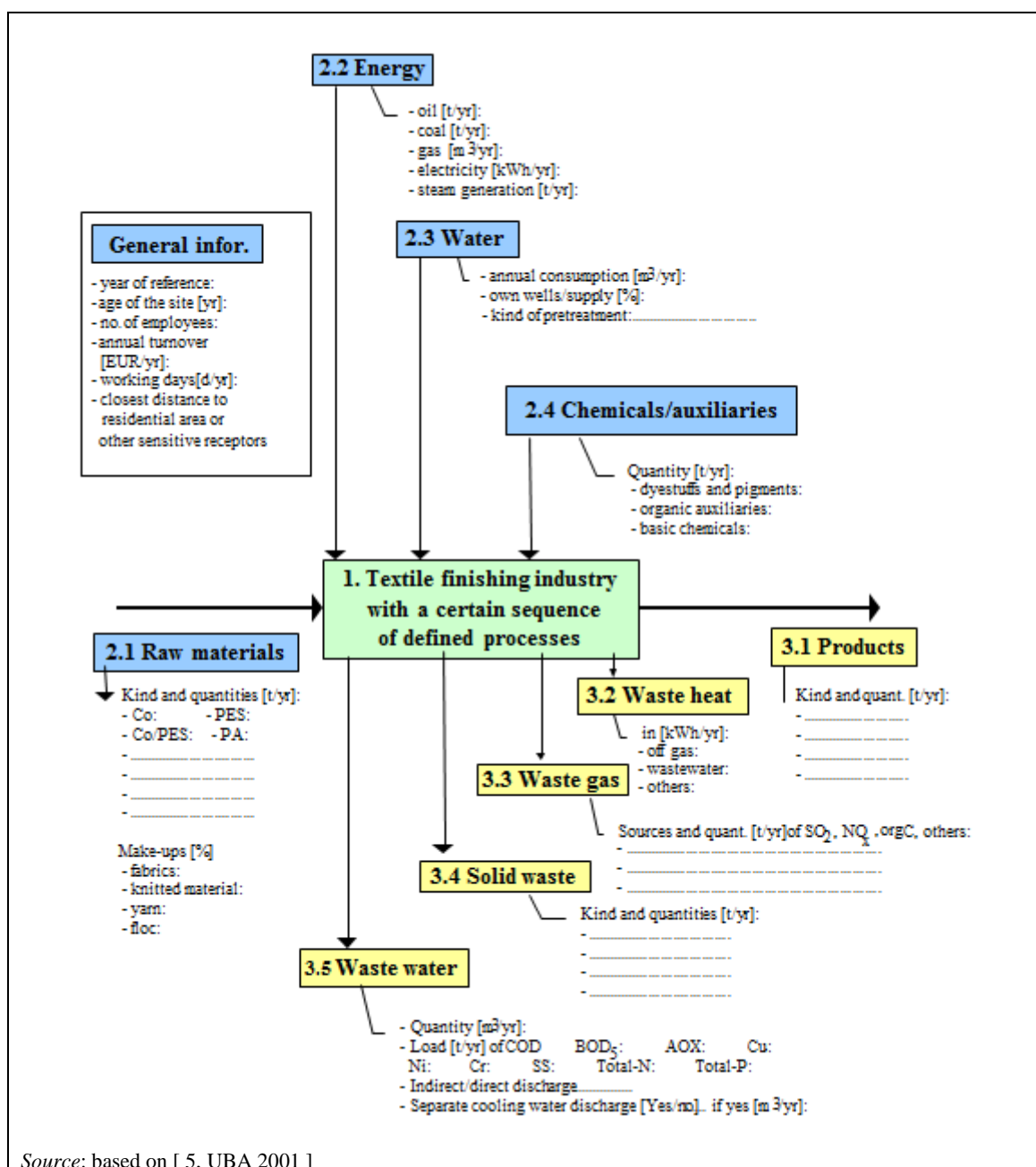
##### Technical description

All environmental problems are directly linked to input/output streams. In the interests of identifying options and priorities for improving environmental and economic performance, it is therefore vital to know as much as possible about their quality and quantity.

Input/output stream inventories can be drawn up on different levels. The most general level is an annual site-specific overview.

Figure 4.2 indicates the relevant input/output streams. Starting from the annual values, specific input and output factors for the textile substrate can be calculated (e.g. litres of water consumption/kg of processed textiles or g of COD in waste water/kg of processed textiles). Although these factors have their limitations, they allow preliminary comparisons with other plants or similar processes and they provide a baseline against which to start tracking consumption and emission levels. Examples of the use of input/output stream inventories are presented in [ 274, Ozturk et al. 2016 ].





**Figure 4.2: Scheme for annual input/output overview at site level**

The inventory contains the following information:

- I. information about the production process(es), including:
  - a. simplified process flow sheets that show the origin of the emissions;
  - b. descriptions of process-integrated techniques and waste water/waste gas treatment techniques to prevent or reduce emissions, including their performance (e.g. abatement efficiency);
- II. information about the quantity and characteristics of materials used, including textile materials and process chemicals (see Sections 4.1.5 and 4.1.6);
- III. information about water consumption and usage (e.g. flow diagrams and water mass balances);
- IV. information about energy consumption and usage;
- V. information about the quantity and characteristics of the waste water streams, such as:
  - a. average values and variability of flow, pH, temperature and conductivity;

- b. average concentration and mass flow values of relevant substances/parameters (e.g. COD/TOC, nitrogen species, phosphorus, metals, priority substances, microplastics) and their variability;
  - c. data on toxicity, bioeliminability and biodegradability (e.g. BOD<sub>n</sub>, BOD<sub>n</sub> to COD ratio, results of Zahn-Wellens Test, biological inhibition potential (e.g. inhibition of activated sludge));
- VI. information about the characteristics of the waste gas streams, such as:
- a. average values and variability of flow and temperature;
  - b. average concentration and mass flow values of relevant substances/parameters (e.g. dust, organic compounds) as well as their variability; emission factors may be used to assess the variability of emissions to air (see Section 4.1.6.4);
  - c. flammability, lower and higher explosive limits, reactivity, hazardous properties;
  - d. presence of other substances that may affect the waste gas treatment system or plant safety (e.g. water vapour, dust);
- VII. information about the quantity and characteristics of waste generated.

Pre-screening of incoming raw materials (fibres, chemicals, dyestuffs, auxiliaries, etc.) is of the utmost importance for pollution prevention (see Section 4.1.5.1.1). The supplier provides adequate information that enables the mill to make a responsible environmental evaluation, even of proprietary products.

The detailed information provided to the finisher about textile raw material is not limited to the technical characteristics of the textile substrate but also includes the type and amount of preparation agents and sizing agents, and the amount of residual monomers, metals and biocides (e.g. ectoparasiticides for wool) present on the fibre. These substances/impurities are carried over into the process and account for a significant percentage of the pollutant load from textile mills. Improved knowledge of the raw material will allow the manufacturer to prevent or at least control the resulting emissions.

#### **Achieved environmental benefits**

The described evaluation and inventory of input/output mass streams is an essential management tool for the identification of optimisation potential, both environmental and economic. It is the prerequisite for a continuous improvement process.

#### **Environmental performance and operational data**

The application of such a management tool requires highly qualified staff and the commitment of the management.

The input/output streams inventory allows cross-media effects to be taken into consideration during the assessment of potential optimisation options. This means the achievement of a high level of protection of the environment as a whole.

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

The technique is applicable to both new and existing installations. Provided that the management of a company is convinced of the benefits of such a tool, there are no limitations to its applicability, regardless of the size of the mill.

The scope (e.g. level of detail) and nature of the inventory will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

### **Economics**

There is no specific information available on economic aspects but, generally speaking, because of the significant potential for improvements in the textile sector, the management tool described pays for itself within a short time [ 5, UBA 2001 ].

### **Driving force for implementation**

One driving force is savings on raw materials and production costs. The application of this type of approach makes it easier to implement environmental management systems such as EMAS or ISO 14001:2015.

### **Example plants**

A total of 104 plants reported applying this technique [ 50, TWG 2019 ].

### **References literature**

[ 5, UBA 2001 ], [ 50, TWG 2019 ], [ 274, Ozturk et al. 2016 ]

## **4.1.1.3 Monitoring and control of operational parameters**

### **Description**

Key operational and process parameters are monitored and controlled by use of advanced automatic process controls and systems (e.g. for on-line monitoring) in process steps and machinery used for processing and treatment of textile fibres.

### **Technical description**

Key operational and process parameters are monitored and/or controlled at both process/machine level (e.g. by means of sensors controlled by PIC/PLC (process-integrated/logic controllers) or microprocessors) and plant level (e.g. by on-line integrated computer control systems like SCADA). These parameters are related to the characteristics of the textile, raw materials, working liquors and treatment conditions. They include:

- volume, dosage, temperature, pH, concentration and liquor ratio and control of uptake of working liquors and treatment conditions in wet treatments;
- temperature, humidity and heat supply control in thermal treatments;
- machine rate control.

Basic control can be upgraded with sophisticated systems that provide feedback on these operational parameters and that are also able to track water, energy and chemical consumption, to store procedures and recipes, to track changes and to enhance the reproducibility of processes.

Expert software systems based on self-learning by algorithms (using fuzzy logic and artificial neural networks) are developed and used in textile processing [ 82, Siemens 2005 ].

### **Achieved environmental benefits**

Reduced effluents, chemicals, water and energy consumption.

### **Environmental performance and operational data**

The energy consumption of textile plants is reduced significantly (e.g. by over 25 %) by the use of retrofitted frequency controllers on motors [ 83, CITEVE 2014 ].

Automatic dye machine controllers offer an effective means for enhanced control of dyeing processes, based on microprocessors, allowing for feedback on process parameters such as the pH, colour shade, and temperature of the working liquor. They analyse process parameters continuously and respond more quickly and accurately than manually controlled systems [ 83, CITEVE 2014 ].

Automatic dye machine controllers have the potential to reduce the volume of effluents by up to 4.3 %.

Individually, process control improvements may result in relatively low reductions of water and energy consumption and costs, however together they result in a significant change (cumulative effect).

Most of these advanced control technologies are usually pre-installed in new equipment and machinery.

On-line monitoring and advanced process control in washing steps after pretreatment, dyeing or finishing, including the measurement of COD concentration, conductivity and redox potential, are used to determine the point at which the dyes, various agents and chemicals are completely rinsed off to control the rinsing process steps, their duration and amount of fresh water used. In the bleaching process, the concentration of reducing or oxidising agents on fabrics and the completeness of H<sub>2</sub>O<sub>2</sub> removal after bleaching can be monitored to prevent the excessive use of chemicals. Similarly in vat dyeing, the concentration of reducing agents can be monitored to regulate the use of chemicals.

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

#### **Economics**

Plant investments in these systems/controls typically have a high financial return and quick payback time. This includes both the initial installation and the ongoing maintenance of the equipment and systems (e.g. sensors, controllers).

Table 4.2 shows the costs and benefits of the implementation of dye machine controllers in plants of different sizes.

**Table 4.2: Dye machine controllers' costs and benefits**

Cost item	Small plant (8 000 kg/week)	Medium plant (60 000 kg/week)	Large plant (117 000 kg/week)
Capital cost (average per plant)	USD 280 000	USD 450 000	USD 800 000
Net annual operating savings (average per plant)	USD 79 770	USD 128 200	USD 227 900
Simple payback period (year)	3.5		
NB: Costs and savings are associated with the volume of production for each plant size and not just for one machine. <i>Source:</i> Marbek Resource Consultants, 2001 as cited in [ 84, Hasanbeigi A. 2010 ]			

#### **Driving force for implementation**

- Reduced water, energy and chemical consumption.
- Reduced operating costs.

#### **Example plants**

Many plants reported using advanced process monitoring and control.

#### **Reference literature**

[ 82, Siemens 2005 ], [ 83, CITEVE 2014 ], [ 84, Hasanbeigi A. 2010 ]

### 4.1.1.4 Other than normal operating conditions (OTNOC) management plan

#### Description

In order to reduce the frequency of the occurrence of OTNOC and to reduce emissions during OTNOC, BAT is to set up and implement a risk-based OTNOC management plan as part of the EMS (see Section 4.1.1.1).

#### Technical description

The risk-based OTNOC management plan includes all of the following elements:

- i. identification of potential OTNOC (e.g. failure of equipment critical to the protection of the environment ('critical equipment')), of their root causes and of their potential consequences, and regular review and update of the list of identified OTNOC following the periodic assessment below;
- ii. appropriate design of critical equipment (e.g. waste water treatment, waste gas abatement techniques);
- iii. set-up and implementation of an inspection and preventive maintenance plan for critical equipment (see Section 4.1.1.1);
- iv. monitoring (i.e. estimating or, where possible, measuring) and recording of emissions during OTNOC and of associated circumstances;
- v. periodic assessment of the emissions occurring during OTNOC (e.g. frequency of events, duration, amount of pollutants emitted) and implementation of corrective actions if necessary;
- vi. regular review and update of the list of identified OTNOC under point i. following the periodic assessment of point v.;
- vii. regular testing of back-up systems.

#### Achieved environmental benefits

Reduced emissions to air and/or water.

#### Environmental performance and operational data

The stability of the environmental performance of a textile and its compliance with the regulatory emission levels is achieved by integrating an OTNOC management plan and risk assessments in the management systems of the installation.

#### Cross-media effects

None identified.

#### Technical considerations relevant to applicability

The level of detail and degree of formalisation of the OTNOC management plan will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

#### Economics

Plant investments in the maintenance and inspection systems/controls, spare parts for the critical equipment and redundant/back-up systems are typically lower than the financial losses incurred by stopping the production/operations.

#### Driving force for implementation

Stability of operation.

#### Example plants

Many plants reported using monitoring, control and preventive maintenance of abatement equipment. Some reported having redundant spare parts and systems in place.

#### Reference literature

No reference literature provided.

## 4.1.2 Monitoring

### 4.1.2.1 Monitoring of influent and effluent

#### Description

For waste water streams identified by the inventory of inputs and outputs (see Section 4.1.1.2), the key parameters (e.g. continuous monitoring of waste water flow, pH and temperature) are monitored at key locations (e.g. at the inlet and/or outlet of the pretreatment, at the inlet to the final treatment, at the point where the emission leaves the installation).

#### Technical description

Proper operation of a waste water treatment facility requires the monitoring and targeted adjustment of various process parameters in the influent and effluent of the facility. Monitoring of the relevant parameters can be accomplished by direct online measurements (that facilitate rapid intervention and control) or indirect analytical results derived from waste water samples. Parameters to be monitored and the frequency of monitoring depend on the characteristics of the waste water to be treated, the final effluent discharge medium and the waste water treatment techniques used within the facility, based on an inventory of waste water streams. They may include, for instance, the waste water flow, pH, temperature, conductivity or BOD.

The monitoring is carried out at key locations, e.g. at the point where the emission leaves the installation and/or at the inlet and/or outlet to pretreatment and at the inlet to final treatment. Important parameters are monitored at the level of each waste water treatment technique to ensure the proper operation of the techniques and the subsequent treatment steps.

When bioeliminability/biodegradability and inhibitory effects are key parameters (e.g. see Sections 3.4.21 and 4.1.7.2), monitoring is carried out before the biological treatment for:

- bioeliminability/biodegradability using standard EN ISO 9888 or EN ISO 7827, and
- inhibitory effects on biological treatment using standard EN ISO 9509 or EN ISO 8192,

with a minimum monitoring frequency to be decided after effluent characterisation. The effluent characterisation is carried out before starting operation of the plant or before a permit for the plant is updated for the first time after the publication of these BAT conclusions, and after each change (e.g. change of 'recipe') in the plant that may increase the pollutant load.

#### Achieved environmental benefits

Monitoring the influent and effluent of a waste water treatment facility helps to maintain the proper operation of the facility and to detect accidental releases and thus helps to prevent any possible adverse environmental effects upon discharge of waste waters.

#### Environmental performance and operational data

No information provided.

#### Cross-media effects

Some equipment, chemicals 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, there are no technical restrictions to the applicability of this technique.

#### Economics

The costs associated with monitoring the influent and effluent waste water of a WWTP relate to personnel and equipment used for sampling and measurement.

### **Driving force for implementation**

To ensure the proper operation of the WWTP and to ensure that the required quality of the effluent waste water from the WWTP is met and in line with the effluent discharge criteria.

### **Example plants**

Monitoring of influent and effluent in a waste water treatment facility is applied in a number of installations throughout the EU.

### **Reference literature**

[ 77, COM 2016 ]

#### **4.1.2.2 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 WWTP) or analytical results derived from waste water samples. Parameters to be monitored and the frequency of monitoring depend on the activities which generate the waste water, the type of waste water treatment and the destination of the effluent (direct discharge or indirect discharge after treatment in an industrial or municipal WWTP).

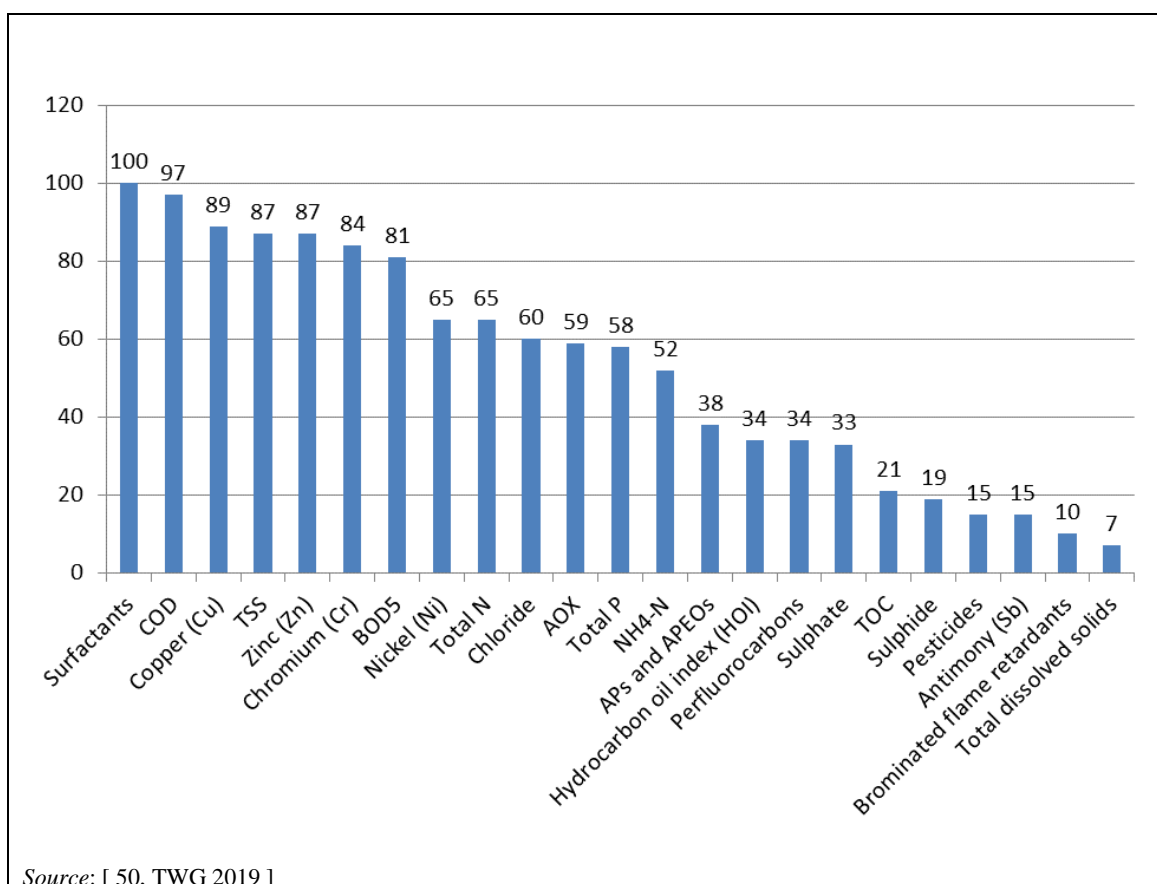
The monitoring of emissions is carried out in accordance with EN standards or, if EN standards are not available, in accordance with ISO, national or other international standards which ensure the provision of data of an equivalent scientific quality.

##### **Achieved environmental benefits**

Monitoring the waste water parameters helps to maintain the proper operation of the waste water treatment plant and to detect accidental releases and thus helps to prevent any possible adverse environmental effects when the waste waters are discharged.

##### **Environmental performance and operational data**

Figure 4.3 summarises the information from the data collection on parameters monitored in textile plants.



**Figure 4.3:** Number of emission points to water monitoring a given parameter

#### **Cross-media effects**

Some equipment, ancillary materials and energy are required for carrying out monitoring. 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 of a waste water treatment plant relate to personnel and equipment used for sampling and measurement.

See [ 73, Brinkmann et al. 2018 ] for more details.

#### **Driving force for implementation**

Environmental legislation.

#### **Example plants**

See examples in Chapter 3.

#### **Reference literature**

[ 73, Brinkmann et al. 2018 ]

### **4.1.2.3 Monitoring of emissions to air**

#### **Description**

Regular monitoring of emissions to air.



### 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 *inter alia* on the activities connected to the emissions to air.

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

Monitoring the waste gas of a textile plant helps to maintain the proper operation of the plant and to detect accidental releases and thus helps to prevent any possible adverse environmental effects when the waste gas is emitted.

### Environmental performance and operational data

Figure 4.4 summarises the information from the data collection on parameters monitored in textile plants.

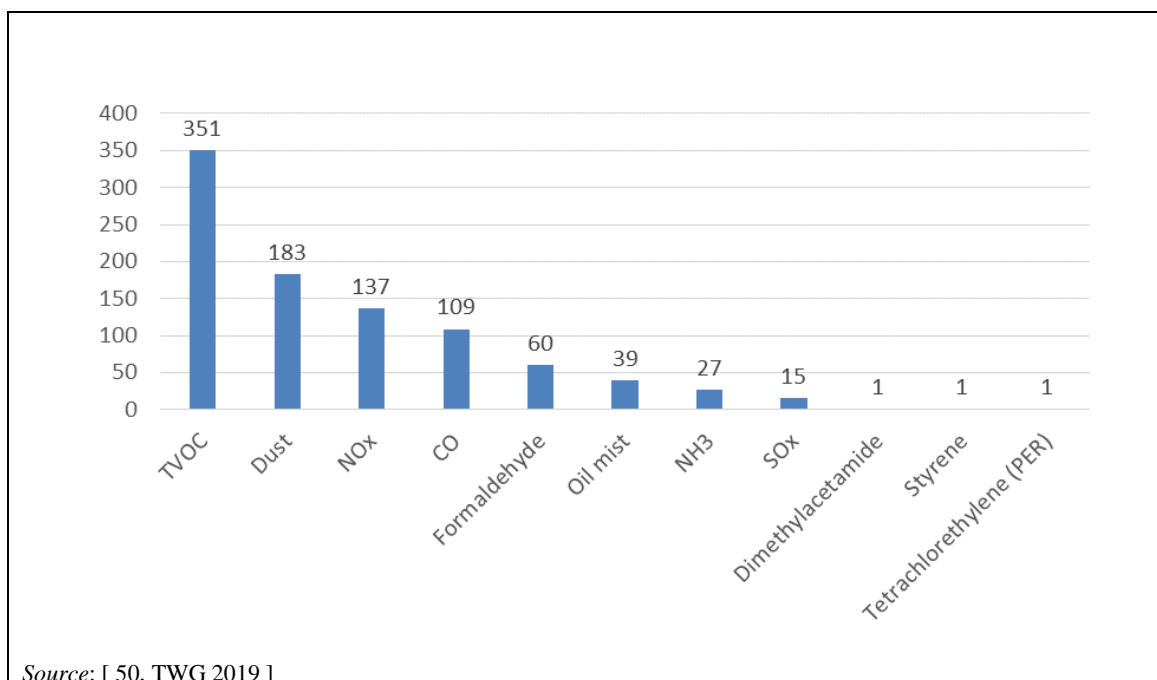


Figure 4.4: Number of emission points to air monitoring a given parameter

### Cross-media effects

Some equipment, ancillary materials and energy are required for carrying out monitoring.

### Technical considerations relevant to applicability

Generally applicable to all 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.

See [ 73, Brinkmann et al. 2018 ] for more details.

### Driving force for implementation

Environmental legislation.

**Example plants**

See examples in Chapter 3.

**Reference literature**

[ 73, Brinkmann et al. 2018 ]

**4.1.2.4 Monitoring resource consumption, waste generation and material recovery****Description**

Monitoring at least once every year of:

- the annual consumption of water, energy and materials used, including textile materials and process chemicals;
- the annual amount of waste water generated;
- the annual amount of materials recovered or reused;
- the annual amount of each type of waste generated and sent for disposal.

**Technical description**

Monitoring preferentially includes direct measurements. Calculations or recording, e.g. using suitable meters or invoices, can also be used. The monitoring is broken down, as much as possible, to process level and considers any significant changes in the processes.

For monitoring of chemical consumption, see Section 4.1.1.2; for monitoring of water consumption, see Section 4.1.3.1; for monitoring of energy consumption, see Section 4.1.4.2; and for monitoring of waste generated, see Section 4.1.9.1]

Considerations and examples regarding the calculation of specific water or energy consumption of repetitive treatments

[ 85, Veiga J. 2021 ]

Specific water and energy consumption levels are calculated according to the formulas explained in Section 0.

Regarding the activity rate calculation, the textile materials treated more than once in a given process can be considered, taking into account *the number of times a given process has been repeated* when it is technically necessary to obtain certain product characteristics. This excludes the situations when the process is repeated or prolonged due to non-conformities, process failures, or other reasons.

Some examples to demonstrate this principle are given below:

- When batch dyeing 200 kg of a knitted fabric which is 70 % cotton and 30 % polyester, the dyeing of the cotton and polyester will require the use of two different dye baths. In this case, the activity rate is 400 kg (= 2 x 200 kg).
- In a continuous dyeing process of a 300 kg fabric of 70 % cotton and 30 % polyester, where the polyester fibre is dyed in a thermosol process and the cotton fibre in a pad-batch process, the activity rate is 600 kg (= 2 x 300 kg).
- If during a batch dyeing process of 200 kg of knitted fabric, the dyeing process needs to be extended to correct the colour, the activity rate is 200 kg.
- When 200 kg of a knitted fabric needs to be treated twice in a stenter, to obtain the dimensional stability defined by client specifications, the activity rate is 400 kg (= 2 x 200 kg).

- If during a thermal treatment process of 200 kg of fabric, the thermal treatment process needs to be extended to correct the treatment performed, the activity rate will be 200 kg.

### **Achieved environmental benefits**

Monitoring the energy, water and chemical consumption and waste generation of a textile plant helps to maintain the proper operation of the plant and minimise its overall environmental impact.

### **Environmental performance and operational data**

Monitoring of the energy, water and chemical consumption and waste generation is an important aspect of operational management. It is based on the selection of appropriate performance indicators, including the setting and regular review of benchmarks and targets. The performance indicators are benchmarked to comparable plants (in terms of feedstocks, processes, operating conditions and products). This is often conducted through participation in voluntary certification schemes (see Section 4.1.6.3). Most modern machinery comes with the inbuilt sensors and metering equipment, enabling digitalised and highly optimised operation control. Meterage (material) counters, dosage metering and other water/energy consumption control equipment can be fitted to the existing machinery (see Section 4.1.1.3).

For more information on water and energy consumption and waste generated, see Sections 3.6 and 3.7.

### **Cross-media effects**

Some equipment and energy are required for carrying out monitoring.

### **Technical considerations relevant to applicability**

Generally applicable to all plants.

### **Economics**

The costs associated with monitoring relate to personnel and measurement equipment.

### **Driving force for implementation**

Environmental legislation and savings from lower consumption costs.

### **Example plants**

[ 50, TWG 2019 ]

The majority of plants that participated in the data collection reported monitoring of energy, water and chemical consumption and of the amounts of waste generated, recovered, recycled or reused.

### **Reference literature**

[ 50, TWG 2019 ]

## **4.1.3 Water efficiency**

### **4.1.3.1 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 balances of the plant and processes;
- establishment of water efficiency objectives;
- implementation of water optimisation techniques (e.g. control of water usage, reuse/recycling, detection and repair of leaks);

Water audits are carried out at least once every year to ensure that the objectives of the water management plan are met. The water management plan and the water audits may be integrated in the overall water management plan of a larger industrial site.

### **Technical description**

The flow diagrams and mass balances are based on the monitoring data (see Section 4.1.2.1) and input/output streams inventory (see Section 4.1.1.2). Further guidance on water management plans and audits are provided in ISO 46001 ‘Water efficiency management systems – Requirements with guidance for use’. Examples of the use of flow diagrams and mass balances are presented in [ 274, Ozturk et al. 2016 ].

### **Achieved environmental benefits**

Significant savings in water and energy consumption are possible (energy is used to a great extent to heat up the process baths).

Benefits include reduced leaks, spillages and emissions to soil and groundwater.

### **Environmental performance and operational data**

No detailed information on the effects of the operational and strategic water management of the well-performing plants (see Example plants section below and the performance of those plants in Sections 3.6.1 and 3.6.2) on the environmental performance was collected.

### **Technical considerations relevant to applicability**

The principles described here are generally applicable.

The level of detail of the water management plan and water audits will generally be related to the nature, scale and complexity of the plant.

### **Cross-media effects**

Reduced water consumption results in a high concentration of pollutants and requires corresponding waste water treatment [ 44, ÖKOPOL 2011 ].

### **Economics**

The management techniques typically do not generate significant costs, on the contrary, the increased control and fulfilling of their objectives often result in cost savings.

### **Driving force for implementation**

Savings in water consumption.

### **Example plants**

See cross-referenced techniques in other sections of this document.

A total of 28 plants from the data collection apply a water-saving plan: BE007, BE008, BE009, BE011, BE014, CZ016, DE021, DE024, DE025, DE029, DE039, DE041, DE044, DE049, DE051, FR130, FR133, FR136, IT065, IT067, IT082, IT092, PT108, PT115, PT117, SE119, SE120 and UK126.

### **Reference literature**

[ 44, ÖKOPOL 2011 ], [ 50, TWG 2019 ], [ 81, bluesign 2018 ], [ 274, Ozturk et al. 2016 ]

## **4.1.3.2 Optimisation of water consumption in textile operations**

Short descriptions of some water optimisation techniques to consider in the determination of the BAT are given in the following subsections.

### 4.1.3.2.1 Production optimisation

The following techniques can be considered for production optimisation:

a) Measurement of water consumption

A prerequisite of any programme to prevent unnecessary use of water is to firstly collect information on the installation and the volumes consumed in the various processes, as part of the collection of information on types, quantities, composition and sources of all streams (see Section 4.1.1.2).

In order to allow a process-specific analysis, water use is monitored and recorded at machine/process level and water meters are regularly maintained and calibrated.

b) Improved working practices

Production procedures are established and the personnel trained, in order to avoid inappropriate working practices that can lead to significant wastage of water, e.g.:

- i. overfilling which may occur during filling and rinsing where machines are equipped only with manual water control valves;
- ii. displacement spillage during immersion of the fibre in the machine which may account for up to 20 % of the total operating volume over the course of a dyeing cycle (this may also lead to losses of dyes and hazardous chemicals if these are introduced before the displacement takes place).

c) Combining and scheduling processes:

Combining and scheduling processes reduces the number of chemical dumps. This is often feasible for pretreatment operations (e.g. scouring/desizing, scouring/desizing/bleaching – see for example Section 4.4.3). Combining pretreatment in the colouration stage is also possible in some cases.

Optimisation of scheduling in production (e.g. in dyeing, dyeing dark shades after pale shades) reduces water, energy and chemical consumption for machine cleaning. In finishing, proper scheduling minimises machine stops and heating up/cooling down steps. Significant savings can also be achieved by adjustment of pretreatment processes to the quality requirements in downstream processes (e.g. bleaching is often not necessary if dark shades are produced).

### 4.1.3.2.2 Segregation of polluted and unpolluted water streams

#### **Description**

Water streams are collected separately, based on the pollutant content and on the required treatment techniques. Polluted water streams (e.g. spent process liquors) and unpolluted water streams (e.g. cooling waters) that can be reused without treatment are segregated from waste water streams that require treatment (see Sections 4.1.7.4.3 and 4.1.7.4.4).

#### **Technical considerations relevant to applicability**

Applicability of segregation of water streams in existing plants may be restricted by the layout of the water collection system and a lack of space for temporary storage tanks.

#### **Economics**

In existing mills, investment in new equipment and/or structural modifications (e.g. for the segregation of streams) is likely to be necessary.

### 4.1.3.2.3 Processes using little or no water

#### Description

Processes include plasma or laser treatment, and processes using low amounts of water such as ozone treatment.

#### Technical description

For more details on laser and/or plasma surface treatment of fabrics and garments, see Section 4.7.1.1; and for use of ozone or air bubbles, see Sections 4.4.7.3 and 4.7.1.2.

Plasma can be described as a mixture of partially ionised gases. Atoms, radicals and electrons can be found in the plasma. The electrons in low-temperature plasmas are able to cleave covalent chemical bonds, thereby producing physical and chemical modifications of the surface of the treated substrate.

Two types of plasma are generally used: corona plasma and low-pressure plasma.

Plasma treatment can be performed on natural fibres as well as on synthetic fibres, to achieve the following effects:

- wool degreasing;
- desizing;
- change of fibre wettability (hydrophilic, hydrophobic properties);
- increase in dyestuff affinity;
- improved dye levelling properties;
- anti-felt finishing in wool (see Section 6.4.2);
- sterilisation (bactericidal treatment), etc.

#### Achieved environmental benefits

- Reduced consumption of water and chemicals.
- Reduced amount of waste water.

#### Environmental performance and operational data

In general, the main advantages of plasma technology are the extremely short treatment time and the low application temperature, along with the fact that water and solvents can be avoided and no or less chemicals are required.

Table 4.3 compares the characteristics of plasma and traditional wet processing.

**Table 4.3: Comparison of plasma and traditional wet processing**

	Plasma processing	Traditional wet processing
Medium	No water used. Treatment by excited gas phase.	Water-based.
Energy	Electricity – only free electrons heated (< 1 % of system mass).	Heat – entire system mass temperature raised.
Reaction type	Complex and multifunctional; many simultaneous processes.	Simpler, well established.
Reaction locality	Highly surface-specific; no effect on bulk properties.	Bulk of the material generally affected.
Potential for new processes	Great potential; technology in rapid development.	Very low.
Equipment	Experimental, laboratory and industrial prototypes; rapid industrial developments.	Mature, slow evolution.

Energy consumption	Low.	High
Water consumption	Negligible.	High
<i>Source: based on [ 86, Shishoo 2007 ]</i>		

Low-pressure plasma contains a high concentration of reactive species compared to corona plasma. It requires a longer process time and only batch processes can be performed. The low-pressure plasma process has been difficult to upscale for continuous processes and batch processing limits commercial application.

Table 4.4 describes the main characteristics for corona and low-pressure plasma.

**Table 4.4: Process characteristics for corona plasma and low-pressure plasma**

Process	Corona plasma	Low-pressure plasma
Generation of plasma	High voltage between coated electrodes	Direct current or high-frequency
pressure	Atmospheric pressure (1 bar)	Low pressure (1 mbar)
Continuous process	Easy	Difficult
<i>Source: based on [ 5, UBA 2001 ]</i>		

With this technology, the following can be achieved: [ 87, TextileLearner 2019 ]

- Desizing: Plasma technology can be used to remove PVA sizing material from cotton fibres. In the conventional desizing process, chemicals and hot water are used to remove size. But desizing with plasma technology uses either O<sub>2</sub>/He plasma or air/He plasma. O<sub>2</sub>/He plasma has a greater effect on PVA surface chemical changes than air/He plasma.
- Dyeing: The dye exhaustion rate of plasma-pretreated wool has been shown to increase by nearly 50 %: plasma-pretreated wool can achieve 90 % exhaustion in 30 minutes as compared to 60 minutes for untreated samples. O<sub>2</sub> plasma treatment increases the wettability of wool fabric, thus leading to a dramatic increase in its wicking properties.

**Cross-media effects**

None identified.

**Technical considerations relevant to applicability**

The applicability may be restricted by the characteristics of the textile materials and/or product specifications.

**Economics**

The investment costs for an atmospheric plasma machine are estimated to be around SEK 2-3 million [ 88, Swedish EPA 2018 ].

**Driving force for implementation**

- Increased energy efficiency of treatment processes.
- Higher productivity (shorter treatment times).

**Example plants**

DE042 reported using corona plasma for PES finishing.

**Reference literature**

[ 5, UBA 2001 ], [ 35, RICARDO 2019 ], [ 86, Shishoo 2007 ], [ 87, TextileLearner 2019 ], [ 88, Swedish EPA 2018 ]

#### 4.1.3.2.4 Optimisation of the amount of process liquor used

The amount of process liquor used can be optimised by the following:

- **Technical modifications**  
Installation of automatic controllers to facilitate accurate control of fill volume and liquor temperature (e.g. batch dyeing machines).
- **Reducing liquor quantity**  
In *continuous* dyeing, the dye is applied in the form of a concentrated liquor. The volume of water consumed per kg of processed fabric in the dyeing process is therefore fairly low even when using conventional application systems (e.g. padders). This volume can be even lower in more recently developed application systems (e.g. fluidyer, foam, flexnip, spray application systems, see Section 8.3.4.2) [ 89, EURATEX 2019 ]. For more details on minimising liquor losses in pad dyeing, see Section 4.5.1.4.

Flexnip application systems are – contrary to U-shaft – unsuitable for dyeing because in the short contact time (0.1-0.2 s) the dyes would not penetrate the fibre effectively (see description of both systems in Section 4.5.1.4). However, this kind of application is applicable for pretreatment and finishing [ 44, ÖKOPOL 2011 ], [ 89, EURATEX 2019 ]

As already explained in Section 2.7.8.2, in batch operations the amount of water used per kg of processed substrate is higher, although there has been considerable improvement in this field too. All major machine manufacturers now have units for dyeing at a low liquor ratio. An investment in such units pays because it cuts operating costs (energy, water, chemicals, dyes, etc.) and raises productivity by reducing processing times (see also Section 2.7.8.2 and Section 4.5.1.7).

#### Technical considerations relevant to applicability

Generally, there are no technical restrictions to the applicability of this technique.

#### 4.1.3.3 Optimised cleaning of the equipment

##### Description

The amount of water used for cleaning is reduced by applying the following techniques:

- dry (water-free) cleaning of process tanks before cleaning them with water;
- cleaning process tanks with the minimum amount of water;
- recycling cleaning waters from process tanks in the production process.

##### Technique description

- **Dry (water-free) cleaning of process tanks**  
A dry cleaning method can be used on process tanks by letting them run empty, using the valve at the bottom of the tanks, and scraping the surface using, for example, rubber blades, brushes, paper, cloths or other absorbent materials.
- **Cleaning process tanks with the minimum amount of water**  
Once process tanks have been dry-emptied (see above), the next step is to clean the process tanks with water and possibly detergents. The quantity of cleaning water can be limited by, for example, cleaning more than once with a limited amount of water. The last-step cleaning water (least polluted) can possibly be reused as the first cleaning water in the next cleaning activity for process tanks.



- Recycling cleaning waters from process tanks in the production process  
Chemical residues in cleaning water from process tanks can be (partly) recovered by separate collection and then reused, for example for preparing chemicals (e.g. via dilution) for the next finishing activity (see Section 4.1.7.4.4).

### **Achieved environmental benefits**

Implementation of this measure helps to limit water consumption, as well as the quantity of waste water released and its load. The use of chemicals (clean products and disinfectants) can also be limited.

### **Environmental performance and operational data**

Process tanks used in the textile industry feature a valve at the bottom. Although process tanks cannot be tilted, their height can be reduced (containers can be lowered) to make the dry cleaning process easier.

The dry cleaning method is often performed using mechanical tools (e.g. squeegee, vacuum cleaner).

The presence of displacement devices (e.g. items placed to fill up unused space in the process tanks and to limit their content) could make it more difficult to access the process tanks.

High-pressure cleaning is implemented in the textile sector to limit water consumption and to reduce the amount of waste water. No concrete data are known to be available for the water-saving effect realised by implementing this technique in the textile industry.

### **Technical considerations relevant to applicability**

Dry cleaning of process tanks is generally applicable to new plants or major plant upgrades. There may be obstacles in existing systems (e.g. displacement devices or other equipment installed in the process tanks), which could limit access. Additionally, although it may not be possible to tilt the process baths, some are designed so that their height can be altered (e.g. containers can be lowered) to make the access and the cleaning process feasible. Nevertheless, water-free cleaning in existing plants may be restricted by accessibility to the equipment (e.g. closed and semi-closed systems).

A number of facilities, e.g. a storage tank, are needed to separately collect cleaning waters from process tanks. Furthermore, in order to reuse this rinsing water, measurement equipment is needed.

There are no indicators that cleaning water from process tanks containing brominated flame retardants (e.g. DBDPE),  $Sb_2O_3$ , or PFOA cannot be collected. Reuse of cleaning water is more difficult to implement for job-processing companies (compared to integrated textile companies), due to the smaller production batches and the varying production activities. Additionally, the sector has identified a number of potential bottlenecks:

- contamination risk from chemicals (e.g. rinsing waters containing NP/NPE and/or PAHs);
- potential reactions between chemicals.

If these cleaning waters cannot be reused in the production process, the other option is to dispose of them via a qualified processing company.

### **Cross-media effects**

None identified.

**Economics**

This measure is not accompanied by a noteworthy increase or decrease in costs and is regarded as economically feasible for all textile companies.

**Driving force for implementation**

Savings in chemical costs and in water consumption.

**Example plants**

A Flemish textile company (integrated company) indicates that 70 % of cleaning waters are reused in the production process.

**Reference literature**

[ 108, Derden et al. 2010 ]

**4.1.3.4 Optimisation of water efficiency in washing and rinsing**

In both batch and continuous processing, water consumption for washing is significantly higher than for the treatment itself (e.g. dyeing) (see also Section 2.7.8.2). Modern *continuous* washing machines have greatly improved their washing efficiency. In *batch* processes, it is not easy to achieve a high washing efficiency with little water and in a short time and therefore a low liquor ratio does not always correlate with reduced water use as one might expect. Indeed, it is not uncommon to find machines able to dye with a liquor ratio of 1:5 and then rinse with a liquor ratio of 1:10. Moreover, conventional machines can only handle unloading by increasing the liquor ratio.

Technological developments have decreased specific water consumption in batch processing to levels more typical of continuous operations. A constant liquor ratio across variable load sizes is now a standard feature of modern equipment for batch processes. Efficient washing techniques have also been specially developed for batch operations (see Section 4.1.3.4.1). Furthermore, various functions typical of continuous processing have been transferred to batch machines, such as (see Section 4.5.1.7):

- in-process separation of the bath from the substrate;
- internal separation of process liquor from the washing liquor;
- mechanical liquor extraction (e.g. by squeeze rollers, vacuum extractors, suction or blowing/ejection of liquid by compressed air) between the washing and/or rinsing steps to reduce carry-over and improve washing efficiency;
- internal countercurrent flow in the batch washing process.

**4.1.3.4.1 Batch washing and rinsing****Description**

In batch processes, efficient washing and rinsing techniques include:

- ‘drain and fill’ rinsing;
- ‘smart rinsing’.

**Technical description**

In overflow or ‘flood’ rinsing, clean water is fed into the machine and drained through an overflow weir, usually set near the normal running level. This technique is useful for removing the surface scum resulting from poor quality water, chemicals or inefficient pretreatment, but it is inefficient in terms of water consumption, especially in machines with a high liquor ratio.

Better options are as follows:

- The 'drain and fill' method [ 350, Bradbury et al. 2000 ]  
The 'drain and fill' method is a more efficient technique in terms of water consumption. Here, rinsing is achieved by successive filling, running and draining steps. Among the various factors playing a role in this process, it is worth noting the influence of the liquor ratio and draining time on the rinsing efficiency, as calculated using the equation below:

$$C_f = C_s \times R/L.R.$$

where:

- C<sub>f</sub> = concentration of solute in the subsequent rinse bath;
- C<sub>s</sub> = concentration of solute in the previous bath;
- R = retention capacity (or carry-over) of the substrate (l/kg);
- L.R. = liquor ratio (l/kg).

From the equation it can be demonstrated that at lower liquor ratios more rinsing steps are required in order to achieve the same dilution effect, but actually using less water. The following example for cotton dyeing with reactive dyes clearly shows this. Considering an exhausted dye liquor containing 60 g/l electrolyte, with a retention capacity of the substrate of 3 l/kg (R) and a liquor ratio of 1:15 (L.R.), the concentration of electrolyte C<sub>f</sub> in the subsequent rinse bath after one drain/fill operation will be 12 g/l and after two drain/fill operations will be 2.4 g/l. Conversely, if the liquor ratio is reduced to 1:7, C<sub>f</sub> becomes 26 g/l and 11 g/l, respectively, for one and two subsequent rinses.

Moreover, the substrate in the machine retains much of the previous bath, which is expressed by the R parameter (retention capacity). This can be reduced by proper draining (increasing draining times) or, in some batch machines (e.g. yarn package dyeing, stock dyeing), by blowing air through the fabric or by vacuum extraction between washing steps.

The main disadvantages of the traditional 'drain and fill' rinsing method are:

- the longer production cycle time, which means lower productivity;
- the thermal shock to which the substrate is subjected during the first rinsing;
- the deposition of scum on the substrate between rinses as the liquor drains; this means that the removed chemicals or impurities can re-deposit on the surface of the textile material, especially if the machine is refilled with cold water.

All these limitations have been solved in modern machinery:

- Cycle time: the machines are equipped with special time-saving devices (power draining and filling, combined cooling and rinsing, full volume heated tanks, etc.), which allows shorter time cycles compared to traditional 'overflow' rinsing.
- Thermal shock: the thermal shock during the first rinsing step can be avoided using the 'combined cooling and rinsing' system. This is again a common feature of modern machinery, which allows simultaneous cooling and rinsing of the processed textile. Clean water is introduced through the jet/overflow nozzle after it has been preheated by passing it through either the machine's main heat exchanger or an external high-efficiency plate heat exchanger. The contaminated waste liquor is then drained.
- Deposition of scum on the substrate: this remains a limitation of the 'drain and fill' method. This is why batch dyeing machines are designed to allow rinsing in either the 'drain and fill' or the 'smart rinsing' mode. The latter, which is

described below, is a ‘controlled overflow’ method that can be used for the first rinsing step before switching to the ‘drain and fill’ mode.

- ‘Smart rinsing’ systems [ 350, Bradbury et al. 2000 ]  
The use of low-liquor-ratio machines is a specific requirement for effective use of ‘smart rinsing’ systems. Rinsing is achieved by feeding clean water into the machine and draining it through an overflow weir set low down in the dyeing machine. In addition, the clean water flow in the machine is regulated at an equivalent rate to that of the liquor draining through the low-level overflow. Compared to traditional overflow rinsing, the dilution effect is increased thanks to the reduced volume of contaminated liquor circulating in the machine. The technique is particularly efficient when hot water is used for rinsing. This can be done in an efficient way by ‘combined cooling and rinsing’, which allows simultaneous cooling and rinsing of the processed textile as described above.

In this case, the final concentration of the solute at the end of the rinsing sequence is given by the following equation:

$$C_f = C_s \times \exp(-Rt/V_k)$$

where:

- $C_f$  = final concentration of the solute;
- $C_s$  = starting concentration of the solute;
- $R$  = flow rate of incoming fresh liquor (l/min);
- $t$  = rinsing time (min);
- $V_k$  = volume of liquor bath (l).

The liquor ratio is one determining factor: the higher the liquor volume, the longer the rinsing time required (and therefore the higher the water consumption) to reach the same dilution effect at the same flow rate. The flow rate  $R$  also significantly influences rinsing efficiency. If the rate is reduced, longer rinsing times are needed to achieve the same end point, but this time the water consumption would be unaltered.

Further process optimisation may be achieved by applying systems such as on-line conductivity meters to signal the attainment of a preset concentration of salt (when using reactive dyes) or by colorimeters to facilitate rinsing to the optimum end point.

#### **Achieved environmental benefits**

Reduced water consumption.

#### **Environmental performance and operational data**

‘Drain and fill’ and ‘smart rinsing’ are both more efficient in terms of water consumption than conventional overflow rinsing.

As far as the ‘drain and fill’ method is concerned, replacing each overflow rinse by two to four ‘drain and fill’ cycles can achieve a water consumption reduction of 50-75 %.

Reduced water consumption also means reduced energy consumption, since hot and warm rinsing steps are often required. In addition, energy savings are obtained with combined cooling and rinsing techniques.

One fundamental feature of both ‘smart rinsing’ and ‘drain and fill’ compared to the conventional overflow method is that it is possible to keep the exhausted concentrated dye liquor and the rinsing waters as separate streams. This means that they can be reused or at least treated separately and thermal energy can thus be recovered.

### **Cross-media effects**

None identified.

### **Technical considerations relevant to applicability**

The adoption of the 'drain and fill' rinsing technique is generally applicable to both new and existing equipment, but is more efficient on low-liquor-ratio machines equipped with time-saving devices (power draining and filling, combined cooling and rinsing, full volume heated tanks, etc.).

The concept of 'smart rinsing' has been developed specifically to solve the problems with fabric rinsing.

Both 'smart rinsing' and 'rapid drain and fill' systems are available on all jet and overflow machines [ 351, MCS 2002 ]. This is also the case for the 'combined cooling and rinsing' system. Most of the new dyeing machines have systems (e.g. stock tanks with internal heat exchangers large enough to accommodate the nominal running capacity of the machine) that allow simultaneous cooling and rinsing of the fabric. If auxiliary tanks to enable these systems are needed in existing plants, such an upgrade may be restricted by a lack of space.

### **Economics**

'Smart rinsing' and 'rapid drain and fill' offer great potential advantages, not only in terms of efficient use of water and energy, but also in allowing shorter production cycles, and thereby a reduction in total production costs.

The application of the conventional 'drain and fill' technique, although easy to implement (i.e. no need for investment in new machinery), will not allow shorter production cycle times or a productivity increase.

### **Driving force for implementation**

Reduction of production cycle time (increase in productivity) without compromising right-first-time performance is the main driving force for the application of this technique.

### **Example plants**

Plants from the data collection: IT064, IT068, IT071, IT072, IT077, IT089, IT090, IT091, IT094, PT108 and PT114.

### **Reference literature**

[ 251, VITO 2001 ], [ 350, Bradbury et al. 2000 ], [ 351, MCS 2002 ]

#### **4.1.3.4.2 Continuous washing and rinsing**

##### **Description**

In continuous processes, typical washing and rinsing techniques include:

- automatic stop valves;
- countercurrent washing;
- reduction of carry-over;
- heat recovery.

##### **Technical description**

- Automatic stop valves  
Automatic stop valves that link the main drive mechanism of the washing machine to the water flow can save considerable quantities of energy and water by shutting off water flow as soon as a stoppage occurs. With manual control, the water flow may not

be switched off until the machine has stopped for more than 30 minutes [ 90, UK 1997 ].

- **Countercurrent washing**

The least contaminated water from the final wash is reused for the second-to-last wash and so on until the water reaches the first wash stage, after which it is discharged. This means that the cleanest fabric comes into contact with the cleanest water. This technique is relatively straightforward and inexpensive and can be applied for washing after continuous desizing, scouring, bleaching, dyeing or printing [ 30, US EPA 1996 ], [ 83, CITEVE 2014 ].

A washer configuration with internal countercurrent (and recycling) capabilities is the vertical counter-flow washer, which sprays recirculated water onto the fabric and uses rollers to squeeze waste through the fabric into a sump, where it is filtered and recirculated. This construction allows for high-efficiency washing with low water use. Energy use decreases greatly because less water must be heated [ 30, US EPA 1996 ].

- **Reduction of carry-over**

Water (containing contaminants) that is not removed from the textile substrate is 'carried over' into the next step, contributing to washing inefficiency. Proper extraction between steps is essential. In continuous washing operations, squeeze rollers or vacuum extractors (more efficient) are used to reduce drag-out and carry-over [ 30, US EPA 1996 ].

Wash boxes with built-in vacuum extractors are available as well as after-printing washers that combine successive spray and vacuum slots without any bath for the fabric to pass through [ 30, US EPA 1996 ].

- **Heat recovery**

Installing heat recovery equipment on a continuous washer is usually a simple but effective measure, since water inflow and effluent outflow are matched, eliminating the need for holding tanks. The effluent from these machines can become contaminated with fibrous material, so it is important to install heat exchangers capable of handling such loads (e.g. self-cleaning elements) [ 90, UK 1997 ].

### **Achieved environmental benefits**

All measures described contribute to an overall reduction of the water and energy consumed. In order to allow full exploitation of the benefits achievable with the new advanced washing machinery, the implementation of low-technology measures is fundamental.

### **Environmental performance and operational data**

Table 4.5 below shows the achievable water consumption levels for washing cotton and viscose woven fabric and their blends with synthetic fibres. The values for the different processes are additive and were submitted by machine manufacturers and confirmed by some finishing mills.

It is worth pointing out that the achievable performances are influenced by the degree of implementation of complementary techniques. Low water consumption levels can only be achieved by synergistic combinations of different possible measures, from the preparation of the fabric through the process chain (e.g. low add-on application techniques for sizing agents, selection of dyes with good washing-off properties).

**Table 4.5: Achievable specific water consumption levels for continuous washing processes during finishing of open-width woven fabric consisting of cotton or viscose and their blends with synthetic fibres**

Pretreatment processes	Water consumption (l/kg)	
	TOTAL	of which HOT WATER
Washing for desizing	3-4	3-4
Washing after scouring	4-5	4-5
Washing after bleaching	4-5	4-5
Washing after cold bleaching	4-6	4-6
Washing after mercerisation		
- Washing to remove NaOH	4-5 (hot)	4-5
- Neutralisation without drying	1-2 (cold)	NA
- Neutralisation and drying	1-2 (warm)	< 1
<b>Washing after dyeing</b>		
Reactive dyestuffs	10-15	4-8
Vat dyestuffs	8-12	3-7
Sulphur dyestuffs	18-20	8-10
Naphthol dyestuffs	12-16	4-8
<b>Washing after printing</b>		
Reactive dyestuffs	15-20	12-16
Vat dyestuffs	12-16	4-8
Naphthol dyestuffs	14-18	6-10
Disperse dyestuffs	12-16	4-8
NB: NA: Not applicable. Source: [ 5, UBA 2001 ]		

Concerning energy consumption, the use of countercurrent washing may also lead to an energy consumption reduction of between 41% and 62 % (related to fuel savings in open-width washing) [ 83, CITEVE 2014 ].

### Cross-media effects

Highly intensive and efficient washing techniques with low water consumption require intensive mechanical washing conditions such as spraying and sucking, which may cause somewhat higher electricity consumption. However, this is largely offset by energy savings achievable by implementing thermal energy recovery measures that are also part of the measures described [ 5, UBA 2001 ].

### Technical considerations relevant to applicability

Generally, there are no technical restrictions to the applicability of this technique.

### Economics

The achievement of performances typical of highly efficient washing machines requires investment in new equipment. However, the application of low-technology measures such as flow-control devices, automatic valves, etc. can also produce some reduction in water and energy consumption.

Detailed information was not made available. In order to indicate the order of magnitude, a continuous washing line for cotton fabric, allowing for minimal water consumption (9 l/kg in total, including odour removal and lint filtration) by combined application of various technical optimisation measures, costs EUR 2.5 million [ 186, Bettens L. 2001 ].

### Driving force for implementation

The main driving forces for the implementation of the techniques described are the increasing cost of water supplies and waste water treatment, and the desire to increase productivity (in the case of new highly efficient washing machinery).

**Example plants**

Plants from the data collection: BE013, DE024, DE044, IT059, IT061, IT064, IT065, IT068, IT069, IT074, IT077, IT078, IT079, IT094, PT108, PT109 and UK127.

**Reference literature**

[ 5, UBA 2001 ], [ 30, US EPA 1996 ], [ 83, CITEVE 2014 ], [ 84, Hasanbeigi A. 2010 ], [ 90, UK 1997 ]

**4.1.3.5 Reuse and/or recycling of water and process baths****Description**

Water streams may be segregated (see Section 4.1.3.2.2) and/or pretreated (e.g. membrane filtration, evaporation) before reuse and/or recycling, e.g. for cleaning, rinsing, cooling or in the processing of textile materials. The degree of water reuse/recycling is limited by the content of impurities in and/or the characteristics of the water streams. Reuse and/or recycling of water originating from several plants operating on the same site may be integrated in the overall site water management of a larger industrial site (e.g. using common waste water treatment).

This includes:

- reuse and/or recycling of washing and rinsing water;
- reuse and/or recycling of cleaning water;
- reuse of process baths;
- reuse and/or recycling of cooling water as process water (and also for heat recovery);
- recycling of treated waste water (permeate) from treatment (membrane, reverse osmosis) of segregated dyeing or desizing effluents.

On waste water treatment for reuse and recycling, see Section 4.1.7.4.4).

**Technical description**

Batch processes do not easily allow for water recycling. When trying to reuse waste water in batch operations, storage facilities for reusable waste water are needed. Other problems associated with reuse of waste water from batch bleaching and scouring are the non-continuous character of the stream and the higher liquor ratios.

However, a continuous countercurrent flow of textiles and water is also possible in batch processing. Machines are available with built-in facilities for waste stream segregation and capture. For example, the washing water from a previous load can be recovered and fully used in the bleach bath for the current load, which can then be used to scour the next load. In this way, each bath is used three times.

The internal separation of process liquor from the washing liquor applied to some modern batch dyeing machines (see above) is essential to allow easier bath segregation and reuse, in cases where the characteristics of the liquor make it feasible.

Storage tanks may be needed to store spent baths, washing or rinsing water for reuse.

- Reuse and/or recycling of washing and rinsing water  
[ 84, Hasanbeigi A. 2010 ], [ 91, Ullah S. 2019 ]

This water can be reused in another washing or rinsing operation which accepts low-grade water, or it can be reused as process water in wet processing operations with or without the addition of chemicals. Examples include:



- the reuse of washing water from bleaching in caustic washing and scouring make-up and rinsing water;
- the reuse of rinsing water from scouring for desizing or washing printing equipment;
- the reuse of washing water from mercerising to prepare scouring, bleaching, and wetting-out baths;
- the use of water for pre-washing carpets in after-washing.

Generally, the rinsing water resulting after bleaching or batch dyeing can be reused several times. For instance, the rinsing water of bleaching processes can be reused for rinsing after a caustic treatment and, in some cases, the water can be reused for a third time to rinse degraded sizing agents.

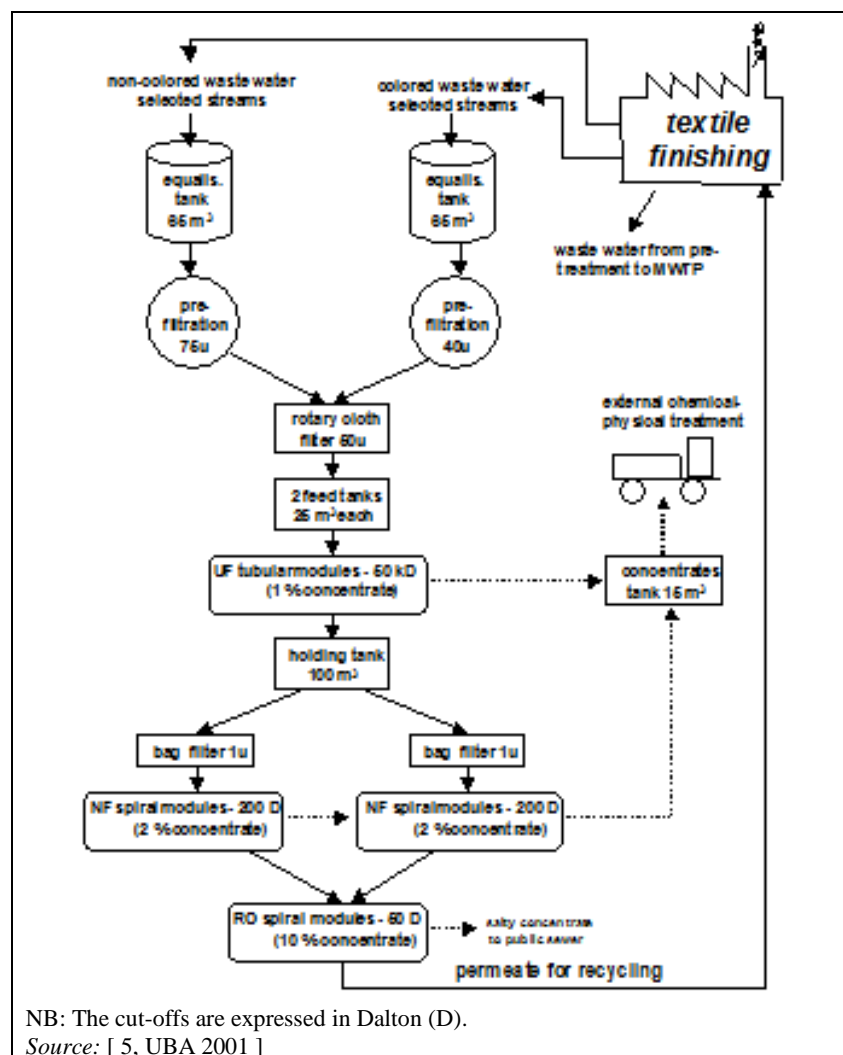
After batch dyeing, the final-step rinsing water is hardly contaminated and can be reused for the first rinsing step of the next dyeing process. If the fabric at the start of the process is put into the bath and is taken out after washing, then the rinsing water can remain in the bath and there is no need to store it separately.

The washing water can also be used in pretreatment before the dyeing process. In practice, the reuse of rinsing water from dyeing processes is complicated due to pigments remaining in the water (especially in the case of dark colours). Consequently, a prerequisite for recycling is the application of light colours (low pigment concentrations) of pigments with a high fixation rate. Before implementing this measure, an assessment is made as to whether the wash and/or rinsing water is sufficiently clean to be reused.

- Reuse and/or recycling of cleaning water  
See examples in Section 4.1.3.3 and Section 4.6.1.1.
- Reuse of process baths  
Spent bleach, dye or finishing baths are reused, after analysis and make-up if needed. See example in Section 4.5.1.8 for the reuse of spent dye bath in batch dyeing. The degree of reuse of the process liquor is limited by the modification of its chemical composition, or by its content of impurities and its perishability.
- Reuse and/or recycling of cooling water  
[ 84, Hasanbeigi A. 2010 ], [ 91, Ullah S. 2019 ]  
Many cooling water systems are operated on a once-through basis. In general, cooling water and condensate water can be pumped to hot water storage tanks for reuse in functions where heated water is required, such as for dye make-up water, bleaching, rinsing and cleaning.
- Recycling of treated segregated waste waters from dyeing and desizing  
The degree of reuse of the process liquor is limited by the modification of its chemical composition, or by its content of impurities and its perishability.

Membrane techniques (e.g. ultrafiltration, nanofiltration, reverse osmosis), ion exchange and evaporation are applied for the treatment of segregated streams from dyeing and desizing to allow water recovery and reuse, closely integrated with these processes (see Figure 4.5). For more details on these techniques, see Sections 4.1.7.3 and 4.4.8.1. A specific combination of sedimentation/ultrafiltration/evaporation used for reuse of waste water and recovery of salt from dyeing processes in large proportions (e.g. full scale) is known as Zero Liquid Discharge [ 35, RICARDO 2019 ]. Energy consumption for such reuse and recovery is substantial. According to [ 92, Inayath Hussain et al. 2018 ], the operation of a typical WWTP (pretreatment, biological treatment, settling, filtration) with additional ultrafiltration/reverse osmosis/evaporation/crystallisation units consumes up to 28 kWh/m<sup>3</sup> of electrical power and

steam, with around 50 % consumed in the evaporation/crystallisation step (see Section 4.1.7.4.4).



**Figure 4.5:** Treatment of selected segregated waste water streams using a series of membrane techniques (ultrafiltration, nanofiltration and reverse osmosis)

Reuse and/or recycling of water originating from several plants operating on the same site may be integrated in the overall site water management of a larger industrial site (e.g. using common waste water treatment).

#### Achieved environmental benefits

Significant savings in water and energy consumption are possible for techniques a, b, c, and d (energy is used to a great extent to heat up the process baths). Section 4.1.4.3 addresses the techniques to recover energy by reuse of warm water.

Technique e reduces consumption of fresh water and chemicals (e.g. salt).

#### Environmental performance and operational data

A bleach bath recovery system can be utilised in both the knit and woven segments, and can result in a reuse of 50 % of the total water used in a typical 100 % cotton full bleach process, including pre-scour, bleach and neutralisation. Savings also arise from reduced energy consumption and waste water disposal charges. The average temperature of the recovered water is estimated to be 40 °C [ 84, Hasanbeigi A. 2010 ].

Holding tanks are needed to store the spent process baths before reuse or treatment for reuse/recovery.

### Cross-media effects

Reduced water consumption results in a high concentration of pollutants and requires corresponding waste water treatment [ 44, ÖKOPOL 2011 ].

Technique e generates concentrated permeate, which has to be treated appropriately (e.g. either handled as waste or treated with evaporation for the recovery of salt – which increases the energy consumption significantly).

### Technical considerations relevant to applicability

Generally, there are no technical restrictions to the applicability of this technique.

### Economics

Table 4.6 describes the capital cost and annual operating savings for water reuse techniques, which vary depending on the size of the plant.

**Table 4.6: Capital costs and annual savings related to water reuse techniques**

Measure	Bleach bath recovery	Reuse of cooling water and condensate
Capital cost	USD 80 000 to USD 246 000 <sup>(1)</sup>	USD 143 000 to USD 212 000 <sup>(1)</sup>
Net annual operating savings	USD 38 500 to USD 118 400 <sup>(1)</sup>	USD 82 900 to USD 161 500 <sup>(1)</sup>
Payback period	2.1 years	1.3 to 1.7 years

<sup>(1)</sup> 2001 value.  
NB: Costs and savings are associated with the amount of production and not just for one machine.  
Source: based on [ 84, Hasanbeigi A. 2010 ]

The principal cost items related to reuse of cooling water are pumps, piping modifications and hot water storage tanks [ 84, Hasanbeigi A. 2010 ].

[ 92, Inayath Hussain et al. 2018 ] reports the running (operation and maintenance) costs of Zero Liquid Discharge (ZLD), specific for Indian circumstances (energy/chemicals market), as EUR 4.5–6.0/m<sup>3</sup>.

### Driving force for implementation

- Savings in water consumption.
- Reduced amount of waste water.

### Example plants

See cross-referenced techniques in other sections of this document.

Plants IT065 and PT108 reuse cooling water. Plant IT065 also reuses rinsing water.

Plant SE118 collects and reuses spent baths and pastes such as softening baths as well as acrylate paste when coating or padding. When the spent baths or pastes are too contaminated, they are treated as hazardous waste.

### Reference literature

[ 35, RICARDO 2019 ], [ 44, ÖKOPOL 2011 ], [ 83, CITEVE 2014 ], [ 84, Hasanbeigi A. 2010 ], [ 91, Ullah S. 2019 ], [ 92, Inayath Hussain et al. 2018 ], [ 93, Austrian EPA 2016 ]

### 4.1.3.6 Environmental performance related to water consumption optimisation

The data about the specific water consumption of different processes is shown in Section 3.6.2. Consumption levels achieved when applying the water-saving measures mentioned in this section are shown in Table 4.4.

**Table 4.7: Specific water consumption when applying water-saving measures**

Specific process(es)		Indicative levels (Yearly average) (m <sup>3</sup> /t)
Bleaching	Batch	10 – 32 <sup>(1)</sup>
	Continuous	3 – 8
Scouring of cellulosic materials	Batch	5 – 15 <sup>(1)</sup>
	Continuous	5 – 12 <sup>(1)</sup>
Desizing of cellulosic materials		5 – 12 <sup>(1)</sup>
Combined bleaching, scouring and desizing of cellulosic materials		9 – 20 <sup>(1)</sup>
Mercerisation		2 – 13 <sup>(1)</sup>
Washing of synthetic material		5 – 20 <sup>(1)</sup>
Batch dyeing	Fabric	10 – 150 <sup>(1)</sup>
	Yarn	3 – 140 <sup>(1)</sup> <sup>(2)</sup>
	Loose fibre	13 – 60
Continuous dyeing		2 – 16 <sup>(1)</sup> <sup>(3)</sup>
<sup>(1)</sup> The lower end of the range may be achieved with a high level of water recycling (e.g. sites with integrated water management for several plants). <sup>(2)</sup> The range also applies to combined yarn and loose fibre batch dyeing. <sup>(3)</sup> The higher end of the range may be higher and up to 100 m <sup>3</sup> /t for plants using a combination of continuous and batch processes.		

### Economics

In existing mills, investment in new equipment and/or structural modifications (e.g. for the segregation of streams) is likely to be necessary.

## 4.1.4 Energy efficiency

### 4.1.4.1 Energy efficiency plan and audits

#### Description

An energy efficiency plan and audits are part of the environmental management system (EMS) and include:

- energy flow diagrams of the plant and processes as part of the inventory of inputs and outputs (see Section 4.1.1.2);
- setting objectives in terms of energy efficiency (e.g. MWh/t of textile materials processed);
- implementation of actions to achieve these objectives.

Audits are carried out at least once every year to ensure that the objectives of the energy efficiency plan are met.

#### Technical description

Extensive information about energy efficiency can be found in the ENE BREF [95, COM 2009]. Some techniques applicable to increase the energy efficiency of textile plants are as follows:

- Appraising the costs and benefits of different energy options.
- Monitoring energy flows (consumption and generation by source - see Section 4.1.1.2) and the targeting of areas for reductions.
- 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 textile produced).
- Carrying out an energy survey to identify the opportunities for further energy savings.
- Using combined heat and power (CHP). Cogeneration of heat and electricity where the heat (mainly from the steam that leaves the turbine) is used for producing hot water/steam to be used in industrial processes/activities or in a district heating/cooling network.
- Applying operating, maintenance and housekeeping measures to the most relevant energy-consuming systems 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 – see Section 4.1.4.4);
  - steam distribution systems (leaks, traps, insulation);
  - room heating and hot water systems;
  - lubrication to avoid high friction losses (e.g. mist lubrication);
  - burner maintenance and control;
  - boiler maintenance, e.g. optimising excess air;
  - other maintenance relevant to the activities within the plant;
  - reviewing equipment requirements on a regular basis.
- 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;
  - efficient plant layout to reduce pumping distances;
  - variable speed drives;
  - heat recovery (see Section 4.1.4.3);
  - ensuring equipment is switched off, if safe to do so, when not in use;
- 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).
- Setting the time of operation of the high-energy equipment to off-peak periods.
- Optimising boilerhouses (reuse of condensed water, preheating of air supply, heat recovery in combustion gases) and optimising boiler design according to energy demand profile (see also the LCP BREF).
- Segregation of hot and cold waste water streams prior to heat recovery and recovery of heat from the hot stream by waste water abatement and reuse (see Section 4.10.4) or by heat exchange.
- Optimising production planning of finishing jobs to avoid downtimes of the stenter frame and related heating periods.
- Installing heat recovery systems for waste gases from stenter frames and waste gas treatment devices applying air/air or air/water heat exchange systems – an example is given in Section 4.1.4.4.
- Optimising air conditioning systems (e.g. by sections or by direct conditioning of specific weaving machines for individual adaptation of volume and humidity).

- Optimising compressed air system and evaluation of a separate system with low pressure (see Section 4.1.4.4).
- Use of the heat content of the cooling air of the compressor (for process water heating by air/water heat exchange or for yarn drying).
- Optimising the cold and hot water systems (installation of a pressure compensation tank, priority circuit for several pressure-boosting pumps, shut-off during shutdown of the plant).
- Monitoring and controlling the moisture content in the circulating air and on the textile in the stenters (see Section 4.1.4.4).
- Proper adjustment of drying/curing temperature and drying/curing time.
- Installing covers on nips and tanks; the fitted covers are easily removable to allow quick access [ 83, CITEVE 2014 ].
- Unnecessary high steam pressure is avoided for both direct and indirect steam heating [ 83, CITEVE 2014 ].
- Point-of-use gas-fired water heaters can be used to enable processes to be run independently of the plant's central boiler systems. This means that boiler and distribution losses associated with centralised systems (which can be as much as 50 % of the fuel input) can be eliminated. Point-of-use heating also offers greater flexibility since it allows operation outside the main boiler operating hours [ 84, Hasanbeigi A. 2010 ].
- Using cold pad-batch for pretreatment (e.g. desizing or bleaching, see Section 2.6.1.1.2) or dyeing of cotton (see Section 2.7.3.1) [ 31, Cotton Incorporated 2009 ].
- Avoiding overheating of the baths and optimising the temperature of rinsing water (see Section 4.5.1.11).
- Optimising the heat demand by: reducing heat losses by insulating equipment components and by covering tanks or bowls containing warm process liquor; optimising the temperature of the rinsing water; and avoiding overheating of the process liquors.
- Wet-on-wet dyeing or finishing: dyestuff or finishing liquors are applied directly to the wet fabric, thus avoiding the need for an intermediate drying step [ 94, Wagaw et al. 2012 ]. To ensure an even application of dyestuff or finishing agent, the constant concentration of process liquor needs to be maintained (e.g. by online monitoring and automatic dosage systems). Appropriate scheduling of production steps and dosing of chemicals need to be considered. See Section 4.1.4.7.
- The following measures contribute to a lower environmental impact from energy production as a whole:
  - management of peak current for reduction and avoidance of consumption peaks;
  - use of low-emission energy sources in the boiler (e.g. natural gas, low-sulphur fuel);
  - use of renewable energy sources (sun, wind, water, biomass) for electricity and steam production;
  - evaluation and use of combined heat and power generation for steam base load and electricity production.

#### **Achieved environmental benefits**

Utilising an energy efficiency plan can reduce the energy consumption and the environmental emissions of that energy use.

#### **Environmental performance and operational data**

The installation of covers on nips and tanks may reduce the energy consumption needed to heat up the baths by 36 % [ 83, CITEVE 2014 ]. Examples of the use of flow diagrams are presented in [ 274, Ozturk et al. 2016 ].

### **Cross-media effects**

None identified.

### **Technical considerations relevant to applicability**

The level of detail of the energy efficiency plan and audits will generally be related to the nature, scale and complexity of the plant.

Applicability of cogeneration to existing plants may be restricted by the plant layout and/or lack of space. Wet-on-wet dyeing or finishing of fabric may not be applicable when chemicals cannot be taken up by the fabric due to insufficient residual pick-up.

Some of these techniques are more extensively applied to large consumers of energy. For energy-intensive industries, the application of energy efficiency techniques to building services may only have a minor impact and should not distract effort away from the major energy issues. They can, nonetheless, find a place in the improvement programme, particularly where they may constitute more than 5 % of the total energy consumption.

### **Economics**

Energy-efficient systems typically have higher investment costs. However, their operating costs are usually lower (or the revenues higher).

The improvement of the energy efficiency needs to be balanced with the cost of achieving this.

### **Driving force for implementation**

Energy savings.

### **Example plants**

A total of 45 plants from the data collection apply an energy-saving plan.

### **Reference literature**

[ 31, Cotton Incorporated 2009 ], [ 44, ÖKOPOL 2011 ], [ 81, bluesign 2018 ], [ 83, CITEVE 2014 ], [ 84, Hasanbeigi A. 2010 ], [ 95, COM 2009 ], [ 96, Pinasseau et al. 2018 ], [ 274, Ozturk et al. 2016 ]

#### **4.1.4.2 Monitoring of energy consumption**

[ 44, ÖKOPOL 2011 ]

##### **Description**

Monitoring of energy consumption, as part of the energy efficiency plan (see Section 4.1.4.1) and the streams inventory (see Section 4.1.1.2).

##### **Technical description**

Monitoring comprises the establishment of a register of energy-consuming processes and of all single aggregates including air conditioning and lighting. Direct measurement of energy consumption is preferred (e.g. over estimation). If no energy consumption meters are installed, the power values of aggregates are registered together with the estimated mean consumption and running times. Consumption data are connected to cost data according to each energy source.

For monitoring consumption, indicators are defined for the entire plant and for single processes, together with determined periods for data collection, e.g. energy consumption (gas, oil, etc.) per tonne of steam produced, electricity consumption for compressed air per tonne of product produced, electricity consumption of big aggregates per tonne of product produced, consumption of steam and electricity per processed good or group of goods, consumption of steam and electricity per processed good during dyeing and drying, gas consumption of the stenter frame per group of goods.

Consumption data are communicated to the workers in charge of the respective process, and training on reduction measures conducted.

The economic viability of potential energy-saving measures are recalculated regularly, based on the latest up-to-date energy cost data.

#### **Achieved environmental benefits**

Reduction of the environmental impact associated with energy production by identification of the main energy consumers and related efficient prioritisation of improvement measures as well as by training and raising awareness of employees.

#### **Environmental performance and operational data**

Plant A: in a fully integrated textile company (producing textiles for private consumers, hotels and hospitals) with approximately 300 employees, the energy consumption of 12 rotor spinning machines was monitored and compared with the electric energy consumption of new machines [ 97, EfA 2004 ].

Plant B: energy consumption was monitored in a textile company with approximately 500 employees, specialised in high-quality textile printing with small runs (8.7 million metres per year; clothes, linen, home textiles).

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

Restrictions for the use of consumption meters may occur in existing installations if potential energy savings are expected to be low in relation to the meter installation costs.

#### **Economics**

Efforts for monitoring energy consumption depend on the size and complexity of the company. Cost savings in Plant A (see below) were reported to be EUR 175 000 per year. No data were available from Plant B.

#### **Driving force for implementation**

Energy savings.

#### **Example plants**

Plant A: HCH.Kettelhack Textilfabrik, DE-48432 Emsdetten.

Plant B: Textile company in Switzerland.

Plant of the data collection: DE042.

#### **Reference literature**

[ 44, ÖKOPOL 2011 ], [ 97, EfA 2004 ]

### **4.1.4.3 Heat recovery by direct reuse of warm water or warm air, or by means of heat exchangers**

[ 44, ÖKOPOL 2011 ]

#### **Description**

Heat is recovered from cooling water or from process water as well as from cooling air, waste gas and steam use. The heat content can be used directly (by reuse) or indirectly (by heat exchangers).



### Technical description

- Heat recovery from water

- Processes which are often appropriate for direct reuse of warm process water are bleaching, dyeing, rinsing and washing, for instance:
- reuse of warm water by counterflow recirculation (for peroxide bleaching and alkali boiling-off, see Section 4.4.1; dyeing, see Section 4.5.1.7.2; continuous washing and rinsing, see Section 4.1.3.4.2);
- reuse of appropriate hot dyeing water after analysis and storage in a tank or in a second machine, adding fresh water to make up the amount which was taken out of the process by the fibres; in some cases it is necessary to cool down the water to the appropriate dyeing temperature at the start of the process (see Section 4.5.1.8);
- reuse of appropriate warm rinsing baths after analysis and storage (see Section 4.1.3.3).

If fresh water is used for process cooling, this can be used directly for warm processes, e.g. for dyeing or rinsing. The examples of warmed-up cooling water streams that can be reused are:

- cooling water of soda lye recovery (see Section 4.4.8.2);
- cooling water from batch dyeing (see Section 4.5.1.7);
- cooling water from water-cooled air compressors.

More generally, water reuse techniques are addressed in Section 4.1.3.3.

The heat content of waste water can often be used indirectly by applying a water/water heat exchanger for heating process water as for example:

- heat exchanger for waste water from raw wool washing (see Section 4.2.2);
- heat exchanger for waste water from reactive dyeing (see Section 4.5.2.5);
- heat exchanger for waste water from dyeing machines (see Section 4.5.1.7.2);
- heat exchanger for waste water from washing and rinsing (see Section 4.1.3.4).

- Heat recovery from air

If cooling air is used in a process, warmed-up air can be used directly for warm processes, e.g. for drying of coils and hanks. For instance, heated cooling air from air compressors can be used.

The heat content of waste gas can be used indirectly by means of air/water or air/air heat exchange. This way, waste gas can be used for example from the following processes:

- air/air heat exchanger for waste gas from stenter frames for preheating air introduced into the stenter frame (see Section 4.1.4.4);
- air/air heat exchanger for waste gas from a thermal waste gas abatement system;
- air/water heat exchanger for waste gas from stenter frames for preheating of process water or heating water;
- air/water heat exchanger for waste gas from a thermal waste gas abatement system for preheating of process water or heating water;
- air/water heat exchanger for cooling air of compressors for preheating of process water or heating water;
- air/water heat exchanger for waste gas from steam boilers for preheating of boiler feed water (see [ 98, Lecomte et al. 2017 ] and [ 95, COM 2009 ]).

- Heat recovery from steam use  
Heat, e.g. from hot condensate and boiler blowdown, is recovered.

### **Achieved environmental benefits**

Energy resources are saved by using the heat content of air or water. The environmental impact associated with heat production is reduced.

Efficiencies are generally 50 % to 60 % [90, UK 1997].

Exemplary calculations show that the use of the heat content of rinsing water from continuous washing for heating of fresh water leads to energy savings of approximately 75 % [99, Kohla et al. 2008].

Plant A reported that the installation of a heat exchanger to recover heat from the waste water of a pad-steam dyeing plant can preheat the water for the washing section from 20 °C to 90 °C. For this installation, 1 600 MWh of natural gas was saved annually [99, Kohla et al. 2008], [100, EfA 2003].

### **Environmental performance and operational data**

When directly reusing dye bathes, it is necessary to undertake a thorough analysis of the chemical content to enable exact addition of lost chemicals of the bath and to achieve the desired bath quality.

Direct reuse of rinsing waters also requires an appropriate analysis to avoid a reduction in the quality of the product. The retention time in the intermediate storage tank does not exceed several hours as otherwise biological degradation processes start, hindering reuse.

When using compressor cooling air for drying coils or hanks, it is generally sufficient to use dust filters for cleaning the air.

In Plant B, energy savings associated with an air/air heat exchanger were calculated with the following data, also taking into account the increased electricity consumption of the fan:

#### Waste gas

Waste gas volume	24 000 m <sup>3</sup> /h 15 523 m <sup>3</sup> /h (at 20 °C)
Pressure drop	100 Pa
Temperature of air inlet	180 °C
Temperature of air outlet	105 °C

#### Heated air

Air inlet volume	13 495 m <sup>3</sup> /h 9 500 m <sup>3</sup> /h (at 20 °C)
Pressure drop	62 Pa
Temperature of air inlet	20 °C
Temperature of air outlet	143.2 °C

#### Heat exchange

Heat exchange	391.7 kW
Efficiency	77 %
Operation hours	4 500 h/yr
Energy recovery	1 762 650 kWh/yr

#### Additional energy consumption

Increased fan power:	2.37 kW
Rotary exchanger power:	0.18 kW
Total power increase	ca. 2.6 kW

Total energy increase ca. 11 700 kWh/yr

Energy savings ca. 1 750 950 kWh/yr

Savings are lower if annual operating times are shorter, e.g. because of set-up times. Furthermore, energy savings are lower if the waste gas has a lower temperature level. For the example above, energy savings were reduced to 18 % when the waste gas temperature was 120 °C instead of 180 °C [ 44, ÖKOPOL 2011 ].

Heat recovery systems are often combined with an aqueous scrubber or electrostatic filtration systems or a combination of these techniques.

Condensed substances (mainly preparation oils) from heat recovery systems are collected separately.

### **Cross-media effects**

Generally, there are no cross-media effects associated with direct reuse of heated water or heated air. If cleaning before reuse is necessary, small waste amounts occur.

Cleaning of heat exchangers leads to liquid or solid waste, depending on the type of cleaning system.

### **Technical considerations relevant to applicability**

Contaminated process water or cooling air could have negative effects in the event of direct reuse. Heat recovery from waste gases is only applicable when the waste gas flow is sufficient.

### **Economics**

No data are available on costs arising from the analysis of recipes for evaluation of reuse potential.

Implementation of heat exchangers requires regular maintenance which is associated with manpower costs. Cleaning is generally done mechanically by hand, therefore there are no or only low material costs.

Plant A invested approximately EUR 40 000 for the plate heat exchange system at the pad-steam dyeing machine. The investment was returned after about 1 year [ 99, Kohla et al. 2008 ], [ 100, EfA 2003 ].

Payback data for heat recovery systems (both air/water and air/air systems) are illustrated in Table 4.8 for drying and heat-setting processes. Information is based on the following reference data [ 5, UBA 2001 ]:

- heat recovery system: counter-flow pipes
- drying temperature: 130 °C
- heat-setting: 190 °C
- off-gas volume flow: 15 000 m<sup>3</sup>/h
- off-gas moisture content (drying): 70 g/m<sup>3</sup>
- off-gas moisture content (heat-setting): 40 g/m<sup>3</sup>
- T of the fresh water (before heat recovery): 15 °C
- efficiency: 70 %
- heating value of the gas 9.3 kWh/m<sup>3</sup>
- cost of the gas: EUR 0.25/m<sup>3</sup>
- maintenance cost: EUR 1 000/yr
- interest rate: 6 %

**Table 4.8: Return on investment for different processes (textiles drying and heat-setting), heat recovery systems (air/water and air/air) and number of shifts per day**

Process		1 shift/day		2 shifts/day		3 shifts/day	
		Savings (EUR)	Payback period (year)	Savings (EUR)	Payback period (year)	Savings (EUR)	Payback period (year)
Air/water	Drying	32 050	5.7	64 150	2.6	96 150	1.7
Fresh water T: 15 °C	Heat-setting	34 450	5.4	68 900	2.4	103 350	1.5
Air/water	Drying	18 050	12.6	36 100	5.9	54 150	3.3
Fresh water T: 40 °C	Heat-setting	23 350	8.6	46 700	3.7	70 050	2.4
Air/air	Drying	8 000	> 20	16 000	15.6	24 000	8.5
Fresh air T: 20 °C	Heat-setting	11 000	> 20	22 000	9.6	33 000	6.6

Source: [ 5, UBA 2001 ]

The above information does not consider the installation of other measures such as fabric moisture control and exhaust humidity control. If these systems are installed, according to some sources, heat recovery may not be cost-effective [ 90, UK 1997 ].

#### Driving force for implementation

Energy savings.

#### Example plants

Air/air heat exchangers and water/water heat exchangers

Plant A: HCH Kettelhack GmbH&Co.KG, DE-48432 Rheine (Plant DE030).

Plant B: Eing Textilveredlung und Handelsgesellschaft mbH & Co. KG, DE-48712 Gescher (Plant DE032).

Air/water heat exchangers at a waste gas treatment system

Schmitz-Werke, DE-48282 Emsdetten (Plant DE042).

Air/water heat exchangers at compressors

Schmitz-Werke, DE-48282 Emsdetten (Plant DE042).

Direct use of waste heat of compressor cooling

Madeira, DE-79100 Freiburg.

#### Reference literature

[ 44, ÖKOPOL 2011 ], [ 90, UK 1997 ], [ 95, COM 2009 ], [ 98, Lecomte et al. 2017 ], [ 99, Kohla et al. 2008 ], [ 100, EfA 2003 ]

#### 4.1.4.4 Optimisation of the compressed air system

##### Description

Organisational and technical measures to reduce the energy consumed by the compressed air system.

### Technical description

Some techniques to reduce energy consumption include the following:

- Recover waste heat from the compressors for building heating, water heating, etc.
- Regular inspection and maintenance of leakages as the energy consumed is significantly increased even by a small leakage. The most common sources of leaks are couplings, hoses, tubes, fittings, pressure regulators, open condensate traps and shut-off valves, pipe joints, disconnects and thread sealants.
- Compressed air production is stopped during long shutdown times or idle times of equipment, and single areas can be isolated (e.g. by valves) from the rest of the system, in particular if they are associated with infrequent use.
- Instead of one single system of compressed air which supplies the entire plant and which is adapted to the consumer with the highest pressure need, two compressed air systems are installed: one to supply air with lower pressure and one to supply air with higher pressure.
- Rotary compressor systems are equipped with an adjustable speed drive to account for varying compressor loads and/or ambient temperature.

### Achieved environmental benefits

Energy needs and the associated environmental impact are reduced by early detection of leakages, the use of waste heat from the compressors, the reduction of the pressure level and the installation of a second pressure system with lower pressure.

### Environmental performance and operational data

Only 15 % of the electricity consumed by an industrial air compressor is actually converted into compressed air, the rest being lost in waste heat. With large water-cooled compressors, heat recovery efficiencies of 50 % to 60 % are typical. When used for workspace heating, the recovered heat amounts to 20 % of the energy used in compressed air systems annually [ 84, Hasanbeigi A. 2010 ].

A typical plant that has not been well maintained could have a leak rate of between 20 % and 50 % of the total compressed air production capacity. Leak repair and maintenance can sometimes reduce this figure to less than 10 % [ 84, Hasanbeigi A. 2010 ].

In the example plant mentioned below, the maximum pressure is only necessary for the weaving section; therefore, a separate pipe for compressed air was installed for the weaving section, and the pressure of the remaining system was reduced by 1 bar. A new compressor was installed for the low-pressure system with a new condensation dryer. For the high-pressure system, new condensation dryers were installed, adapting their power to the required compressed air and therefore resulting in additional energy savings [ 44, ÖKOPOL 2011 ].

### Cross-media effects

None identified.

### Technical considerations relevant to applicability

The technique can be applied in new and existing installations. In existing installations, the economic benefit of an additional compressed air system depends on the distance to the users.

### Economics

The total investment for the example plant mentioned below was approximately EUR 80 000. The return on investment was after 18 months [ 44, ÖKOPOL 2011 ].

### Driving force for implementation

Energy savings and the related cost reduction are the main drivers for implementing this technique.

**Example plants**

Schmitz-Werke, DE-48282 Emsdetten (Plant DE042).

**Reference literature**

[ 44, ÖKOPOL 2011 ], [ 84, Hasanbeigi A. 2010 ]

**4.1.4.5 Minimisation of energy consumption of stenter frames and dryers****Description**

Techniques to reduce the energy consumed by stenters and dryers include:

- mechanical dewatering of the fabric;
- wet-on-wet dyeing or finishing;
- optimising exhaust airflow;
- insulation;
- optimising burner efficiency;
- optimised air circulation;
- avoiding overdrying;
- instrumentation and control of the stenters;
- optimal scheduling of the batches;
- avoiding loss of latent heat in cylinder dryers;
- using high-frequency drying.

**Technical description**

Stenters are mainly used in textile finishing for heat-setting, drying, thermosol processes and finishing. It can be roughly estimated that, in fabric finishing, each textile substrate is treated on average 2.5 times in a stenter.

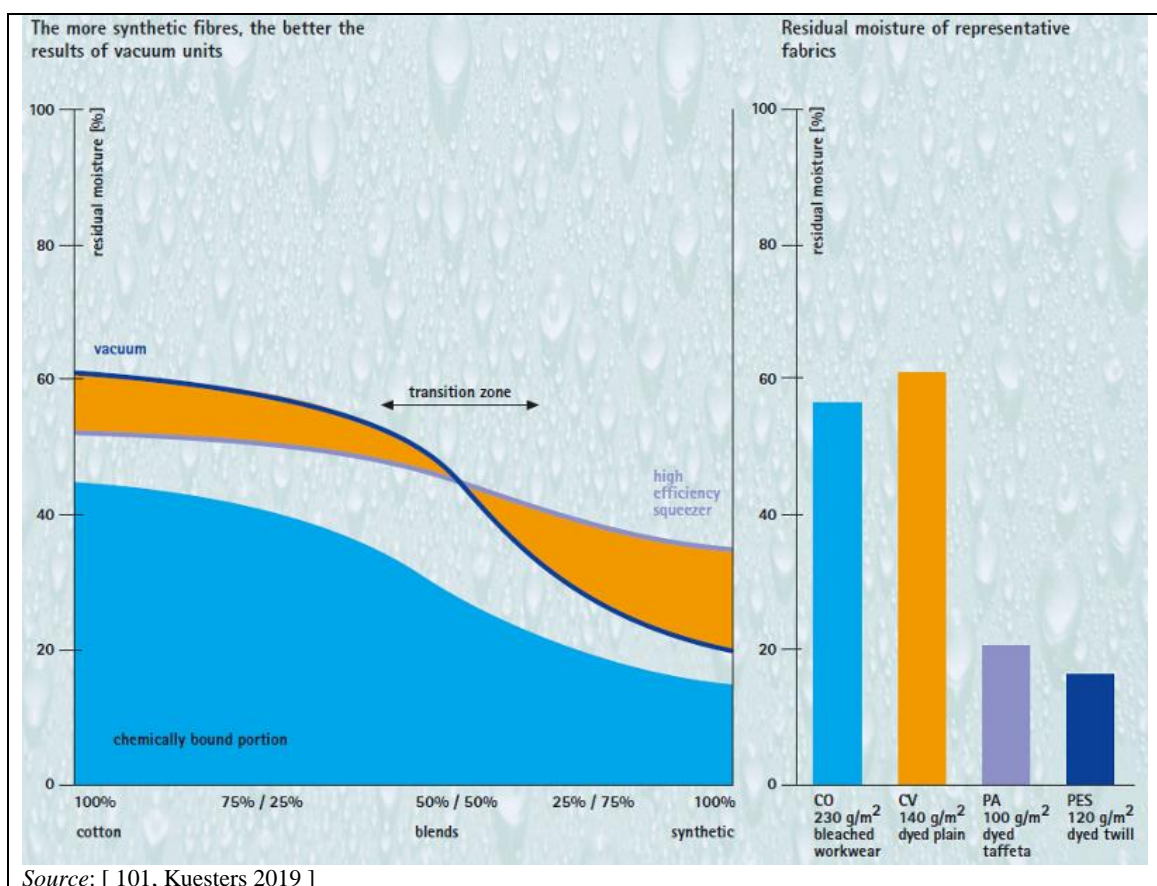
The main energy needs for a stenter are for air heating and evaporation. It is therefore fundamental that the fabric moisture content be minimised before the fabric enters the stenter and that the exhaust airflow within the oven be reduced. For more details on stenters operation, see Section 8.4.

Energy savings in stenters can be achieved by applying the following techniques.

- Mechanical dewatering of the fabric  
The water content of the incoming fabric can be minimised using dewatering equipment such as centrifugation, vacuum extraction systems, optimised squeezing rollers. (the latter is less efficient but less energy-consuming). Up to 15 % energy savings in the stenter (depending on the type of substrate) can be obtained if the moisture content of the fabric is reduced from 60 % to 50 % before it enters the stenter.

For synthetic fibres, vacuum extraction achieves approximately 20 % better dewatering efficiency compared to squeezing rollers; the opposite is true for cotton fibres, where squeezing rollers prove more efficient (see Figure 4.6) [ 44, ÖKOPOL 2011 ], [ 101, Kuesters 2019 ].

In vacuum extraction, the air flow through textile fabrics is mainly affected by the fabric structure, e.g. its tightness, porosity and air permeability. For example, for woven fabrics with different porosities dried by the vacuum extraction method, it was found that the lower the porosity or the lower the air permeability, the higher the water removal effects with a lower energy requirement [ 102, Cay et al. 2008 ].



**Figure 4.6: Residual moisture of different fabrics (cotton – synthetic blends) related to the mechanical dewatering equipment used**

- Optimising exhaust airflow

Exhaust airflow optimisation is another determining factor. Many stenters are still poorly controlled, relying on manual exhaust adjustment and operator estimation of fabric dryness. For optimum performance, exhaust humidity is maintained between 0.1 kg and 0.15 kg water/kg of dry air. It is not unusual to find that less efficient stenters have an exhaust humidity of only 0.05 kg water/kg of dry air, indicating that the exhaust volume is too high and excessive energy is being used to heat air [ 90, UK 1997 ]. Energy consumption for air heating can reach up to 60 % of the total energy consumption, if the airflow is not monitored [ 103, Bellini V. 2001 ].

Equipment is available (dampers and variable-speed fans) which will automatically adjust the exhaust airflow according to the moisture content of the exhaust air or according to the moisture content or temperature of the fabric after the process. A reduction of fresh air consumption from 10 kg fresh air/kg of textile to 5 kg fresh air/kg of textile results in a 57 % energy saving [ 5, UBA 2001 ], [ 84, Hasanbeigi A. 2010 ]

The exhaust dampers are partially or fully closed during idling time (changing of batches, etc.) [ 84, Hasanbeigi A. 2010 ]

- Insulation

Proper insulation of stenter encasement reduces heat losses to a considerable extent. Savings in energy consumption of 20 % can be achieved if the insulation thickness is increased from 120 mm to 150 mm (provided that the same insulation material is used).

The insulation of end sections of cylinder dryers can reduce heat waste, thereby saving fuel. This measure, however, is more practical for cylinders with a diameter of one metre or

more. For small-diameter cylinders, this may not be practicable since the steam pipe, condensate pipe and safety valve get in the way [ 84, Hasanbeigi A. 2010 ].

- Optimising burner efficiency

With optimised firing systems and sufficient maintenance of burners in directly heated stenters, the methane emissions can be minimised. A typical range for an optimised burner is 10-15 g methane (calculated as organic carbon)/h, but it has to be taken into account that methane emissions from burners are strongly linked to actual burner capacity.

Stenters are maintained by specialised companies at regular intervals, the burner air inlet is regularly checked for blocking by lint or oil, pipework is cleaned to remove precipitates and burners are adjusted by specialists.

The following parts are typically included in the maintenance programme [ 58, EURATEX 2020 ]:

*Management instruction for burner maintenance and control*

- Burner

Weekly:

- Visual inspection of the burners.
- Checking of the intake filter on the burner, cleaning / replacement when necessary.

Annually:

- Annual functional test, measurement and adjustment. This also includes a safety check of the temperature monitor or the temperature safety switch to ensure that if the temperature control of the burner does not work, no temperature overheating will occur.

- Burner lines:

Leakage check(s)

*Management instruction for exhaust air ducts maintenance and control*

Weekly visual inspection and, if required, cleaning of the exhaust air ducts yearly.

- Optimised air circulation

The circulation of hot air within the stenter is optimised: the number of air injection nozzles is adapted to the width of the fabric, the distance between nozzles and fabric is as short as possible, and the pressure drop caused by the stenter internal components is as small as possible.

[ 104, Brückner 2019 ]

- Avoiding overdrying

Fibres have a natural moisture level (see Table 4.9) below which it is useless to dry them. It is therefore important to monitor the moisture content of the fabric and to adapt the residence time of the fabric in the stenter/dryer so that the natural moisture level is not exceeded. Hand-held moisture meters can be used with a roller sensor to monitor the moisture content of fabrics leaving the stenters or drying cylinders [ 84, Hasanbeigi A. 2010 ].

**Table 4.9: Natural moisture level of some fibres**

Fibre	Natural moisture level (%)
Cotton	7
Wool	16-18
Viscose	12.5
Triacetate	4.5
Nylon 6.6	4.3



Nylon 6	4.4
Polyester	0.4
Acrylic	1.5
Polypropylene	0
<i>Source:</i> [ 84, Hasanbeigi A. 2010 ]	

- Advanced process monitoring and control of the stenters

The stenter operation and the energy consumption are optimised by measuring and controlling the following parameters [ 84, Hasanbeigi A. 2010 ]:

- humidity content and temperature of the inlet air;
- exhaust air humidity and temperature, in order to load exhaust air most efficiently with humidity; drying efficiency is optimised by an appropriate humidity content (e.g. above 0.1 kg water/kg dry air); this reduces the volume of hot exhaust air, and thus energy losses, dramatically;
- residual moisture of the fabric to avoid overdrying and overheating of fabric;
- fabric and air temperature; several fabric temperature sensors placed inside the stenter along with the fabric provide a good system for the supervision and optimisation of heat treatment processes, mainly for controlling the residence time of the fabric in the stenter.

The exhaust airflow is adjusted to optimise drying efficiency and is reduced during idle periods of the drying equipment.

- Optimal scheduling of batches

Careful scheduling of fabric batches arriving at the stenters or cylinder dryers can reduce idling time, thereby saving energy [ 84, Hasanbeigi A. 2010 ].

Proper scheduling in finishing minimises machine stops and heating-up/cooling-down steps and is therefore a prerequisite for saving energy.

- Avoiding loss of latent heat in cylinder dryers

The cylinder dryers are regularly maintained to avoid steam leaks. The condensate is recovered and returned to the boiler. In addition, flash steam which is produced when condensate is reduced to atmospheric pressure can be recovered as low-pressure steam, and used to heat water or other low-pressure steam processes [ 84, Hasanbeigi A. 2010 ].

- Using high-frequency drying

Energy savings could be accomplished by switching from conventional dryers to low-pressure (LP) high-frequency drying (microwave or radio frequency). The LP high-frequency drying method features good drying efficiency and the capability to prevent products from overdrying, which often happens in convection dryers.

[ 48, Carr et al. 2006 ], [ 84, Hasanbeigi A. 2010 ]

### **Achieved environmental benefits**

Savings in energy consumption and therefore minimisation of emissions associated with energy production are the main environmental advantages.

### **Environmental performance and operational data**

The following data describe an optimised air-to-textile ratio in a stenter: [ 99, Kohla et al. 2008 ]

PES or PA raw material	10-12 kg air/kg textile
pre-washed PES material	5-7 kg air/kg textile
thermo-isolated PES	5-7 kg air/kg textile
condensation of finishing CO	4-5 kg air/kg textile

In principle, the waste gas humidity should be as high as possible but 20 % humidity can rarely be achieved due to condensation. A level of 12-15 % humidity in waste gas is commonly found in practice [ 99, Kohla et al. 2008 ].

Minimising energy consumption in the stenters, especially if heat recovery systems are installed, requires adequate maintenance (cleaning of the heat exchanger and stenter machinery, checking of control/monitoring devices, adjusting of burners, etc.)

Data collected on specific energy consumption of thermal treatment is described in Section 3.6.2.12. When applying this technique, the specific energy consumption ranges from 0.5 MWh/t to 4.4 MWh/t.

[ 50, TWG 2019 ]

#### Cross-media effects

None identified.

#### Technical considerations relevant to applicability

All techniques described are applicable to new installations. For existing equipment, the applicability is in some cases limited. For example, improving stenter insulation is not always practicable, although on some older machines it may be cost-effective to insulate the roof panels.

The installation of high-frequency drying systems may be applicable only to new plants and major plant upgrades. Furthermore, it may not be applicable to textile materials containing metallic parts or fibres.

#### Economics

Examples of investment costs are given in Table 4.10.

**Table 4.10: Investment costs for energy-saving measures**

Measure	Investment cost	Payback period (years)
Recovery of condensate in wet processing plants	USD 1 000 to USD 16 000 <sup>(1)</sup>	2.5-6
Low-pressure microwave drying machine for bobbin drying	USD 500 000 <sup>(2)</sup>	< 3
Radio frequency dryer for drying acrylic yarn	USD 220 000 <sup>(3)</sup>	NI
Instrumentation and control system for stenter	Humidity control: USD 20 000 to USD 220 000 <sup>(1)</sup> Residence time control: USD 80 000 to USD 400 00 <sup>(1)</sup>	Humidity control: 1.5-5 Residence time control: 4-6.7
<sup>(1)</sup> 2007 value. <sup>(2)</sup> 1997 value. <sup>(3)</sup> 1993 value. NB: NI: No information. Source: [ 83, CITEVE 2014 ], [ 84, Hasanbeigi A. 2010 ].		

As RF and microwave systems operate on electric power, the unit of energy cost is usually higher than for conventional dryers. However, the energy efficiency of RF and microwave

systems are normally much higher than for conventional systems, which tends to offset the higher energy unit cost [48, Carr et al. 2006].

### **Driving force for implementation**

Minimisation of energy consumption (and therefore costs) is the main reason to retrofit optimised stenter technology.

### **Example plants**

In total, 33 plants from the data collection apply techniques to minimise the energy consumption of stenter frames.

The indirect heating system based on a flue-gas/air exchanger is installed in 15 plants from the data collection. Meanwhile, 50 plants from the data collection apply direct heating.

### **Reference literature**

[5, UBA 2001 ], [48, Carr et al. 2006 ], [50, TWG 2019 ], [84, Hasanbeigi A. 2010 ], [90, UK 1997 ], [103, Bellini V. 2001 ], [104, Brückner 2019 ]

#### **4.1.4.6 Self-cleaning heat exchanger**

##### **Description**

Heat exchangers that recover heat from polluted hot waste water streams and avoid obstruction with rotating components (a rotating shaft with heat exchanging surfaces creates the necessary turbulence to keep the pollutants of hot discharged effluent water from sticking to the exchanger surface).

##### **Technical description**

Rotating exchangers heat up fresh water and simultaneously cool down water effluent streams, thus cutting down energy usage and meeting legal requirements on effluent temperatures. The operating principle, based on a rotating exchanging shaft, makes the unit self-cleaning and avoids obstruction or reduced heat transfer related to waste water. Moving components minimise plugging issues.

##### **Achieved environmental benefits**

Heat is recovered from the effluent and the temperature of water effluent released to the environment is reduced (otherwise the heat is not recovered when the stream contains solids and blocking would limit heat recovery). The consumption of water and chemicals used to clean heat exchangers (to solve plugging) is reduced.

##### **Environmental performance and operational data**

Rotating exchangers are used for high-solids polluted waters. An average energy saving of over 70 % for process water heating can be achieved (compared to without this exchanger). A high pressure is needed to force liquid through the exchanger. If it is gravity-fed, then there is no need for pumps except in exceptional situations where the flow is intermittent and for which a surge tank is recommended.

##### **Cross-media effects**

None identified.

##### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

It is applied to both continuous and discontinuous processes when water effluent is discharged at a high temperature from the process.

**Economics**

Operational and maintenance costs are reduced by the self-cleaning feature. Capex costs are higher than conventional heat exchangers. The reduction in opex may justify the increase in capex compared to conventional heat exchangers.

**Driving force for implementation**

- Lower operating and maintenance costs.
- Lower energy usage due to efficiency gains in heat transfer.

**Example plants**

Esquire Knit Composite Ltd.& Echotex Ltd (Bangladesh) [ 105, Munir S. 2013 ].

**Reference literature**

[ 35, RICARDO 2019 ], [ 105, Munir S. 2013 ]

**4.1.4.7 Wet-on-wet dyeing or finishing of textile fabric****Description**

Dyeing or finishing liquors are applied directly to the wet fabric, thus avoiding an intermediate drying step. Appropriate scheduling of production steps and dosing of chemicals need to be considered.

**Technical description**

[ 106, Aspland J.R. 1992 ]

The wet-on-wet process is only suitable for those fabrics which have the ability to retain large amounts of water (e.g. terry cloth).

The process parallels the pad-steam process, but without the drying between padders, and is also called pad-pad-steam process.

Typically the textiles which enter the second pad have a wet pick-up of 60 % to 70% of the dye from the first pad, and leave the second pad with a higher total wet pick-up of 100 % to 200 %. The increase in wet pick-up, the differential wet pick-up, ensures that some alkali and hydro are added to the pigment to facilitate subsequent reduction in the steamer (e.g. for vat dyes). Problems can arise from interchange of the two pad liquors in the second pad trough. This differential pick-up criterion cannot be met by many flat goods, which have low water inhibition, but is fine for terry cloth and corduroy.

Wet-on-wet processes are also used for finishing treatments and screen printing.

**Achieved environmental benefits**

Lower energy consumption due to absence of a drying step.

**Environmental performance and operational data**

[ 94, Wagaw et al. 2012 ]

Wet-on-wet dyeing is often used for dyeing cellulosic fibre (e.g. with vat, direct dyes). For cotton fibres, it is recommended to carry out causticisation on a padding mangle followed by washing and dyeing on a jigger. In some cases, the wet-on-wet dyeing can be used only for exhaust dyeing whereas for pad dyeing it may not be suitable because of the exchange of water from wet fabric resulting in dilution of pad liquor.

The major concern associated with wet-on-wet processing is the changing chemical concentration in the pad bath; especially for processing long fabrics (e.g. several hundred metres), the chemical add-on considerably decreases, affecting the shade depth of finished goods. To obtain a constant bath concentration and add-on, an appropriate initial concentration and a

continuously dosed reconstitution stream with a higher concentration than the initial concentration should be used. The bath concentration is modelled by complex mathematical models relating online monitored parameters in wet-on-wet with the automatic dosage of the bath.

Wet-on-wet dyeing can give higher colour yields compared to dyeing after drying.

Some machine producers design ranges for wet-on-wet continuous pretreatment (e.g. mercerising, bleaching) and dyeing.

### **Cross-media effects**

None identified.

### **Technical considerations relevant to applicability**

May not be applicable when chemicals cannot be taken up by the fabric due to insufficient residual pick-up.

### **Economics**

No information provided.

### **Driving force for implementation**

Lower energy usage due to the absence of drying step.

### **Example plants**

DE045 reports using wet-on-wet bleaching.

Many plants in the EU use the technique for specific products.

### **Reference literature**

[ 94, Wagaw et al. 2012 ], [ 106, Aspland J.R. 1992 ]

## **4.1.5 Management of textile material quality**

The textile materials that are to be treated in the textile plant can be in the form of fibre, yarn, grey fabric or untreated textile products (woven, knitted, non-woven).

Due to the large amounts of textile materials treated during textile manufacturing, even trace amounts of contaminants in them can produce non-negligible amounts of pollutants in the waste gases or waste waters. Incoming quality-control systems for textile materials are important for reducing the pollutant loads in emissions to air and water.

### **4.1.5.1 Textile materials containing a minimised content of contaminants**

#### **Description**

Criteria for the selection of incoming textile materials (including recycled textile materials) are defined to minimise the content of contaminants including hazardous substances (see IED Article 3(18) for definition), poorly biodegradable substances and substances of very high concern. These criteria may be based on certification schemes or standards.

#### **Technical description**

Procurement of controlled raw materials from carefully selected suppliers that fulfil environmental performance criteria based on certifications, standards, ecolabels, private initiatives/cooperation or results of sustainability assessments is common practice to ensure compliance (e.g. with legal and quality requirements) in the textile sector.

Many voluntary certification schemes, initiatives and labels which aim to control the presence of hazardous chemicals along the supply chain have been established (e.g. GOTS, Textile Standard, OEKO-TEX, bluesign, ZDHC) in response to regulatory approaches (e.g. REACH, EU Ecolabel, sustainability product standards) and non-governmental campaigns (e.g. Greenpeace Detox campaign). Restricted Substance Lists are used for setting the thresholds of unwanted impurities/residues.

For more information on voluntary certification schemes see Section 4.1.6.3.

#### **Achieved environmental benefits**

Reduced chemical load in the effluent.

#### **Environmental performance and operational data**

The requirements for the chemicals used in upstream processing and their quantities remaining on the incoming raw textile materials can be reflected in the agreements and contracts with selected suppliers. The documentation (e.g. certificates, laboratory test reports) verifying the residue/impurity content of the raw textile material are checked on delivery. This can be facilitated by the involvement of both suppliers and textile plants in the voluntary certification schemes and labelling initiatives.

Substantial progress on replacement and reduction of hazardous substances used in the textile supply chain has been achieved in recent years [ 107, Greenpeace 2018 ].

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

#### **Economics**

The additional (purity) requirements on the quality of incoming raw textile materials may increase their price. Incoming textile materials with known history and proven impurity/residual content may be more costly.

#### **Driving force for implementation**

- Environmental regulations for pollutants.
- Chemical regulations (REACH, CLP, BPR, PPP and POPs)
- Economics (Market reputation of the brands).
- Product standards (internal, national, international).
- Reduced effluent treatment costs.

#### **Example plants**

Many plants from the data collection report choosing suppliers within a certain certification scheme.

#### **Reference literature**

[ 107, Greenpeace 2018 ], [ 108, Derden et al. 2010 ].

#### **4.1.5.1.1 Selection of man-made fibres containing preparation agents with improved environmental performance**

##### **Description**

The selected man-made fibres have not been prepared with auxiliaries containing mineral oil.

### Technical description

As a consequence of pretreatment operations (e.g. washing and heat-setting), auxiliaries used during the production of man-made fibres find their way into the waste water and exhaust air of finishing mills.

Among the auxiliaries used, coning oils and other preparation agents applied to the fibre after it has been manufactured have been identified as the major causes of the pollution in the downstream processes. This is due to the quality of the formulations employed and to the high loads applied (see also Section 2.6.4.2).

Conventional preparation agents are mainly based on mineral oils, with their well-known disadvantages of high add-on, low temperature stability (they smoke during high-temperature treatments), poor biodegradability, presence of polyaromatic hydrocarbons and generation of difficult-to-sediment sludge in biological waste water treatment plants (see also Section 8.1.2).

Alternatives to the mineral-oil-containing preparation systems are preparation agents based on [ 5, UBA 2001 ]:

- polyether/polyester or polyether/polyester carbonates;
- special polyolesters;
- special sterically hindered fatty acid esters.

### Achieved environmental benefits

Reduced emissions to air and to water.

### Environmental performance and operational data

Alternative preparation systems are less volatile and have higher thermal stability. Moreover, they can be applied in lower amounts on the fibre. As a result, reduced odour nuisance in the workplace and reduced emission levels of volatile organic compounds in the exhaust air are achieved.

Table 4.11 below compares the performance of the alternative products with the conventional systems in heat-setting conditions for grey materials.

**Table 4.11: Emission factors and corresponding organic-C concentration in the off-gas**

Substance	Emission factor (g C/kg textile)	Concentration (mg C/m <sup>3</sup> )
<i>Conventional products</i>		
Mineral oils	10-16	500-800
Classic fatty acid esters	2-5	100-250
<i>Optimised products</i>		
Sterically hindered fatty acid esters	1-2	50-100
Polyolesters	0.4-4	20-200
Polyether/polyester or polyether/polyester carbonates	0.2-1	10-50
NB: Preparation agent add-on: 2 %; air-to-textile ratio: 20 m <sup>3</sup> /kg; heat-setting temperature: 190 °C; curing time: 1.5 min.		
Source: [ 4, EURATEX 2000 ], [ 5, UBA 2001 ]		

The optimised products indicated in the table above are easier to wash out (lower consumption of water, energy and chemicals) and are in general characterised by a higher level of biodegradability compared to mineral-oil-based preparation agents. Polyester/polyether carbonate compounds, in particular, show extremely good biodegradability in comparison with mineral oils. Sterically hindered fatty acid esters, on the other hand, only represent an

improvement with respect to classic fatty acid esters for emissions to air from thermal treatment (thermofixation). They are in fact less volatile, but they are more difficult to biodegrade due to the increased branching of the chain.

Preparation agents made of polyester/polyether carbonates are water-soluble which results in optimised washing processes, i.e. washing processes can be substituted by a short rinsing process with cold water (20-40 °C) without any detergents or completely dropped, leading to savings in water and detergent consumption [ 44, ÖKOPOL 2011 ].

#### *Yarn producers*

Some machine components have to be made up of high-grade steel due to potential corrosion problems. With polyester/polyether-carbonate-based products, compatibility problems with conventional hydrophobic preparation systems mean that thorough equipment cleaning is needed following use.

Low-emission preparation agents are applicable on PES, PA 6.6, PA 6, CV and their blends with PES or CV [ 5, UBA 2001 ].

The main fields of application are spooling, lubricating of PA 6-FDY yarns, twisting and texturing. The latter process is done at high temperatures. Using these products prevents deposition of cracking products in machine parts.

Additionally, emissions in the workplace may be reduced notably [ 44, ÖKOPOL 2011 ].

#### *Fabric producers*

Because of compatibility problems the equipment has to be cleaned carefully (especially in the case of polyester/polyether-carbonate-based auxiliaries).

#### *Finishing mills*

Processes in pretreatment have to be adjusted to the new preparation systems. In some cases (e.g. with polyester/polyether-carbonate-based auxiliaries), washing steps in pretreatment can be simplified or even omitted.

Especially in PA 6-FDY yarns for lingerie, the application of these new products shows advantages. Washing before dyeing can be avoided, i.e. washing and dyeing can be performed in one step for fabrics made of PA 6/EL. However, PES fibres/yarns finished with these new products – used especially in the technical field – also demonstrate significant advantages. Raw materials finished with these products can be heat-set at once - without further washing. Due to the low waste gas impact, waste gas purification may not be necessary [ 44, ÖKOPOL 2011 ].

#### **Cross-media effects**

Since new products are less volatile, off-gas emissions are reduced, but a higher amount remains on the fabric after heat-setting and eventually ends up in the waste water.

However, because of the lower quantities applied and the better biodegradability of the new products, the replacement will always bring benefits [ 5, UBA 2001 ].

#### **Technical considerations relevant to applicability**

The applicability depends on the type of fibre and the particular end use of the final product [ 5, UBA 2001 ].

Commission finishers often receive no information from the supplier concerning the quality of preparation agents used and have little leverage on this issue.

In these cases, it is necessary to work with clients to eliminate these materials from the supply chain.



### **Economics**

The following economic aspects affecting all members of the textile processing chain have to be taken into consideration [ 5, UBA 2001 ]:

#### *Yarn producers*

Low-emission auxiliaries are expensive products. This can be compensated by a lower add-on.

#### *Finishing mills*

Savings in exhaust-air cleaning equipment, simplified waste water treatment and prevention of oil-contaminated wastes will reduce investment, maintenance and disposal costs.

Additional cost savings can be achieved with those preparation agents that allow total or partial omission of the washing step. Increased operational reliability is also to be expected.

### **Driving force for implementation**

Environmental legislation and water savings in washing.

### **Example plants**

Some fibre/yarn and fabric producers in Europe use low-emission preparation agents. Some examples of textile manufacturers applying this technique are listed below: [ 44, ÖKOPOL 2011 ].

- Elastic Textile Europe GmbH, DE-34626 Neukirchen;
- Gütermann AG, DE-79261 Gutach im Breisgau;
- Röcker & Kohler GmbH & Co KG, DE-72131 Offerdingen.

Plants from the data collection: BE011, DE034, PT108 and UK127.

### **Reference literature**

[ 4, EURATEX 2000 ], [ 5, UBA 2001 ], [ 44, ÖKOPOL 2011 ]

#### **4.1.5.2 Control of residues, impurities and upstream preparations in textile materials**

The textile finisher needs detailed information about the chemicals present on the textile substrate. This includes information on the amount of preparation agents and sizing agents, and the amount of residual monomers, metals, biocides (e.g. ectoparasiticides for wool) present on the fibre. These substances/impurities are carried over into the process and account for a significant percentage of the pollutant load from textile mills. Improved knowledge of the raw material will allow the manufacturer to prevent or at least control the resulting emissions [ 109, EA 2013 ].

Pre-screening of incoming textile materials (fibres, chemicals, dyestuffs, auxiliaries, etc.) is of the utmost importance for pollution prevention. The supplier provides adequate information that enables the mill to make a responsible environmental evaluation, even on proprietary products. This can be achieved by implementing a chain of custody document to accompany the incoming textile material. Testing and analysis of the delivered textile materials at the reception stage, as part of the incoming textile material quality control, can also be done by the operator. Some information about analytical methods used to control the presence of impurities may be found in [ 110, ECHA 2016 ].

Table 4.12 gives an overview of the typical impurities and residues on the incoming textile materials.

**Table 4.12: Overview of the typical impurities and residues on incoming textile materials**

Substrate/Fibre	Impurities/Residues	Section
All substrates (PES, CO, PA etc.) and all textiles (fibers, yarns, fabrics, non-woven, etc.)	<ul style="list-style-type: none"> <li>• APEO (OP, NP, OPEO, NPEO)</li> <li>• Sizing agents</li> <li>• Mineral oils</li> </ul>	4.1.5.2.4
Dope dyed textiles	Banned dyes and pigments; impurities from pigments and dyes	4.1.5.1
Materials with added functionalities	Banned substances in functional finishes (e.g. biocides, flame retardants, DWOR or nano-materials)	4.1.5.1
Wool	<ul style="list-style-type: none"> <li>• Chlorine (chlorinated wool)</li> <li>• Permethrin (biocides) (raw wool)</li> <li>• APEO (soured wool)</li> <li>• Chromium (after-chrome dyed wool)</li> </ul>	4.1.5.2.1 4.1.5.1
Cotton, Linen	Biocides	4.1.5.2.2
Modacrylic	<ul style="list-style-type: none"> <li>• Residual fibre solvents (N,N-DMAC, N,N-DMF)</li> <li>• Co-monomer (e.g. vinyl – or vinylidenechloride)</li> <li>• Antimony</li> </ul>	4.1.5.2.3
Viscose (incl. modal)	CS <sub>2</sub>	
Polyester (PES, PET)	Catalysts (antimony trioxide)	
Recycled polyester (RPET)	PVC residuals or other impurities from blend materials	
Polyamide 6	Residual monomers (ε-caprolactam)	
Polyacrylonitrile	Residual fibre solvents (N,N-DMAC, N,N-DMF)	
m-Aramid	Residual fibre solvents (N-methylpyrrolidone, N,N-dimethylacetamide)	
Solvent-based PU fibres (e.g. elastane)	Residual fibre solvents (N,N-DMAC)	
PU fibres (non-solvent based)	Tin-organics	
Rubber	Vulcanisation accelerators (e.g. mercaptobenzothiazole), sensitising proteins in natural rubber	

*Source:* based on [ 111, bluesign 2019 ] and references in the sections of Chapter 4 as mentioned above.

#### 4.1.5.2.1 Control of ectoparasiticides (veterinary drugs) and biocides on wool fibres

##### Description

The content of ectoparasiticides (veterinary drugs) and biocides in the incoming raw (or semi-processed) wool is regularly monitored and does not exceed the predefined acceptance threshold.

##### Technical description

Tests are conducted with test methods such as the IWTO draft test method 59 to verify the ectoparasiticides content of the incoming wool, namely organochlorines (banned from use but may still be present) (OC), organophosphates (OP), synthetic pyrethroids (SP) and insect-growth regulators (IGR).

The limit values not to be exceeded are, for example, those from the EU Ecolabel for textile products (2014/350/EU), or maximum residue limits set by the Australian Pesticides and Veterinary Medicines Authority (APVMA).

The tests are carried out by the operator or upstream of the supply chain (e.g. by the farmer or seller) on the sales lots. In that case, the certificates with information on the pesticide content accompany the wool lots when delivered to the operator. The geographic origin of the fibre may also be indicative of its ectoparasiticides content.

In mainstream wool-producing countries the competent bodies responsible for wool production and marketing have recognised the importance of minimising OP and SP residues by good flock management, controlled application procedures and the use of recommended withholding periods between sheep treatment and wool harvesting.

**Achieved environmental benefits**

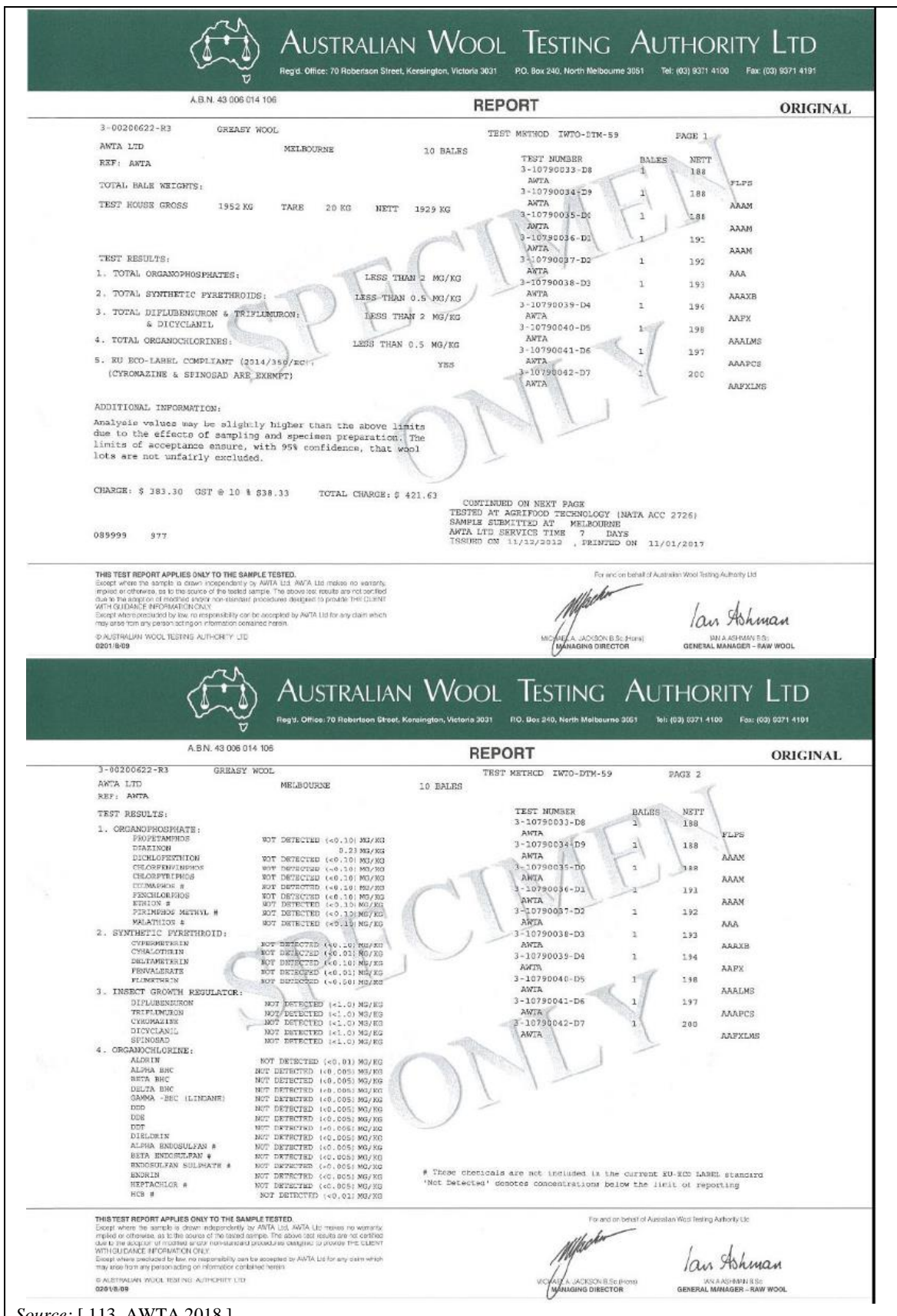
Reduced pesticide loads in the effluents, waste water treatment sludge and by-products (lanolin) from wool scouring process.

**Environmental performance and operational data**

Some of the laboratories licensed by the International Wool and Textile Organisation (IWTO) (like Wool Testing Authority Europe, Australian Wool Testing Authority (AWTA), New Zealand Wool Testing Authority, etc) also conduct testing and certification on compliance with the EU Ecolabel ectoparasiticide concentration thresholds (see Table 4.13) in order to allow European processors to purchase wool with confidence (see Figure 4.7).

**Table 4.13: Sum total restrictions on ectoparasiticide concentrations in wool from the EU Ecolabel for textile products (2014/350/EU)**

Ectoparasiticide groups		Sum total limit value (ppm)
Organochlorines (OC)	γ-Hexachlorocyclohexane (lindane), α-hexachlorocyclohexane, β-hexachlorocyclohexane, δ-hexachlorocyclohexane, aldrin, dieldrin, endrin, p,p'-DDT, p,p'-DDD	0.5
Synthetic pyrethroids (SP)	Cypermethrin, deltamethrin, fenvalerate, cyhalothrin, flumethrin	0.5
Organophosphates (OP)	Diazinon, propetamphos, chlorfenvinphos, dichlofenthion, chlorpyrifos, fenchlorphos	2
Insect-growth regulators (IGR)	Diflubenzuron, triflumuron, dicyclanil	2
NB: ppm: mg/kg. Source: [ 112, COM 2014 ]		



Source: [ 113, AWTA 2018 ]

Figure 4.7: Example pesticide residues analysis report from AWTA

Emissions of pesticides to water (e.g. Plants UK128 and UK 129) are reported in Section 3.4.15.

Recent analysis of a database from Australia and New Zealand [ 114, IWTO 2021 ], developed over 30 years of monitoring ectoparasiticides in greasy wool, provides evidence of cleaner wool production. Regulatory changes, i.e. EU Ecolabel [ 112, COM 2014 ], have had a positive impact on declining trends of residue levels in greasy wool. As demonstrated in Figure 4.8, the mean pesticide residue levels have been reduced significantly, and the median levels are consistently below the EU Ecolabel limits (see Table 4.13).

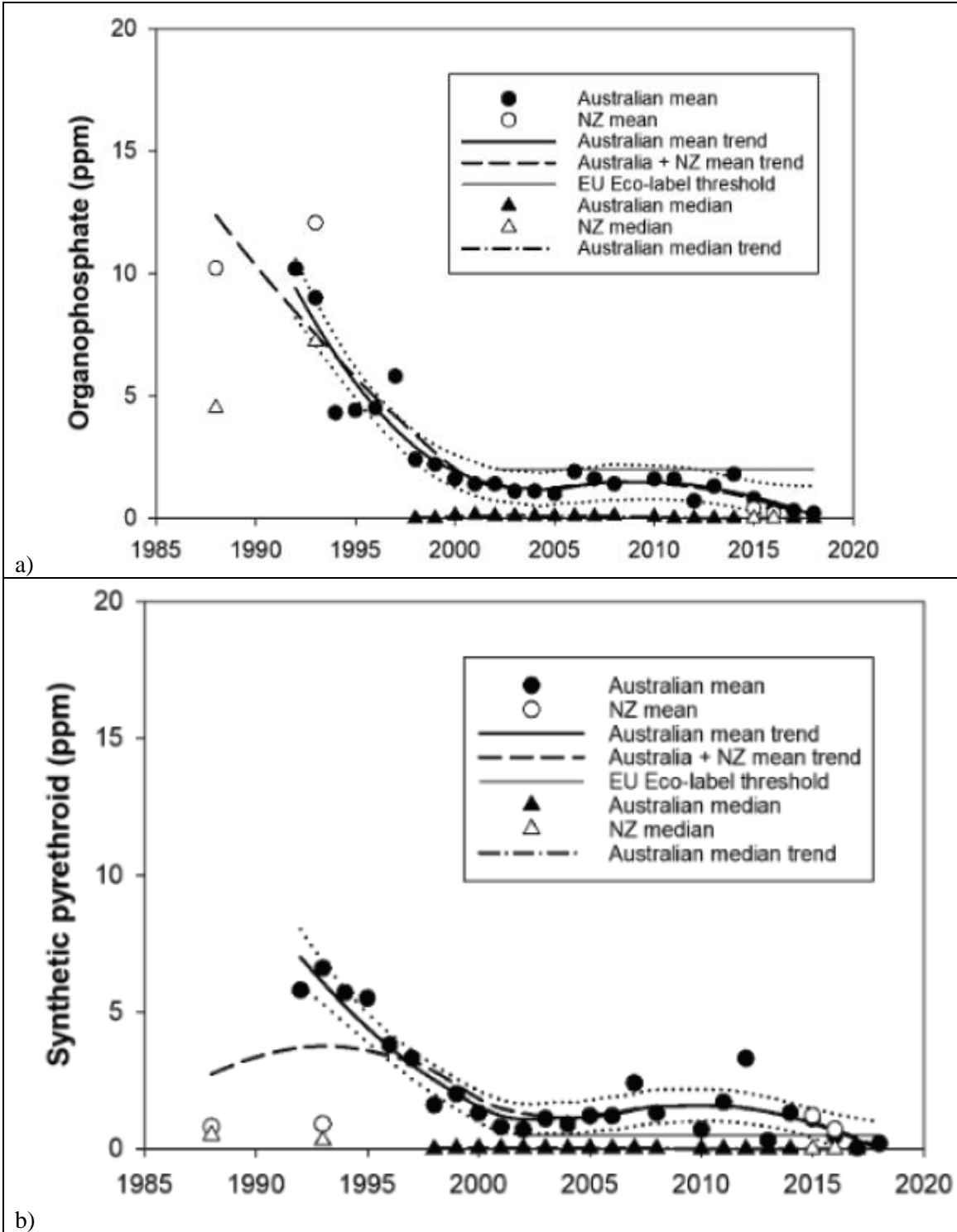


Figure 4.8: a) Organophosphate (OP) and b) synthetic pyrethroid (SP) levels reducing over time to comply with EU limits

**Cross-media effects**

None identified.

**Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

These measures can be adopted by all manufacturers who purchase their own raw materials and by commission processors with the cooperation of their clients.

**Economics**

The costs of analytical testing are in the range from EUR 130 to EUR 250 per sales lot (e.g. example from Figure 4.7: AUD 421.63 for 1 929 kg of wool (10 bales) = AUD 0.22/kg of raw wool) [ 115, AWTA Ltd 2018 ].

**Driving force for implementation**

- Economics (lower costs for effluent treatment and sludge disposal and lower costs for lanolin purification).
- Environmental legislation (environmental quality standards for direct discharges).

**Example plants**

Plants from the data collection that check the incoming wool for pesticides: CZ016 (by measurements), CZ017, BE010 (by measurements), IT088, UK128 (checking with the EU Pesticide database) and UK129 (by measurements).

**Reference literature**

[ 112, COM 2014 ], [ 113, AWTA 2018 ], [ 115, AWTA Ltd 2018 ], [ 116, Russell I.M. 2009 ], [ 184, ENco 2001 ]

**4.1.5.2.2 Control of biocides on cotton fibres****Description**

The content of biocides in the incoming cotton fibres or fabrics is regularly monitored and does not exceed the predefined acceptance threshold.

**Technical description**

Biocides (e.g. pesticides, fungicides and insecticides) may be present on the cotton fibre applied during growing<sup>2</sup>, harvesting, transport or storage, in order to protect the fibre and preserve its quality.

In terms of cotton production, different types of cotton are available, in order of decreasing use of pesticides in cotton production: conventional, integrated pest management (IPM) and organic cotton [ 112, COM 2014 ], [ 117, Dodd et al. 2014 ]. These types of production and the cotton produced are checked and verified for compliance by certified independent control bodies in conformity with appropriate regulations (e.g. Regulation (EC) No 834/2007, Regulation No 1920/2003) or international standards (UN FAO or government IPM or Integrated Crop Management (ICM) programme, Global Organic Textile Standard - GOTS).

Some test methods used to verify the content of pesticides on the raw cotton fibre are as follows: US EPA 8081 B (organochlorine pesticides, with ultrasonic or Soxhlet extraction and apolar solvents (iso-octane or hexane)), US EPA 8151 A (chlorinated herbicides, using methanol), US EPA 8141 B (organophosphorus compounds) and US EPA 8270 D (semi-volatile organic compounds). In Germany, test methods §64 LFGL L 00.00-34 (GC/MS) and §64 LFGL L 00.00-114 (LC/MS/MS) are used [ 118, GOTS 2017 ].

<sup>2</sup> As plant protection use under European Biocidal Products Regulation [ 348, EU 2012 ].

The tests can be done upstream of the supply chain (e.g. by the farmer or seller) and the certificates with information on the pesticide content can accompany the cotton bale when delivered to the operator.

The acceptable residual pesticides thresholds are given in international standards such as the OEKO-TEX standards [ 119, OEKO-TEX 2017 ], bluesign [ 120, bluesign 2019 ] and the EU Ecolabel for textile products [ 112, COM 2014 ].

Different certification schemes are used to track the origin and the content of pesticides in cotton at all stages of the production cycle. For example, GOTS issues a: [ 118, GOTS 2017 ]

- ‘*transaction certificate*’ to track the organic cotton passed from one producer to another in the production chain;
- ‘*scope certificate*’ to ensure that the operator is qualified to produce textiles based on organic cotton so that the products remain free of hazardous substances.

By using this dual (parallel) system (certifying the material and the operator), traceability and quality throughout the supply and production chain (from the plant to the final product) are ensured.

### **Achieved environmental benefits**

Reduced pesticide loads in the effluents and waste water treatment sludge from wet processing (pretreatment, dyeing, finishing) of cotton fibre.

### **Environmental performance and operational data**

The EU Ecolabel, bluesign (BSSL - Consumer safety limits) and OEKO-TEX (Standard-100) threshold concentration for the sum of pesticides for organic cotton is 0.5 ppm (mg/kg) [ 112, COM 2014 ], [ 119, OEKO-TEX 2017 ], [ 120, bluesign 2019 ].

Possible pesticides (residues) detected in the cotton products include chlorpyrifos, malathion, profenofos and cypermethrin [ 121, Attallah et al. 2017 ].

### **Cross-media effects**

None identified.

### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

### **Economics**

No information provided.

### **Driving force for implementation**

- Economics (lower costs for effluent treatment and sludge disposal).
- Environmental legislation (environmental quality standards for direct discharges).

### **Example plants**

Plants from the data collection that check incoming cotton raw materials for pesticides: BE010 (with measurements), FR133 (measurements for OEKO-TEX Standard-100 compliance), FR134 (with measurements), IT088 and PT117.

### **Reference literature**

[ 112, COM 2014 ], [ 117, Dodd et al. 2014 ], [ 118, GOTS 2017 ], [ 119, OEKO-TEX 2017 ], [ 120, bluesign 2019 ], [ 121, Attallah et al. 2017 ]

#### 4.1.5.2.3 Control of residues and impurities on synthetic fibres

##### Description

The content of impurities and residues on the incoming (undyed) synthetic fibres (yarns) or untreated (greige) fabric (knit or woven) is regularly monitored so that it does not exceed the predefined acceptance threshold.

##### Technical description

Impurities and residues from fibre production found on synthetic fibres are:

- polymer synthesis by-products (e.g. residual non-reactive monomers, low-molecular-weight oligomers, residual catalyst);
- additives to facilitate processing (e.g. antistatic agents, lubricants, humectants);
- residual solvents and others.

Examples of residues from fibre production are: antimony oxide catalyst used on polyester fibres [ 122, bluesign 2020 ], caprolactam on polyamide 6 fibres, cyclic dimers on polyamide 6.6 fibres, N,N-dimethylformamide (DMF) and N,N-dimethylacetamide (DMAc) solvents on polyacrylonitrile and elastane fibres, 1-methyl-2-pyrrolidone (NMP) in aramid fibres [ 123, TEIJIN 2020 ]. For more details, see Sections 2.1.1.1 to 2.1.1.9.

The impurities and residues can have a considerable environmental impact; therefore, their content is controlled by analytical testing or by checking of documentation (e.g. certificates) of incoming fibre, to minimise their load in pretreatment and dyeing effluents [ 112, COM 2014 ].

Some impurities and residues are now strictly regulated. For example, for N,N-dimethylacetamide (DMAc) importers and producers of articles have to submit a notification to ECHA if DMAc is present in their articles (i.e. above one tonne per year and in a concentration above 0.1% w/w), and its presence in textiles articles placed on the market is also regulated by entries 30 and 72 of Annex XVII to REACH (with a limit value of  $\leq 3\,000$  mg/kg or 0.3 % w/w).<sup>3</sup>

Sometimes fibres are substituted by environmentally friendly alternatives with a reduced quantity of impurities and residues (e.g. replacing PES fibres produced by using catalyst antimony trioxide with acrylic fibres) [ 51, Hansson. S 2020 ].

##### Achieved environmental benefits

Reduced amount of hazardous or poorly or non-biodegradable substances in the effluents.

##### Environmental performance and operational data

As examples of the controls carried out on incoming textile fibres, Plants BE007, BE009, BE010 and BE011 from the data collection check incoming polyamide, rayon (viscose) and polyester fibres for residues of halogenated and organic solvents by measurements performed by an OEKO-TEX and GUT accredited laboratory.

##### Cross-media effects

None identified.

##### Technical considerations relevant to applicability

Generally, there are no technical restrictions to the applicability of this technique.

##### Economics

No information provided.

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<sup>3</sup> Other regulatory obligations, see EUCLEF portal <https://echa.europa.eu/legislation-obligation/-/obligations/100.004.389>



### **Driving force for implementation**

- Economics (lower costs for effluent treatment and sludge disposal).
- Environmental legislation (environmental quality standards for direct discharges).

### **Example plants**

Plants BE007, BE009, BE010 and BE011 from the data collection.

### **Reference literature**

[ 51, Hansson. S 2020 ], [ 112, COM 2014 ], [ 122, bluesign 2020 ], [ 123, TEIJIN 2020 ]

#### **4.1.5.2.4 Control of mineral oils and sizing agents on incoming fibre and fabric**

##### **Description**

The content of mineral oils and sizing agents on the untreated (greige) incoming fibre, yarn and fabric (knit or woven) is regularly monitored so that it does not exceed the predefined acceptance threshold.

##### **Technical description**

Preparation agents for production and processing of synthetic fibres, and yarns or fabric from synthetic fibres can contain mineral oils (e.g. in coning, spooling oils, knitting lubricants, etc.). For more details, see Sections 4.1.5.1.1 and 8.1.2. Sizing agents used for warp yarn production can be responsible for high COD/BOD loads in pretreatment effluents. For more details, see Section 4.3.1.2.1.

As a consequence of pretreatment operations (e.g. washing, heat-setting), the auxiliaries used during fibre, yarn and fabric production find their way into the waste waters and gases of the textile finishing plants.

These agents can have a considerable environmental impact; therefore, their content is controlled by analytical testing and certification of the incoming fibre, to minimise their release in pretreatment/dyeing effluents [ 112, COM 2014 ].

##### **Achieved environmental benefits**

Reduced emissions to water and air.

##### **Environmental performance and operational data**

Information on add-on preparations used in fibre, yarn or fabric production is needed for appropriate treatment and to avoid unwanted pollutant loads in the effluents or waste gases. For emission factors of organic carbon concentrations in off-gases of various preparation agents from heat-setting of synthetic fibres, see Table 4.11.

The effects of this technique are reflected in the data on emissions to water of COD and BOD (see Section 3.4.4 and Section 3.4.5).

##### **Cross-media effects**

None identified.

##### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

##### **Economics**

No information provided.

**Driving force for implementation**

- Environmental legislation.
- Economics (lower costs for effluent treatment and sludge disposal).

**Example plants**

Plants from the data collection that check incoming fibre for preparation agents: BE007, BE008, BE009, BE010, BE011, CZ015, CZ016, CZ017, CZ018, CZ020, DE021, DE023, DE025, DE042, DE046, DE050, IT059, IT065, IT088, SE118, UK124 and UK127.

Plants from the data collection that check the incoming elastane (for add-on of preparations): CZ020, IT063, IT073, PT098, PT111, PT114 and PT117.

Plants from the data collection that check incoming fibre for sizing agents: AT003, CZ017, CZ018, DE022, DE026, DE030, DE032, DE042, DE045, DE047, DE049, DE050, FR134, IT059, IT064, IT065, IT068, IT069, IT074, IT077, IT078, PT108, SE118 and UK127.

**Reference literature**

[ 112, COM 2014 ]

**4.1.5.3 Textile fibres with reduced processing requirements**

Textile fibres with inherent characteristics which reduce the need for wet processing are presented in the following sections.

**4.1.5.3.1 Spin-dyed man-made fibres****Description**

Use of spin-dyed man-made fibres that do not require dyeing treatment.

**Technical description**

Spin-dyed (sometimes also referred as dope-dyed) man-made fibres that do not need a dyeing process in their finishing treatment are purchased or produced. The dyeing (colouring) of the fibre takes place in a process upstream of fibre production. The dyestuff is added (doped) and mixed into the molten polymer melt or solubilised cellulose solution before its extrusion or spinning into fibre (the combination of dyeing and spinning is called 'spin-dyeing'). The fibre has good colour consistency, homogeneous hues and colour fastness (withstanding sunlight, laundry washing, abrasion and even bleach) [ 124, SpinDye 2019 ], [ 125, Lenzing 2019 ].

**Achieved environmental benefits**

The technique avoids using a conventional dyeing process, which reduces the energy, water, chemicals and dyestuff needed.

**Environmental performance and operational data**

Spin-dyeing of rayon (modal) fibres uses 50 % less energy, has a 60 % lower carbon footprint and requires 50 % less water than conventional 'wet' dyeing of fabric from rayon (modal) fibres. In addition, spun-dyed fabric needs 20 % less pigment [ 125, Lenzing 2019 ]. The life cycle analyses show that spin-dyeing is environmentally beneficial compared to the conventional dyeing process [ 126, Terinte et al. 2014 ].

**Cross-media effects**

None identified.

**Technical considerations relevant to applicability**

The applicability may be restricted by the product requirements.

The technique is applicable to man-made cellulosic and synthetic fibres (e.g. rayon (modal), polyester, polypropylene, polyamide) [ 124, SpinDye 2019 ], [ 125, Lenzing 2019 ], [ 127, TWD Fibres 2020 ].

### **Economics**

No information provided.

### **Driving force for implementation**

- Reduced consumption of water, energy, chemicals and dyestuff.
- Reduced effluent treatment.

### **Example plants**

These fibres are commercialised by the producers in several EU countries.

### **Reference literature**

[ 124, SpinDye 2019 ], [ 125, Lenzing 2019 ], [ 126, Terinte et al. 2014 ], [ 127, TWD Fibres 2020 ]

#### **4.1.5.3.2 Composite man-made fibres with flame retardants**

##### **Description**

Use of fibres with inherent flame-retardant properties (i.e. the polymer itself has or can be modified to flame-retardant properties or it is spin-doped with flame-retardant constituents during the fibre production).

##### **Technical description**

Fibres with inherent flame-retardant properties can be produced in three ways [ 128, CIRFS 2020 ]:

- the polymer used to make the fibre already has the intrinsic properties of flame retardancy;
- additives with flame-retardant properties are incorporated in the fibre during extrusion;
- chemical polymer is modified during polymerisation, or production of the fibre, to acquire flame-retardant properties.

Regarding the second pathway, the flame retardant (FR) is added (doped) and mixed into the molten polymer melt (matrix) before the extrusion or spinning of the fibre. Such flame-retardant doped fibres can be used to reduce the need for the external application (finish) of flame retardants.

Some examples of such fibres are: PP matrix with 5-10 % FR additives (e.g. DBDPE, tris(Tribromoneopentyl) phosphate (TTBNP), or organophosphorus compounds); PA matrix with 1-10 % FR additives (e.g. nitrogen-based like melamine cyanurate or brominated such as DBDPE) or PET matrix with 2.5-15 % FR additives (e.g. phosphor-based additives: polyphosphonate polymer or phosphinate, or brominated such as DBDPE) [ 129, Centexbel 2019 ].

##### **Achieved environmental benefits**

- The technique avoids using a conventional functional finishing process, which reduces the energy, water and chemicals needed.
- Reduces risk of flame retardant leaching during textile use.
- Ensures durability of flame-retardancy treatment.

**Environmental performance and operational data**

Spin-doping of fibres uses less energy and requires less water than conventional ‘wet’ finishing of fabric.

**Cross-media effects**

None identified.

**Technical considerations relevant to applicability**

The applicability may be restricted by the product requirements.

The technique is applicable to the man-made cellulosic and synthetic fibres (e.g. rayon (modal), polyester).

**Economics**

No information provided.

**Driving force for implementation**

- Reduced consumption of water, energy, chemicals and dyestuff.
- Reduced effluent treatment.

**Example plants**

No information provided.

**Reference literature**

[ 128, CIRFS 2020 ], [ 129, Centexbel 2019 ]

**4.1.5.3.3 Low-finish elastane and blend yarns of elastane with other fibres****Description**

Elastane (so-called low-finish) or blend yarns of elastane and other polymer fibres (e.g. with recycled PET or other synthetic fibres) that contain a reduced amount of preparation agents (e.g. knitting oils, lubricants, silicon oils, detergents, residual solvents). Blends of synthetic fibres with thermoplastic elastomers are also a viable alternative.

**Technical description**

Conventional elastane fibre yarns are replaced by low-finish elastane fibres and multicomponent elastane blend yarns (e.g. blend of elastane and other synthetic fibres spun in the same yarn). Their properties are similar to or better than conventional elastane yarns, but the amount of preparation agents needed for their production is much lower.

Conventional elastane fibres’ silicon oil content is 5 % and the residual solvent (DMAc) content up to 3 %. Low-finish elastane fibres and blends containing between 0 % and 2 % preparation agents and < 1 % residual solvent are used instead, if these yarns can be processed on the equipment (e.g. warp knitting) [ 44, ÖKOPOL 2011 ]. Fibres produced by melt spinning thermoplastic polyurethane elastomers can be used instead of elastane fibres produced by dry spinning (out of a DMAc solvent solution) (e.g. [ 130, Lubrizol 2017 ]).

**Achieved environmental benefits**

Reduced pollutant load to the effluent from pretreatment.

**Environmental performance and operational data**

Processing and dyeing of the blend fibres are the same as for conventional PES fibres.

The blend fibres are used especially in the field of stretch denims for their elastic properties. Due to their greater chlorine resistance, they withstand special bleaching and washing

techniques which destroy conventional elastane fibres. Tapes with very high washfastness and elastic linings for jackets or trouser waistbands are other applications.

### **Cross-media effects**

Possible emissions of antimony in effluent (from PES fibres, as it is used as catalyst in their production).

### **Technical considerations relevant to applicability**

The applicability may be restricted by the product requirements.

Blend fibres can be used everywhere where material elasticity is recommended, in particular in the case of denim and low-weight fabrics.

### **Economics**

No information provided.

### **Driving force for implementation**

- Economics.
- Environmental legislation.

### **Example plants**

No information provided.

### **Reference literature**

[ 44, ÖKOPOL 2011 ], [ 130, Lubrizol 2017 ]

#### **4.1.5.3.4 Dyeing of PES fibres without carriers**

##### **Description**

Dyeing is carried out on dyeable polyester fibres, such as polytrimethylene terephthalate (PTT), with no carriers needed for dyeing.

##### **Technical description**

Fibres made from polytrimethylene terephthalate can be dyed or printed using standard disperse dyestuffs without the need for any special processing steps or carriers to accelerate the dyeing process. The dyeing process of PTT fibres with disperse dyes is a diffusion-controlled process. Therefore, a higher temperature (e.g. above 80 °C) and longer exhaustion time (e.g. > 1 hour) are recommended for dark and full shades like red, navy blue and black.

Historically the high costs of synthesis of the starting monomer (1,3-propanediol) prevented wider use of PTT fibre, but for the past decade a lower-cost synthesis process and even new biomaterial synthesis routes (e.g. starting monomer (1,3-propanediol) is produced from corn (sucrose-based) have been developed that have made it more accessible [ 44, ÖKOPOL 2011 ].

##### **Achieved environmental benefits**

- Reduced emissions (of carriers) to water.
- Reduced energy consumption.

##### **Environmental performance and operational data**

Disperse dyes are the recommended dye class for light and medium shades for PTT, although some specially developed disperse dyes can be used for dark shades as well. Basic dyes may also be used, but only for light shades.

Dyeing equilibrium for a medium shade is obtained in 30 to 60 minutes, depending on the dyes selected. To achieve a good dye utilisation without compromising productivity, 30 to 45 minutes holding time at 100 °C is recommended [ 131, VITO 2001 ].

The recommended dyeing conditions are pH 7 and 100 °C (PTT at 100 °C was dyed with the same or a slightly deeper shade than PET at 130 °C) [ 131, VITO 2001 ].

Properties of PTT are similar to those of PET and nylon fibres.

Thanks to their performance, PTT fibres may have extensive applications in carpeting, textiles and apparel, engineering thermoplastics, non-wovens, films and mono-filaments.

Advantages of PTT fibres are soft handling, higher extensibility, higher stability with regard to UV light as well as higher chlorine fastness, which result in their preferred use in underwear, sportswear and swimwear [ 44, ÖKOPOL 2011 ].

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

The applicability may be restricted by the product requirements.

#### **Economics**

The new biomaterial synthesis route has made PTT fibres even more competitive on the market compared to standard PES fibres.

The low dyeing temperature and the broad dyeing pH allowance help to decrease the cost of dyeing. Moreover, the environmental costs associated with the presence of carriers are avoided.

In the carpet industry, the possibility of dyeing PES carpets in pieces in atmospheric conditions without the use of carriers is particularly convenient (due to the high cost of pressurised machinery for dyeing in pieces in HT conditions).

#### **Driving force for implementation**

- Environmental legislation (emissions to water).
- Chemical legislation restrictions (for carriers).
- Emission limit values and restrictions on dye carriers that are currently required by environmental legislation and the leading voluntary Ecolabel schemes.

#### **Example plants**

A total of 32 plants from the data collection apply this technique.

#### **Reference literature**

[ 44, ÖKOPOL 2011 ], [ 131, VITO 2001 ]

### **4.1.6 Chemicals management, consumption and substitution**

#### **4.1.6.1 Chemicals management system**

##### **Description**

The chemicals management system is part of the EMS (see Section 4.1.1.1) and is a set of technical and organisational measures to limit the impact of the use of chemicals on the environment.

### Technical description

The chemicals management system (CMS) contains the following components:

- I. A policy to reduce the consumption and risks associated with process chemicals, including a procurement policy to select less harmful process chemicals and their suppliers with the aim of minimising the use of and risks associated with hazardous substances and substances of very high concern as well as avoiding the procurement of an excess amount of process chemicals. The selection of process chemicals is based on:
  - a. the comparative analysis of their bioeliminability, ecotoxicity and potential to be released into the environment (which in the case of emissions to air can be determined by using emission factors for example (see Section 4.1.6.4));
  - b. the characterisation of the risks associated with the process chemicals, based on the chemicals' hazard classification, pathways through the plant, potential release and level of exposure;
  - c. the potential for recovery and reuse (see Sections 4.1.3.3 and 4.5.1.8 as well as Section 4.4.8.2);
  - d. the regular (e.g. annual) analysis of the potential for substitution with the aim to identify potentially new available and safer alternatives to the use of (groups of) hazardous substances and substances of very high concern, such as PFAS, phthalates, brominated flame retardants, chromium-(VI)-containing substances; this may be achieved by changing process(es) or using other process chemicals with no or lower environmental impacts;
  - e. the anticipatory analysis of regulatory changes related to hazardous substances and substances of very high concern, and safeguarding compliance with applicable legal requirements.

The inventory of process chemicals (see Section 4.1.6.2) may be used to provide and keep the information needed for the selection of process chemicals.

The criteria for selecting process chemicals and their suppliers may be based on certification schemes or standards. In that case, the compliance of the process chemicals and their suppliers with these schemes or standards is regularly verified.

- II. Goals and action plans to avoid or reduce the use of and risks associated with hazardous substances and substances of very high concern.
- III. Development and implementation of procedures for the procurement, handling, storage and use of process chemicals (see Section 4.1.6.6), disposal of waste containing process chemicals (see Section 4.1.9.2) and return of unused process chemicals, to prevent or reduce emissions to the environment.

### Achieved environmental benefits

- Reduction of the use of hazardous chemicals.
- Reduction of emissions of hazardous chemicals to air, water, groundwater and soil.
- Reduction of the amount of hazardous chemicals in waste.

### Environmental performance and operational data

The selection of chemicals and chemical suppliers is facilitated by adherence to voluntary certification schemes, private initiatives or cooperation in which the presence of hazardous chemicals is controlled along the supply chain and chemicals and preparations are regularly screened for compliance against criteria and thresholds of established manufacturing restricted substance lists. Examples of such certification schemes include GOTS, Textile Standard, OEKO-TEX (ECO PASSPORT), bluesign, ZDHC and others.

Effective communication between downstream users and suppliers at all stages in the REACH process also helps to ensure that relevant information is provided in the supply chain [132, ECHA 2019].

The list of REACH restrictions regarding textile products may be consulted at [ 133, ECHA 2019 ].

Methodologies and tools for conducting qualitative and/or quantitative chemical risk assessments are available (e.g. REACH Annex I or XII [ 7, EU 2006 ], the European Union System for the Evaluation of Substances (EUSES) software [ 134, EU 2019 ] and Exchange Network on Exposure Scenarios (ENES)).

Section 8.8 gives an example of a methodology for identifying process chemicals for which prevention and reduction measures need to be taken in order of priority as far as emissions to water are concerned. This could also be used as a tool to select process chemicals. As sources of information on hazardous and risk properties of substances, Annex VI to the CLP Regulation, the REACH registration dossiers, the CoRAP evaluations, literature, etc. could be used.

Precisely estimating the quantities of chemicals/preparations needed in formulations for treating textiles (production planning) lowers the quantities of leftover chemicals (see Section 4.1.6.5). To free up storage space and reduce the risks of chemical expiry (and the potential risks and costs of treating them as waste), the unused chemicals (in their original packaging) are preferably returned to the supplier before their expiration date, for possible resale and use. This is achieved especially by using innovative business models like chemical leasing, closed-loop chemical management, etc.

The information on unwanted hazardous substances in the purchased chemicals/preparations and the quantities of returned unused leftover chemicals/preparations is also used in overviews of material flows through the installation (see Sections 4.1.1.1 and 4.1.1.2).

More details about the operational data of some components of the CMS may be found in Sections 4.1.6.2 to 4.1.6.8.

Information about substitution of hazardous chemicals is given in Section 4.1.6.9 and in the process-specific sections of Chapter 4 (Sections 4.2 to 4.7).

#### **Cross-media effects**

None reported.

#### **Technical considerations relevant to applicability**

The components described above can typically be applied to all installations within the scope of this document. The scope (e.g. level of detail) and nature of the CMS will be related to the nature, scale and complexity of the installation, and the range of hazardous chemicals it may use.

#### **Economics**

No information provided.

#### **Driving force for implementation**

The driving forces for the implementation of a CMS include:

- improved environmental performance;
- compliance with regulations (e.g. chemical, product safety) and/or certification schemes;
- optimised consumption of hazardous chemicals.

#### **Example plants**

In total, 51 plants from the data collection apply a CMS.



### Reference literature

[ 7, EU 2006 ], [ 108, Derden et al. 2010 ], [ 132, ECHA 2019 ], [ 133, ECHA 2019 ], [ 134, EU 2019 ], [ 135, ZDHC 2015 ], [ 136, OEKO-TEX 2019 ], [ 137, Rodríguez P.U. 2018 ]

#### 4.1.6.2 Chemicals inventory

##### Description

Drawing up and maintaining chemicals inventory to elaborate and implement as part of the CMS.

##### Technical description

Textile plants use a considerable number of chemical products (100-300) for the different processes (pretreatment, dyeing, printing and final finishing).

In order to ensure the availability and completeness of information necessary for responsible chemical management, the relevant data for the process chemicals used are entered, collected and managed in one dedicated computer-based inventory. From this inventory, tailored information can be generated.

The chemicals inventory and tracking system is computer-based and contains information about:

- the identity of the process chemicals;
- the quantities, location and perishability of the process chemicals procured, recovered (see Section 4.1.6.5), stored, used and returned to suppliers;
- the composition and physico-chemical properties of process chemicals (e.g. solubility, vapour pressure, n-octanol/water partition coefficient) including properties with adverse effects on the environment and/or human health (e.g. ecotoxicity, bioeliminability/biodegradability).

Such information may be retrieved from Safety Data Sheets, Technical Data Sheets or other sources.

The main and most commonly used sources of data used for the different chemical products are the Safety Data Sheets (SDS) and to some extent the Technical Instruction Sheets. In order to facilitate evaluations, it is important to link the inventory to a comprehensive modern production planning and control system.

The inventory may be used for the following purposes:

- Identification of process chemicals with acute and chronic aquatic and sediment toxicity [ 138, ECHA 2019 ].
- Identification of process chemicals containing substances in the candidate list of substances of very high concern [ 139, ECHA 2020 ].
- Identification of process chemicals which are readily, inherently or non-biodegradable in waste water treatment.
- Qualitative and/or quantitative risk assessment of the process chemicals (see Section 4.1.6.1).
- Identification of all combustible/flammable products and those which can decompose (thermally or by reaction with other chemicals).
- Planning the use of consumption and implementing adequate storage and handling. This also allows the reduction of the risks of chemicals' expiry (and potential risks and costs of treating them as waste) and for the unused chemicals to be returned to the supplier before their expiration date, for possible resale and use (see Section 4.1.6.1).

- Assessing compatibility of process chemicals and storing the process chemicals accordingly (see Section 4.1.6.5.1).
- Compilation of data relevant for communication and reporting (with competent authorities or customers) and/or certification purposes (e.g. OEKO-TEX (STeP), GOTS).
- Cross-verification with restriction, authorisation and candidate lists under the REACH Regulation and manufacturing restricted and/or positive substances lists (e.g. ZDHC Manufacturer restricted substances list, bluesign system substances list), specific customer restricted substances lists or other lists.

Concerning emissions to air from stenters, a reference may be made to the product-specific emission factors for chemical products used for finishing on these machines (see Section 4.1.6.4).

Figure 4.9 and Figure 4.11 show examples of useful information regarding chemicals which can be included in the chemicals inventory. More examples may be found in [ 135, ZDHC 2015 ], [ 140, Textilbündnis 2019 ] and [ 141, bluesign 2019 ].

Form 3		List of used chemicals sorted according to annual consumption quantities										Name of the textile finishing industry												
3. Textile auxiliaries for dyeing and printing 3.1 Dyeing agents and production aids 3.2 Dyeing agents and production aids 3.3 Dyeing agents, auxiliaries 3.4 Levelling agents 3.5 Colors 3.6 Color preservatives 3.7 Dyeing agents, auxiliaries 3.8 Fixing agents 3.9 Fixing agents for crosslinking and printing 3.10 Reducing agents for dyes		3.10 Bleaching agents for eg 3.20 bleaches 3.11 Fixing dyes 3.12 Hydrolysis and dyeing agents 3.13 Fixatives for goods 3.14 Fiber production agents 3.15 Agents to remove pH 3.16 Regulators, wet and alkali depressors 3.17 Fixing and edge softeners 3.18 Dyeing agents 3.19 Reducing agents 3.20 Reducing agents and discharging materials 3.21 Dyeing agents										Year:												
No.	Commercial name	Producer	Chemical characterization Discolor and individual substances if available (see CAS no.)	Raw no.	Process, application	Annual consumption [kg/yr]	MSZ date	CRS Number	Conf. list, substances according to GHS, CLP, REACH and other legislation for water, soil, air	Isopropyl character	Dyeing, degradation/bleaching product and technical substances in [%] and test duration [d] and testing method	spec. COD value [mg O <sub>2</sub> /l]	spec. BOD <sub>5</sub> value [mg O <sub>2</sub> /l]	Heavy metal content [mg/kg]	Org. halogen content [mg/kg]	Total phosphorus [mg P/kg]	Chlorination with/without reference	Toxicity hazard ECSO [mg/l]	Toxicity acute ECSO [mg/l]	Toxicity dermal ECSO [mg/l]	Toxicity inh ECSO [mg/l]	Max. quantity stored [t]	Characterization conc. storage	
3.8.1	Ruoz Print PM1	Rudolf GmbH	Polyacrylat	55965-84-9	Appretur		429/1	14317	0,0025-0,01 Mixture from 5-Chlor		< 30 [OECD 302B]	150	< 10				1						12	
3.1.1	Peripret PW	Textilchemie Dr. Peter Gm	Polyacrylat Copolymere, wässrige Dispersion		Appretur		16.05.2017				> 70 [OECD 302B]	365	5				1 > 1000						12	
3.2	Dekol SN New liq	Archroma Distribution and	Polyacryloyl, Copolymerisat, Natriumsalz, in water		Färberei		23.01.2015				> 70 [OECD 302B]						1 > 1000						-	
		Archroma Distribution	Allylphosphat, Ammoniumsalz, in water	298-07-7 4971-47-5 78-42-2	Färberei		26.10.2016		H318 H314		> 70 [OECD 302B][28]	995	90				2 > 1000				100-500		10	
3.8	Primasol NF liq	Archroma Distribution and	naphthalenesulfonic acid formaldehyde polycondensate as sodium salt		Färberei		20.08.2015		H302, H314, H315, H336		20-70 [OECD 302A]	1300					1 EC10 > 1000mg/l				100-500			
3.2	Setamol Disperse WS	CHT	Reduktionsmittel	319-73-2 10949-66-2	Färberei		27.11.2017	H302, H314, H336									2	750			25		6,1C	
3.17	Reduflit EX	CHT	Kombination aus Polycarboxylaten und Phosphonaten		Färberei		06.02.2017				30-60 [OECD 302B][28]	210	< 5		0,230	1,250	2 > 1000				3350		12	
3.2	Metopan DPE	CHT		68186-64-1 73070-48-1 27408-92-0 143-25-6 68185-67-7 107-41-5 69011-30-5 1058-34-8 104-76-7 112-34-5 34590-94-8					H302, H314, H315, H336															
3.3	Kollasol IND	CHT	Phosphorsäureester		Färberei		05.12.2017	H315, H318			> 70 [OECD 302B][28]	1777	343		0,240	2,400	2	> 1000						10

Source: [142, HAZBREF 2019]

Figure 4.9: Example of useful information related to the substances and mixtures used in a textile plant

List of used chemicals sorted according to annual consumption quantities				Name of the textile finishing company:			
				Year:			
No.	Commercial name	Producer	Chemical characteristics General and of the individual substances if available (see CAS no.)	CAS no.	Process / application	Annual consumption [kg/yr]	MSDS date

Continued from above

GHS hazard	Containing substances of very high concern (SVHC), PBT, vPvB (as in ZDHC) [weight-%] for individual substance	Biodegradation / bioelimination of formulation and individual substances [%], test duration [days] and testing method	Specific COD value [mg O <sub>2</sub> /g]	Specific BOD <sub>5</sub> value [mg O <sub>2</sub> /g]	Specific heavy metals content [mg/g]	Specific organic halogen content [mg/g]

Continued from above

Specific Total nitrogen [mg N/g]	Specific Total phosphorous [mg P/g]	Toxicity bacteria EC50 [mg/l]	Toxicity algae EC50 [mg/l]	Toxicity daphnia EC50 [mg/l]	Toxicity fish eggs EC50 [mg/l]	Maximum quantity stored [kg or t]	Storage classification

Source: [ 142, HAZBREF 2019 ]

Figure 4.10 Template table of the example from the previous figure.

Proposal for the content of the chemical inventory			
Data source	1	<b>Product information</b>	<b>Product 1</b>
SDS 1.1		Product name	<i>name</i>
SDS 1.3		Suppliers name	<i>name</i>
SDS 9.1		Physical form	<i>description</i>
SDS 2.1		Mixture classification (if applicable)	<i>classification</i>
	2	<b>Uses of product</b>	
	2.1	<b>Use 1</b>	
Own data		Identifier for workplace/process step in company	<i>description</i>
SDS 1.2/supplier data		Technical purpose of product	<i>description</i>
Own data		Amount used per day	<i>number</i>
Own data		Fate of residues after use (air, wastewater, waste)	<i>description</i>
	2.1.1	Conformity check with REACH ES for use 1	
ES		Title of suppliers' applicable exposure sceanrio	<i>title/code</i>
Own data		Contributing activities in ES match onsite use of product	<i>yes/no</i>
Own data		If not: what is the mismatch?	<i>description</i>
Own data		Conditions of use in ES match onsite conditions	<i>yes/no</i>
Own data		If not: what is the mismatch?	<i>description</i>
Own data		Safe amout per site in ES > use amount on site	<i>yes/no</i>
Own data		If not: what is the mismatch?	<i>description</i>
	2.2	<b>Use 2</b>	
Own data		Identifier for workplace/process step in company	<i>description</i>
SDS 1.2/supplier data		Technical purpose of product	<i>description</i>
Own data		Amount used per day	<i>number</i>
Own data		Fate of residues after use (air, waste-water, waste)	<i>description</i>
	2.2.1	Conformity check with REACH ES for use 2	
ES		Title of suppliers' applicable exposure sceanrio	<i>title/code</i>
Own data		Contributing activities in ES match onsite use of product	<i>yes/no</i>
Own data		If not: what is the mismatch?	<i>description</i>
Own data		Conditions of use in ES match onsite conditions	<i>yes/no</i>
Own data		If not: what is the mismatch?	<i>description</i>
Own data		Safe amout per site in ES > use amount on site	<i>yes/no</i>
Own data		If not: what is the mismatch?	<i>description</i>
	2.n	<b>Use n</b>	
		...	...
	3	<b>Ingredients information</b>	
	3.1	<b>Substance 1</b>	
SDS 3.1		Substance name	<i>name</i>
SDS 1.2/supplier data		Technical function	<i>description</i>
SDS 3.1		CAS or EC	<i>number</i>
SDS 3.1		Concentration %	<i>number</i>
SDS 2.1 or 3.2		Classification	<i>classification</i>
SDS 9.1		Vapour pressure	<i>number</i>
SDS 12.2		Biodeg.	<i>number</i>
SDS 8.1		DNEL	<i>number</i>
SDS 8.1		OEL	<i>number</i>
SDS 8.1		PNEC	<i>number</i>
2008/105/EC		EQS	<i>number</i>
SDS 15.1		Regulatory flag	<i>info relevant to substance 1</i>
	3.1.1	<b>Release fractions from use 1</b>	
Own data/ES		% incorporated as such to article	<i>number</i>
Own data/ES		% consumed/reacting during use	<i>number</i>
Own data/ES		% release to waste water	<i>number</i>
Own data/ES		% related to air	<i>number</i>
Own data/ES		% disposed of as waste	<i>number</i>
Own data/ES		Onsite treatment and effectiveness for substance 1	<i>description, remarks</i>
	3.1.2	<b>Release fractions from use 2</b>	
Own data/ES		% incorporated as such to article	<i>number</i>
Own data/ES		% consumed/reacting during use	<i>number</i>
Own data/ES		% release to waste water	<i>number</i>
Own data/ES		% related to air	<i>number</i>
Own data/ES		% disposed of as waste	<i>number</i>
Own data/ES		Onsite treatment and effectiveness for substance 1	<i>description, remarks</i>
	3.1.n	<b>Release fractions from use n</b>	
		...	...

Source: [ 143, Pillet et al. 2019 ]

Figure 4.11: Example of the inventory entry for a chemical product used in a textile plant

**Achieved environmental benefits**

- Reduced risks associated with the storage and handling of hazardous substances.
- Reduction of chemical leftovers.
- The systematic identification of substances with undesirable environmental and toxicological (adverse) properties allows risk-driven prioritisation of management actions such as substitution of process chemicals as well as abatement of emissions to air and to water.

**Environmental performance and operational data**

The inventory is based on data from the respective SDS (as defined in CLP Regulation (EC) No 1272/2008 [ 289, EU 2008 ], and Article 31 of and Annex II to REACH Regulation No 1907/2006 [ 7, EU 2006 ]).

The 16 Sections of the SDS are:

- Section 1: Identification of the substance/mixture and of the company/undertaking;
- Section 2: Hazards identification;
- Section 3: Composition/information on classified ingredients;
- Section 4: First aid measures;
- Section 5: Firefighting measures;
- Section 6: Accidental release measure;
- Section 7: Handling and storage;
- Section 8: Exposure controls/personal protection;
- Section 9: Physical and chemical properties;
- Section 10: Stability and reactivity;
- Section 11: Toxicological information;
- Section 12: Ecological information;
- Section 13: Disposal considerations;
- Section 14: Transport information;
- Section 15: Regulatory information;
- Section 16: Other information.

With regard to environmental protection, information on the chemical composition of the respective chemical products (Section 3 of the SDS), information on handling and storage (Section 7 of the SDS) as well as the exposure values (e.g. Predicted No Effect Concentration (PNEC) reference values of aquatic systems in Section 8 of the SDS) and ecological information (from which PNECs have been derived in Section 12 of the SDS) are the most relevant in practice. The downstream user may receive additional environmental information from the formulator of hazardous mixtures, i.e. the SDS may be extended with information on exposure scenarios for the hazardous substances in the mixture. A general overview of what type of information can be expected in an extended SDS is presented in the ECHA guide on SDS and exposure scenario [ 144, ECHA 2019 ].

Other sources of information are Annex VI to the CLP Regulation, the REACH registration dossiers, the CoRAP evaluations, literature, etc.

Concerning emissions to air from stenters, the emission factors for the various products are not contained in the SDS but are provided separately by the suppliers (for more information see Section 4.1.6.4). Thus, updating information on emission factors for the products concerned requires regular contact with chemical suppliers. To date, only one German company has established a laboratory stenter to determine the emission factors for the chemical products (Modern Testing Services Germany GmbH).

The software application for the establishment and implementation of the inventory and associated evaluation tools can be obtained from a range of providers available on the market (as part of an integrated business or stand-alone applications) or can be developed in-house.

### **Cross-media effects**

None identified.

### **Technical consideration relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

### **Economics**

The investment and operating costs for a chemical inventory depend on the level of sophistication intended. Estimates put the investment costs in the range of EUR 20 000 to EUR 50 000. Savings usually arise from streamlined stocks, improved management of surplus chemicals, simplification or automation of procedures/processes (e.g. by using chemical inventory software), simplification of the verification of compliance with the chemicals regulations as well as indirectly from reduced environmental management costs based on the gradual substitution of hazardous chemicals and emissions to the environment.

### **Driving force for implementation**

- Reduction of chemical leftovers.
- Certification schemes.
- Chemicals regulations.

### **Example plants**

Plants from the data collection: IT082 and IT097 [ 145, EIPPCB 2019 ].

### **Reference literature**

[ 135, ZDHC 2015 ], [ 138, ECHA 2019 ], [ 139, ECHA 2020 ], [ 140, Textilbündnis 2019 ], [ 141, bluesign 2019 ], [ 142, HAZBREF 2019 ], [ 144, ECHA 2019 ], [ 145, EIPPCB 2019 ]

## **4.1.6.3 Selection of process chemicals**

### **Description**

Use of screening tools based on restricted substance lists and environmental labelling to reduce the amount or presence of hazardous substances or to find alternative process chemicals (dyestuffs, pigments, finishing agents, etc.) containing substances with a lower environmental impact (e.g. toxicity, biodegradability/bioeliminability).

### **Technical description**

Restricted substances are chemical substances whose use and/or presence has been banned or otherwise restricted by organisations, authorities or producers. In order to avoid using dyestuffs or chemicals that contain these substances, the textile plants can use products that are labelled or certified as appropriate for use in a certain labelling scheme (e.g. Type I, II or III product labels according to ISO 14 020). There are various voluntary labelling (restriction) schemes like EU Ecolabel, and schemes provided by ZDHC, OEKO-TEX, bluesign, GOTS, AFIRM, GUT, etc.

EU Ecolabel contains a list of restricted substances that are to be avoided or limited in the textile products certified according to this label [ 112, COM 2014 ].

The ZDHC (Roadmap to Zero Programme) is a coalition of fashion brands, value chain affiliates and associates dedicated to enabling the global textile, leather, apparel and footwear production chains to substitute hazardous chemicals for safer ones [ 146, ZDHC 2019 ].

The International Association for Research and Testing in the Field of Textile and Leather Ecology (OEKO-TEX Association) is a union of 18 independent textile research and test institutes in Europe and Japan and their worldwide representative offices. The member institutes are responsible for the joint development of test methods and limit values which form the basis of the product labels (e.g. OEKO-TEX STANDARD 100, MADE IN GREEN) as well as the production site certifications (e.g. STeP - Sustainable Textile Production) and the chemical

management tool DETOX TO ZERO. They are also entitled to carry out the corresponding laboratory tests and site audits. Additional services of the OEKO-TEX Association are the MySTeP database for supply chain management and the ECO PASSPORT certification for the verification of chemicals and auxiliaries [ 147, OEKO-TEX 2019 ].

The Global Organic Textile Standard (GOTS) label was developed in 2006 through collaboration by leading carpet producers with the aim of defining requirements that are recognised worldwide and that ensure the organic status of textiles from harvesting of the raw materials through environmentally and socially responsible manufacturing all the way to labelling in order to provide credible assurance to the consumer [ 148, GOTS 2019 ].

Bluesign sustainability labels and certifications are set by a private company (founded in 2000) for the production of textiles with a particular focus on chemical safety. They relate to both the companies supplying chemicals and the textile industry in order to avoid hazardous chemicals along the manufacturing process. The company also provides their members with services in chemicals management (e.g. substitution of chemicals, inventories, through the bluesign SYSTEM) [ 149, bluesign 2019 ]. The bluesign® FINDER offers a ‘positive’ list of more than 12 500 process chemicals that are commercially available for various applications in textile (and other) industries (as of January 2020).

All registered chemicals are assessed by a comprehensive chemical hazard and risk assessment for more than 900 substances (600 thereof defined with a usage ban) based on verified data provided by contracted bluesign® SYSTEM PARTNER chemical suppliers.

This system covers substance restrictions but also considers the hazard statements (H-phrases) and environmental aspects such as AOX in emissions to water and air emission characteristics [ 150, bluesign 2020 ].

AFIRM is private company aiming to reduce the use and impact of harmful substances in the apparel and footwear supply chain by managing the restricted substance lists for its members (e.g. brands) [ 151, AG AFIRM 2019 ].

European carpet manufacturers founded the Association of Environmentally Friendly Carpets e.V. (Gemeinschaft umweltfreundlicher Teppichboden) – GUT – in 1990 in Aachen (Germany). The aim of GUT is to continuously improve all environmental and consumer protection aspects throughout the life cycle of a textile floor covering (from production to installation, to use phase and recycling). In cooperation with officially recognised European testing institutions, GUT-registered products are regularly controlled on the basis of GUT’s test criteria. Also, regular annual inspections of production sites are conducted [ 152, GUT 2019 ].

The above-mentioned entities (ZDHC, OEKO-TEX, GOTS, bluesign, AFIRM, GuT) carry out certification/labelling according to their restriction schemes (Manufacturing Restricted Substance Lists – MRSL). If the product is to be labelled/certified according to these schemes, certain restricted substances must be absent or present in limited concentrations from the manufacturing inputs (raw materials) and outputs (e.g. emissions, effluents) or from the finished textile products.

The main substance groups of ZDHC MRSL [ 153, ZDHC 2020 ] are presented in Section 8.9. Process chemicals conforming with one of the four MRSL ZDHC conformance levels are reputed not to contain substances listed in the MRSL above a certain limit (corresponding to unintended contamination). The higher the conformance level, the higher the confidence that the process chemical does not contain restricted substances [ 154, ZDHC 2019 ].

Substances are restricted for various reasons: due to environmental concerns, health and safety concerns for workers or consumers, or due to legislation. A substance restriction (in the MRSL scheme) is usually accompanied by a test (standard) method to be used to verify if a chemical is present and, if so, to ensure the chemical is below the restricted level. These labelling schemes



can also be used to select raw materials and chemical suppliers (see Sections 4.1.5.1 and 4.1.6.1).

Some chemical screening tools for finding suppliers of alternative chemicals or mixtures (without restricted substances) are available online (e.g. Marketplace [155, ChemSec 2019]).

In addition to these screening tools, the regulatory context of a given substance may be verified by using the ECHA search tool [138, ECHA 2019].

In some EU Member States, schemes have been developed in cooperation with industry in order to support the permitting process and lower the pollutant loads of hazardous substances to waste waters. They may help in the selection process as screening tools. Examples of these schemes include the General Assessment Methodology in the Netherlands (RIZA Concept), the SCORE System in Denmark, the BEWAG Concept in Switzerland and the TEGEWA scheme in Germany.

### **Achieved environmental benefits**

Reduced pollutant loads in the effluents from textile processing.

### **Environmental performance and operational data**

The change of chemicals may affect the number, scope and technological parameters of various operation steps, which would need to be adapted to ensure the required product specifications. Also, it can affect the waste water treatment needed, because it may need to be adapted for a different pollutant load. Also, it is possible that alternative chemicals are needed in higher quantities and require special treatments and accommodation of production processes – all of these could affect the environmental impact.

Schemes are useful tools that allow the user to select textile dyes and auxiliaries for ecotoxicological aspects. Indirect benefits for water quality are therefore expected, although difficult to quantify/evaluate.

Alternative process chemicals containing substances with a lower environmental impact may not always be possible for high technical performance textiles such as automotive, hygienic, military or protection products. Early restrictions and bans of critical substances in apparel are not always implemented for high technical performance textiles, due to lack of alternatives. To keep product quality at the necessary high level, transition periods and exception clauses are typically needed [156, UBA 2020].

### **Cross-media effects**

None identified.

### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

### **Economics**

It is possible that alternative chemicals are more expensive, needed in higher quantities and require special treatment – all of these could affect the economic costs of production.

### **Driving force for implementation**

- Environmental and product safety regulation (e.g. Ecolabel).
- Chemical regulation (e.g. REACH).
- Market demands (customer pressure).

### Example plants

Many plants from the data collection reported using labelling and certification schemes (e.g. 47 use OEKO-TEX, 13 use ZDHC, 6 bluesign, and many others).

### Reference literature

[ 5, UBA 2001 ], [ 93, Austrian EPA 2016 ], [ 112, COM 2014 ], [ 138, ECHA 2019 ], [ 146, ZDHC 2019 ], [ 147, OEKO-TEX 2019 ], [ 148, GOTS 2019 ], [ 149, bluesign 2019 ], [ 150, bluesign 2020 ], [ 151, AG AFIRM 2019 ], [ 152, GUT 2019 ], [ 154, ZDHC 2019 ], [ 156, UBA 2020 ], [ 157, Danish EPA 2001 ]

#### 4.1.6.4 Emission factor

##### Description

Use of an emission factor calculation to select process chemicals to reduce emissions to air.

##### Technical description

The emission factor concept concerns the emissions of volatile organic compounds and dangerous substances (expressed as organic carbon) that are potentially found in the exhaust air from heat-setting, the thermosol process, impregnation and fixation of finishing agents. The concept was developed in Germany by public authorities (national and federal state level) in cooperation with the German textile finishing industry association (TVI-Verband) and TEGEWA.

The fundamental principle of this concept is that in most cases the emissions produced by the single components in the auxiliary formulations are additive. As a result, the emission potential of each recipe can be calculated on the basis of emission factors given for the single substances present in the formulation (for certain substances, however, the correlation between emission and process parameters is more complex).

It is necessary to distinguish between:

- a substance-based emission factor; and
- a textile substrate-based emission factor.

The *substance-based emission factor* ( $f_c$  or  $f_s$ ) is defined as the amount of substances (organic or inorganic) in grams that can be released at defined process conditions (curing time, curing temperature and type of substrate) from one kilogram of auxiliary. There are two types of substance-based emission factors: 1)  $f_c$ , which gives the total emission produced by the organic substances present in the formulation, expressed as total organic carbon; 2)  $f_s$ , which gives the emission attributable to specific toxic or carcinogenic organic substances or to inorganic compounds, such as ammonia and hydrogen chloride, etc. present in the formulation.

In Germany, where the technique is widely applied, the substance-based emission factors are provided to the finisher **by the auxiliary supplier**, in addition to the information reported in the Safety Data Sheets. The factors are based on measurements, calculations or conclusions made by analogy (according to TEGEWA guidance for calculation of substance-based emission factors) [ 158, Germany 2002 ].

The *textile substrate-based emission factor* ( $WF_c$  or  $WF_s$ ) is defined as the amount of organic and inorganic substances in grams that can be released at defined process parameters (curing time, curing temperature and type of substrate) from one kilogram of textile treated with a given auxiliary formulation. The textile substrate-based emission factor can be calculated on the basis of the emission factors of the individual components of the formulation/recipe ( $f_c$  or  $f_s$ ), their concentration in the liquor (FK) and the liquor pick-up. One example of the calculation of the textile-based emission factor is reported in Table 4.14.

Table 4.14: Two examples for the calculation of air emission factors

	FK (g/kg)	FA (g/kg)	fs (g/g)	fc (g/g)	FK*FA*fs (g/kg)	WFs (g/kg)	FK*FA*fc (g/kg)	WFc (g/kg)
RECIPE 1 Cotton; 170°C								
Fatty acid ester	20	0.65		0.015			0.2	
Polysiloxane	20	0.65		0.005			0.07	
Cross-linking agent	100	0.65	0.0041FO	0.0009	0.27FO	0.48FO	0.06	
Stearyl urea derivative (catalyst)	20	0.65	0.0165FO	0.0162	0.21FO		0.21	
<b>Total 1</b>								0.54
RECIPE 2 Cotton; 150°C								
Softening agent	50	1	-	0.005	-		0.25	
Formaldehyde-free cross-linking agent	12	1	-	0.01	-		0.12	
Catalyst	12	1	-	0.008	-		0.1	
<b>Total 2</b>						-		0.47
NB: FK: concentration in the recipe (g auxiliary/kg liquor). FA: liquor pick-up (kg liquor/kg textile substrate). fs: substance-based emission factor (g emission/g auxiliary) (in the case of toxic or carcinogenic organic substances or in the case of inorganic substances such as ammonia, hydrogen chloride, etc.) fc: substance-based emission factor, expressed as total organic carbon (g Org-C/g auxiliary). WFs: $\Sigma(\text{FK} * \text{FA} * \text{Fs})$ - textile-based emission factor, within the same class of substances. WFc: $\Sigma(\text{FK} * \text{FA} * \text{Fc})$ - textile-based emission factor, expressed as total organic carbon . FO: formaldehyde. Source: [ 5, UBA 2001 ]								

The calculated textile substrate-based emission factors WFc/s can then be compared with the limit values for textile substrate-based emission factors set by environmental authorities by using a standard air to textile substrate ratio of 20 m<sup>3</sup> air/kg of textile substrate (see 'Environmental performance and operational data' below). Some typical substance-specific emission factors of textile auxiliaries are given in Section 8.5.4.1.

### Achieved environmental benefits

The concept can be regarded as a system to control but also to prevent emissions to air from textile finishing. The auxiliary-based substance emission factor makes it possible to predict the emissions of a given recipe based on the emission factors of the single components. In this way, the operator knows the emissions of their process before carrying it out. The operator can therefore concentrate, at the product and process design stage, on minimising the emissions at the source, for example by reducing the amount of auxiliaries or selecting auxiliaries with lower emission potential (see Section 4.1.6.3). In addition, the concept may allow the identification of the situations where the emissions would be the highest and therefore inform the planning of the emission measurement campaign to include these situations.

### Environmental performance and operational data

The control of the emissions to air of the recipes/formulations for finishing by pre-calculation of the textile substrate-based emission factors is done regularly (at least once a year) and especially before using a new recipe or changing the components of an existing recipe.

The following reflects the air emission limit values, related to an air to textile substrate ratio of 20 m<sup>3</sup>/kg, achieved in Germany with the use of the emission factor concept [ 159, Germany 2002 ], [ 160, LAI 2015 ]:

- Harmful organic substances such as toxic substances, suspected carcinogens (further details are to be found in TA Luft):  $\leq 0.40$  g/kg of textile substrate as the total emission, with an emission mass flow from the entire plant of 0.10 kg/h or higher [ 159, Germany 2002 ].
- Formaldehyde if the emission mass flow from the entire plant exceeds 12.5 g/h [ 160, LAI 2015 ]:
  - directly heated thermal treatment for:
    - drying processes:  $\leq 0.10$  g/kg of textile substrate as the total emission;
    - heat-setting:  $\leq 0.30$  g/kg of textile substrate as the total emission;
  - from textile finishing processes (including combustion process from directly heated thermal treatment):
    - easy-care finishing, water- and soil-repellant finishing, thermosol dyeing:  $\leq 0.20$  g/kg of textile substrate as the total emission;
    - crease-free finishing, flame-retarding finishing, coating including lamination, handle-modifying (hard) finishing:  $\leq 0.40$  g/kg of textile substrate as the total emission;
  - in case of application of a thermal oxidiser as a waste gas abatement unit:  $\leq 0.10$  g/kg of textile substrate as the total emission;
  - all other cases:  $\leq 0.10$  g/kg of textile substrate as the total emission.
- Carcinogenic, mutagenic or reprotoxic substances [ 159, Germany 2002 ]:
  - Class I: max. 0.0010 g/kg of textile as the total emission (if the mass flow of the entire plant is 0.15 g/h or higher);
  - Class II: max. 0.010 g/kg of textile as the total emission (if the mass flow of the entire plant is 1.5 g/h or higher);
  - Class III: max. 0.020 g/kg of textile as the total emission (if the mass flow of the entire plant is 2.5 g/h or higher).
- Total organic substances:  $\leq 0.80$  g C/kg of textile substrate, as the total emission of all organic substances, with an emission mass flow from the entire plant of 0.80 kg C/h or higher.

All harmful organic substances exceeding 500 ppm in the auxiliary formulation have to be declared by the suppliers. In addition, information on substances classified as CMR (H340, H350, H350i, H360D or H360F) exceeding 10 ppm is obligatory.

Substances or preparations that are classified under CLP as CMR with H Statements H340, H350, H350i, H360D or H360F have to be substituted by less harmful substances within the shortest possible time.

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

The emission factor concept is generally applicable, if the producer of chemicals determines the emission factor of the auxiliaries (preparations), as the information is not readily accessible in the SDS concerned.

#### **Economics**

There are no costs for the textile finisher apart from the cost of calculating the emission factors for the finishing recipes used in the process, which is negligible. A correct selection of low-emission auxiliaries can significantly reduce costs for air emissions abatement.

#### **Driving force for implementation**

- Reduced emissions to air.
- Reduction of abatement costs (Economics).

In Germany, where the emission factor concept is accepted by the environmental authority, an important driving force for implementing this technique has been the possibility that it gives of avoiding or reducing expensive emission measurements (pre-calculation).

### Example plants

This technique is widely applied in Germany, where it is accepted by the environmental authorities.

According to the data collection, a total of 47 plants from DE and 1 plant from IT reported using this approach.

### Reference literature

[ 5, UBA 2001 ], [ 44, ÖKOPOL 2011 ], [ 159, Germany 2002 ], [ 160, LAI 2015 ], [ 161, Schlachta R. 2020 ], [ 162, Schröder V. 2020 ], [ 163, Sedlak D. 2020 ], [ 164, Kohla M. 2020 ], [ 165, TEGEWA 2011 ], [ 166, Zietlow B. 2020 ]

### 4.1.6.5 Optimisation of chemical consumption

#### Description

The techniques (organisational and technical measures) are applied to reduce the consumption of chemicals in the finishing processes. These include control of chemical consumption, low-liquid application technology, liquid removal and recovery techniques.

#### Technical description

Some of the chemical-saving techniques to consider are as follows:

- Reducing the need for process chemicals
  - Regularly revising and optimising the recipes in order to identify unnecessary chemicals (dyes, auxiliaries) that can be avoided.
  - Optimising the process by improving the control of process parameters such as temperature, chemical feed, dwell times, moisture (for dryers), etc. (see Section 4.1.1.3).
  - Avoiding or reducing the use of chemicals to prevent side effects caused by the presence of impurities (e.g. complexing agents) in process waters by using high-quality water (e.g. soft water /water softened by ion exchange, membrane filtration or other techniques). Avoiding or minimising any kind of surplus of applied chemicals and auxiliaries (e.g. by automated dosing and dispensing of chemicals - see Section 4.1.6.7).
  - Optimising scheduling in production (e.g. in dyeing: dyeing dark shades after pale shades reduces water and chemical consumption for machine cleaning).
- Low-liquid application techniques
  - Giving preference to low-add-on devices for chemicals (machine selection) such as transfer rollers (e.g. engraved, lick-, kiss-), pad transfer (padding), spraying and foam application for continuous processes.
- Liquid removal techniques

Removing liquors (chemicals) from the textile substrate leaving the process bath by mechanical extraction (e.g. squeeze rollers, vacuum extractors, suction or blowing/ejection of liquid by compressed air) to recover chemicals (e.g. sizes, bleaching chemicals, finishing agents like fluorocarbons, resins, softeners, pigments) and reuse them in the process; (see also Sections 4.1.3.4 and 4.1.4.4).
- Recovery techniques
  - Recovering and reusing mother baths (e.g. overestimated surplus amounts), leftover process chemicals (e.g. from emptying pipes or package) whenever

- possible. The degree of use may be limited by the content of impurities and the perishability of the process chemicals.
- Recovering vapour during delivery of volatile substances.

#### **Achieved environmental benefits**

The consumption of chemicals is reduced and therefore the pollutant load in the effluents, emissions to air and amounts of waste are reduced.

#### **Environmental performance and operational data**

For data on decreasing the amounts of leftover chemicals, reflecting precise planning and controlled consumption of chemicals, see Section 3.7.7.

Regarding low-liquid application techniques, specifically spray dyeing, the liquor (bath) volumes as low as 90 litres (versus 10 000-50 000 litres of conventional slasher dyeing) are achieved for indigo dyes; and 45 litres (versus 1 200-4 000 litres by using conventional boxes) for sulphur dyes [[167, ROTASPRAY 2019](#)], [[168, Swedish EPA 2019](#)].

#### **Cross-media effects**

Some techniques for reducing the consumption of chemicals require energy, so energy consumption may increase.

#### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of these techniques.

However, sometimes the complexing agents need to be used to ensure lower water consumption in rinsing and washing.

#### **Economics**

In existing plants, investment in new equipment and infrastructural modifications (e.g. for the segregation of streams) is necessary.

#### **Driving force for implementation**

- Environmental legislation.
- Reduced consumption of chemicals.

#### **Example plants**

Many plants report using low-add-on machinery.

A total of 35 plants from data collection use mechanical dewatering (liquid removal) techniques prior to drying.

DE047, FR130 and FR133 report recycling/reuse of spent dye baths and padding liquors.

DE025, DE032, DE049 and UK127 report recycling/reuse of spent printing pigment/dye pastes.

CZ016, DE049, FR135 and SE119 report recycling/reuse of spent finishing baths/padding liquors.

In total, 22 plants report having no leftover chemicals.

#### **Reference literature**

[[35, RICARDO 2019](#)], [[108, Derden et al. 2010](#)], [[167, ROTASPRAY 2019](#)], [[168, Swedish EPA 2019](#)]

#### **4.1.6.5.1 Treatments with enzymes**

##### **Description**

Enzymes are used to activate or catalyse the reactions with fibres in wet processing and lower the consumption of chemicals for those purposes.

### **Technical description**

Enzymes are proteins that act as biocatalysts activating and accelerating chemical reactions. Their excellent substrate selectivity allows milder process conditions compared to conventional processing.

Various enzyme-based solutions have been developed for different textile pretreatment and finishing processes. Typical enzymes used in these processes are amylases, cellulases, catalases, laccases, lipases, pectinases and proteases for textile wet-processing applications like desizing, bio-polishing, denim finishing, bleach clean-up, scouring, anti-felting of wool and others [169, Danish EPA 2019]. The application of cellulases for denim finishing and lactases for decolourisation of textile effluents and textile bleaching are the most recent commercial advances.

Similarly, esterases, lipases, and cutinases can replace sodium hydroxide in improving the softness and moisture absorption characteristics, as well as surface softness and reduced pilling of polyethylene terephthalate (PET) fabrics.

For more information on the application of enzymes in pretreatment processes, see Section 4.4.2.

For more information on the application of enzymes in soaping after dyeing, see Section 4.5.1.5; for more information on the use of enzymes in softening (bio-polishing) cotton, see Section 4.7.3.2; and for enzymatic wool anti-felting, see Section 6.4.1.

### **Achieved environmental benefits**

- Reduced or even avoided use of hazardous and/or poorly biodegradable or bioeliminable substances (chemicals).
- Reduced energy consumption (lower processing temperatures).
- Reduced water consumption (reduced number of rinsing steps).

### **Environmental performance and operational data**

The process parameters change, depending on the process, substrate and enzymes used. The processing time and consumption of chemicals, water and energy for fabric treatment may be reduced. Enzyme treatments are sensitive to temperature, pH, humidity and contaminants.

### **Cross-media effects**

Enzymes contribute to the organic load in the effluent. This means special attention may need to be paid to the operation of the biological waste water treatment plant to treat higher organic loads.

### **Technical considerations relevant to applicability**

Not applicable to synthetic man made fibres.

The use of enzymes in wet processing of textile fibre, fabric and products is limited by the availability of suitable enzymes.

### **Economics**

Apart from additional investments in the equipment that integrating enzyme-based technologies may require, the costs of enzymes can be substantial.

### **Driving force for implementation**

- Reduced water, energy and chemical consumption.
- Reduced waste water treatment.

**Example plants**

19 plants (CZ019, DE022, DE026, DE047, DE049, FR136, IT064, IT065, IT068, IT069, IT077, IT078, IT094, PT108, PT109, PT111, PT114, SE120 and UK127) report using enzymes for desizing (12 amylases).

8 plants (FR136, IT059, IT068, IT069, IT074, IT077, IT091, PT114 and SE120) report using enzymes for scouring of cotton (amylases and cellulase).

6 plants (DE034, DE049, FR131, IT070, IT097 and PT108) report using enzymes for bleaching (2 amylases, 2 catalase, 1 cellulase, 1 other).

3 plants (IT064, IT070 and IT078) report using enzymes for softening and other batch finishing treatment (cellulase and protease).

**Reference literature**

[ 11, Beton et al. 2014 ], [ 31, Cotton Incorporated 2009 ], [ 35, RICARDO 2019 ], [ 169, Danish EPA 2019 ], [ 170, Saxena et al. 2017 ], [ 171, Cotton Incorporated 2018 ], [ 172, Novozymes 2019 ]

**4.1.6.5.2 Recovery and reuse of chemicals****Description**

Some chemicals consumed at large scale can be recovered and reused, like alkalis (from mercerisation) or brine and/or salts (from dyeing).

For technical description, achieved environmental benefits, economics and cross-media effects, see Section 4.4.8.2 for caustic soda recovery, and Sections 4.1.7.4.4 and 4.5.1.10 for brine and/or salt (NaCl) recovery in Zero Liquid Discharge effluent treatments.

**4.1.6.6 Chemical handling and storage****Description**

Techniques are applied to ensure safe storage and prevent leakage and spilling of chemicals during storage and handling. These include:

- optimised storage location of process chemicals to eliminate or minimise the unnecessary transport of process chemicals within the plant (e.g. the transport distances on site are minimised);
- tanks for liquids are located in a suitable secondary containment; its volume is sized to accommodate at least the complete loss of the liquid of the largest tank that is within the secondary containment;
- containment of storage and handling areas;
- isolation of tanks and secondary containment (e.g. by closing valves);
- dedicated areas for unloading hazardous process chemicals;
- segregated storage of process chemicals (e.g. depending on their properties);
- the surfaces of the process and storage areas are impermeable to the liquids concerned;
- regular inspection and maintenance of plant and equipment to ensure proper functioning: this includes in particular checking the integrity and/or leak-free status of valves, pumps, pipes, tanks and containments/bunds and the proper functioning of warning systems (e.g. overflow detectors);
- prevention of spillage, leakage and overflows (e.g. by automatic level adjustment of process liquors, double-walled tanks);
- segregated drainage system;
- appropriate training of the personnel.



### Technical description

Each chemical is stored according to the instructions (e.g. storage precautionary statements) given by the manufacturer in the Safety Data Sheet and in accordance with chemicals' storage compatibility.

All areas where chemicals are stored or spillages are likely to occur are bunded so that spillages do not enter soil, surface waters or sewers. Toxic and hazardous chemicals are stored separately. More detail on these issues can be found in [ 173, COM 2006 ] and in 'Environmental performance and operational data' below.

First aid facilities are available and evacuation and emergency procedures in place and rehearsed regularly. Records of accidents and incidents (near misses) are kept.

Transfer of chemicals from storage to machine is often prone to leakage or spillage. Pumps and pipework used for transfer are regularly inspected (see equipment maintenance in Section 4.1.1.1) and provisions are made to ensure the safety of manual transfer (including appropriate training of workers, use of buckets with leakproof lids, etc.). For handling and transfer of concentrates to dyeing machines, see also Section 4.7.7.1.

Accurate weighing, dispensing and mixing are fundamental for avoiding/minimising spillages in manual operation. It is better to have only one or two workers do all the weighing, with proper training and precautions [ 174, HSE 2020 ]

An automated chemical dosing and dispensing system offers some important advantages over the manual method (better laboratory-to-dyehouse correlation; minimises the chance of worker injury when handling hazardous chemicals; faster delivery times, etc.). For more details, see Section 4.1.6.7.

The training of the staff addresses in particular the understanding and use of the SDS, the preventive environmental and works safety practices, the practices to save chemicals, the regulatory requirements and the use of the chemicals inventory [ 135, ZDHC 2015 ].

### Achieved environmental benefits

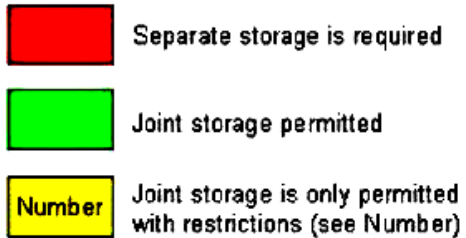
- The spillage, leakage (loss) and emissions of chemicals are reduced.
- Reduced emissions to soil and groundwater.

### Environmental performance and operational data

To ensure appropriate storage, chemical segregation charts (see Figure 4.12 for an example from the German Technical Rule for Hazardous Substances TRGS 510 (2013)) are used together with information gathered from the corresponding Safety Data Sheets (SDS).

For example, hydrogen peroxide is stored separately in a dedicated catchment facility and sodium dithionite is stored in a separate dry room.

Storage class		10-13	13	12	11	10	8 B	8 A	7	6.2	6.1 D	6.1 C	6.1 B	6.1 A	5.2	5.1 C	5.1 B	5.1 A	4.3	4.2	4.1 B	4.1 A	3	2 B	2 A	1		
Explosive substances	1																										1	
Gases	2 A	2			2			2								1										2	3	
Aerosol packages	2 B															1												
Flammable liquids	3	5			5						6						4											
Other explosive substances	4.1 A	1	1	1	1	1	1	1							1							1	1					
Flammable solid or desensitizing explosive substances	4.1 B										6			4	1		4		6	6								
Pyrophoric or self-igniting substances	4.2	6			6	6	6	6			6	6							6									
Substances producing oxidizing gases with water	4.3	6		6	6	6	6	6			6	6																
Highly oxidising substances	5.1 A																											
Oxidizing substances	5.1 B	7			7	7		7			6	6	4	4		1												
Ammonium nitrate and mixtures containing ammonium nitrate	6.1 C	1	1	1	1	1	1	1								1												
Organic peroxides and self-reactive substances	5.2	1			1	1																						
Combustible, acutely toxic substances	6.1 A	5			5																							
Non-combustible acutely toxic substances	6.1 B	5			6																							
Combustible acutely toxic or chronic substances	6.1 C																											
Non-combustible acutely toxic substances or substances with chronic effects	6.1 D																											
Infectious substances	6.2																											
Radioactive substances	7								1																			
Combustible corrosive substances	8 A																											
Non-combustible corrosive substances	8 B																											
Combustible liquids	10																											
Combustible solids	11																											
Non-combustible liquids	12																											
Non-combustible solids	13																											
Other combustible and non-combustible substances	10-13																											





Separate storage is required  
 Joint storage permitted  
Number Joint storage is only permitted with restrictions (see Number)

Source: Technical Rules for Hazardous Substances TRGS 510 in [ 142, HAZBREF 2019 ]

Figure 4.12: Storage class compatibility check used in Germany

The following figure outlines exemplary measures (common good chemical management practices) for the proper storage and handling of chemical products:

<p>Dedicated unloading area with precautionary measures in case of spillages for liquid bulk chemicals; typically acetic acid, NaOH, KOH, H<sub>2</sub>O<sub>2</sub>, urea, main surfactants; the area should have a collection/drainage system enabling separate collection of spills and stormwater. Occasional spillages are collected and sent for treatment.</p>	 <p>Unloading area for trucks</p> <p>Locked door for fixing the flexible pipe for unloading liquid bulk chemicals</p> <p>Stormwater drain: Underground, there is a valve and tank to catch accidental releases of chemicals during unloading (during unloading, the valve is switched to the catchment tank)</p>
<p>Double-walled tanks with overfilling prevention and leakage detection for bulk chemicals (NaOH, KOH, H<sub>2</sub>O<sub>2</sub>, detergents, urea); for H<sub>2</sub>O<sub>2</sub>, explosion prevention is required (e.g. a safety relief valve and an over-roof pipe).</p>	



**Figure 4.13: Measures for proper storage and handling of chemical products**

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of these techniques. The moving of the storage location may be restricted by the plant layout and a lack of space for existing plants.

#### **Economics**

There are no precise figures available for the different measures described. Potential savings arise from reduced risks of uncontrolled reactions and connected costs (losses, damage, insurance costs).

### Driving force for implementation

- Environmental and chemical legislation.
- Reduced consumption of chemicals.

### Example plants

All techniques are used by many plants from the data collection (e.g. prevention of overflows by 38, prevention of piping leakage by 31, strategic positioning of storage areas by 24, sealing of operational areas by 16, containment and/or bunding by 12, bag filters 1).

### Reference literature

[ 135, ZDHC 2015 ], [ 142, HAZBREF 2019 ], [ 173, COM 2006 ], [ 174, HSE 2020 ], [ 175, Benninger et al. 2016 ]

#### 4.1.6.7 Emptying and storage of packaging containing chemicals

##### Description

Packaging containing liquid process chemicals is completely emptied by gravity or by mechanical means (e.g. brushing, wiping) without the use of water. Packaging containing process chemicals in powder form is emptied by gravity for small packaging and using suction for large packaging. Empty packaging is stored in a dedicated area.

##### Technical description

The packaging types used for textile finishing chemicals include intermediary bulk containers (IBCs), big bags, 25 kg metal buckets (paste), containers (1000 l), metal recipients (50 kg), and plastic or paper bags (up to 25 kg).

##### IBCs, buckets, containers and recipients

Packaging for chemicals like IBCs, buckets, containers and recipients for ready-to-use solutions, mixtures of active substances, aqueous dispersions or viscous paste is emptied without the use of water: by gravity and by scraping the inner surface when possible. The packaging is not rinsed.

Thereafter, the emptied packaging is stored in an appropriate manner in a dedicated storage area, until it is taken over by a qualified processing company or by the chemicals supplier.

##### Sacks and big bags

Sacks or big bags with chemicals in powder form are emptied under negative pressure. Thereafter, emptied sacks and big bags are stored in an appropriate manner, until they are taken over by a qualified processing company or by the chemicals supplier. Emptied sacks are packed in polyethylene sacks and sacks and big bags are stored in enclosed conditions.

##### Achieved environmental benefits

- Reduction of water consumption and of generation of waste water.
- Reduced emissions to soil and groundwater.

##### Environmental performance and operational data

Water consumption is limited by emptying the packaging materials without the use of water. This also limits the pollutant load of the waste water. If the chemical leftovers are recovered, the chemical consumption can also be limited. Emissions to air are avoided when sacks of powder-form chemicals are emptied under negative pressure. Emissions of chemicals into waste water and the soil can be prevented by storing chemicals packaging in an appropriate manner. The amount of waste is reduced when reusable packaging is returned to the chemicals supplier.

It is estimated that around 25 litres of chemicals are left behind per 1 000-litre IBC. The chemicals remaining in the packaging can be reduced to a fifth (5 litres) by placing the IBCs on a sloping surface.

**Cross-media effects**

None identified.

**Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

**Economics**

If packaging material for chemicals is emptied without the use of water, it is possible to make savings in the purchase of chemicals by recovering a certain quantity. The storage of chemical packaging in an appropriate manner is not accompanied by a cost increase or decrease. However, additional costs will be encountered when disposing of this packaging via a qualified processing company or via the chemicals supplier.

Some examples are given in [ 108, Derden et al. 2010 ]:

- The cost for a system where sacks are emptied under negative pressure amounts to approximately EUR 10 000. This price also includes the dust filter.
- The cost for a system where big bags are emptied amounts to EUR 5 000-6 000 (used in major companies).
- The cost for disposing of packaging material amounts to EUR 40 per IBC. This is the cost for rinsing the IBC and bringing the packaging onto the market via a tank cleaning company. However, there must only be maximum 5 l of leftover product in the to-be-cleaned IBC and penalties are paid for higher residue contents.

**Driving force for implementation**

Savings in chemical purchase.

**Example plants**

No information provided.

**Reference literature**

[ 108, Derden et al. 2010 ], [ 174, HSE 2020 ]

#### **4.1.6.8 Automatic systems preparation, dispensing and dosing of chemicals and dyestuffs**

**Description**

Automatic and semi-automatic weighing, dissolving, measuring and dispensing systems for precise delivery of textile chemicals and dyestuffs to the production machines.

**Technical description**

Tanks in storage facilities (storage vessels), dispensing units (for weighing, mixing and dissolving the chemicals) and machinery are connected by the pipework equipped with valves, pumps, sensors and meters (e.g. for flow, temperature, pressure, level, conductivity, weighting) enabling automated and computerised control and handling of solid and liquid chemicals (basic and auxiliary) and dyestuffs (dyes and printing pastes).

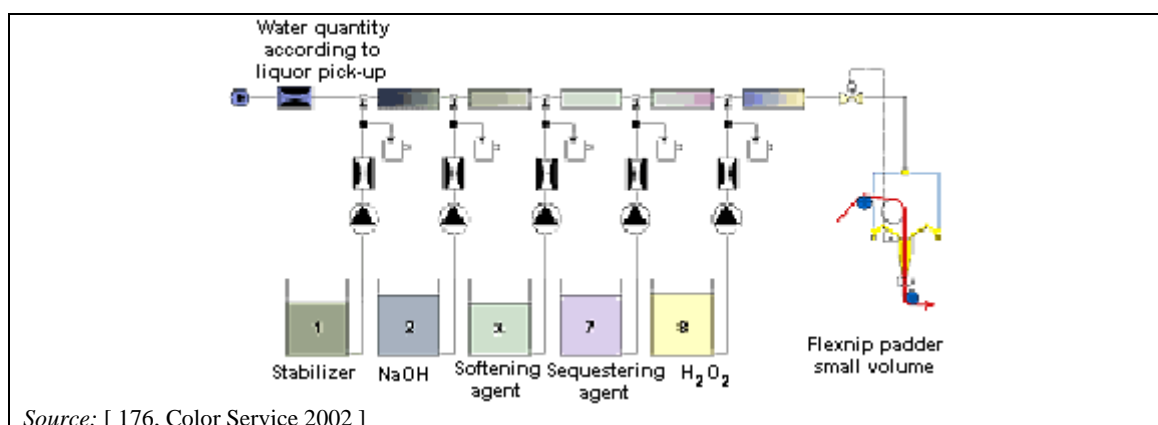
Gravimetric or volumetric distribution systems are used to serve the preparation ranges, pretreatment, dyeing, printing and finishing machines (ranges).

Systems are available for dispensing of chemicals and dyes as either aqueous solutions, powders or pastes. Plants can choose various levels of automation, from quantitative dispensing systems for preparation chemicals and/or dyes to simpler semi-automatic addition systems for manually prepared solutions.

The so-called just-in-time chemical and dyestuff preparation systems are employed in the following areas [ 175, Benninger et al. 2016 ]:

- preparation of enzymatic desizing solutions;
- preparation of bleaching and scouring liquors;
- ratio dosing for dyeing with reactive dyestuffs;
- preparation of resin finishing and finishing liquors.

Figure 4.14 shows an example of an automated system for dispensing chemicals for the preparation of pretreatment and finishing liquors (without premixing of the chemicals). Similar devices can be used in semi-continuous (cold pad-batch - see the relevant described technique in Section 8.3.4.2).



**Figure 4.14: Example of automated systems for dispensing chemicals**

Concerning carpets and bulky fabrics, the equipment allows on-line real-time preparation, dosing and application of each of the individual components. The machines and application systems work on the colour-on-demand principle. There is no need to make measurements; the liquors are injected or applied digitally and quantitatively. As a result, there are no liquor residues at the end of the process.

All laboratory operations needed in batch dyeing can be carried out with fully automated systems with practically no need for manual intervention. These sophisticated systems have been successfully applied in some large dyehouses.

### Achieved environmental benefits

- Reduced consumption of chemicals and water.
- Reduced amounts of effluent and pollutant loads in emissions to water.
- Increased productivity (right-first-time performance).

### Environmental performance and operational data

Semi-automatic addition systems are more common, but automatic dispensing systems are used in larger and more modern plants, especially for batch dyeing of yarns and knits.

Coupled with on-line measurement of the liquor pick-up and of the quantity of processed fabric (see Section 4.1.1.3), the exact amount of liquor can be prepared and added. These systems improve the accuracy of material additions and the consistency of production, while reducing waste (surpluses) in dyes and chemicals.

Automation of dye and chemical dispensing can significantly improve right-first-time performance, as well as lot-to-lot shade reproduction.

In automated systems with separate dispensing of the different chemicals, the resulting environmental benefits are particularly important where chemicals and auxiliaries are used in large amounts in the mill and in long continuous lines. When the different chemicals are not mixed before the process, they can be easily reused for the next run. Separate dispensing of each dye, although technically possible, is very expensive and advantageous only for trichromatic systems where a few dyes are used (maximum nine different dyes) and the volumes recovered are high enough to justify the investment.

In Table 4.15 below, data from a textile dyehouse (dyed textile capacity of 3 500 t/year) show the following improvements before and after the installation of an automated dosing and dispensing system for chemicals.

**Table 4.15: Example of savings due to automatic dosing and dispensing system**

	Before	After
Reworks	4.5 %	3.7 % (17 % reduction)
Reduced chemicals costs	NA	11.2 %
Reduced labour cost (in the dyehouse)	NA	10 %
Increased dye machine efficiency	NA	5 %
NB: NA: Not applicable. Source: [ 176, Color Service 2002 ]		

Another example comes from a manufacturer who, due to the installation of an automated dosing and dispensing system for dyes and auxiliaries, no longer needed a sampling operation on the batches and so was able to replace it with an extra daily batch on each machine [ 176, Color Service 2002 ].

Automated laboratories can reduce reworking to 2-3 % of total production.

#### **Cross-media effects**

Compressed air, steam and electricity are needed for the operation of the system. If water used for cleaning of equipment and piping (needed for dosing and dispensing) is not reused, there is additional effluent to be treated.

#### **Technical considerations relevant to applicability**

Typical automated dosing and dispensing techniques described in this section are applicable to both new and existing installations. However, an exception is made for highly sophisticated systems such as dosing systems based on the colour-on-demand principle and automated laboratories, which are still very expensive and as a consequence more suitable for large installations.

The size and age of the plant do not seem to represent a limitation to the applicability of automated dosing and dispensing systems in general.

Space availability may represent an issue in existing companies, especially for the automation of dyes. While liquid chemicals are easy to automate due to the limited number of chemicals used in the process, some companies may regard the high number of dyes as a limitation due to lack of space and the higher investment costs required.

Also, for dyehouses with many (e.g. > 150) different dyes, it is not uncommon that those more frequently used (highest consumption) are selected for automation. A typical situation is the one in which a company uses 60 colourants with a daily consumption of 5-6 kg and 20 colourants in amounts as low as 10 g/day. In such a situation, it is likely that the company will decide to automatise the 60 dyes with higher consumption and leave the others for manual dosing and



dispensing. Very often this choice encourages the company to give preference to dyes that are automatised, gradually reducing the consumption of the other dyes [ 176, Color Service 2002 ].

For long-distance pipelines, the minimum quantities of liquor needed for the operation of the distribution system (e.g. filling volume of piping and pumps, the so-called dead volume) can exceed the volume of the liquor used in padders or batches (e.g. a 100-m textile good (patterning) requires 30 litres of liquor and the minimum quantity of the dosing/dispensing system is 60 litres), making it uneconomical and environmentally controversial for small batches (lots).

### Economics

The time for preparation and dispensing of chemicals and dyestuffs is short compared to the overall treatment time. Investment into preparing the treatment range and associated dispensing/distribution and dosing systems is therefore economically viable when larger numbers of machines are served. The cost/utilisation factor is weighted versus a higher quality of treatment (e.g. right-first-time) and productivity.

Investment costs for the automated dosing of liquid chemicals, depending on the number of machines to be served, liquors to be prepared and chemicals to be used, range from EUR 7 000 to EUR 250 000 [ 44, ÖKOPOL 2011 ].

Data from a recent study for small and medium-sized enterprises are provided in the Table 4.16 below.

**Table 4.16: Cost and payback periods of automated preparation and dispensing of chemicals in dyeing plants**

	Investment cost	Payback period (years)
Automatic chemical dispensing system	USD 150 000-890 000	1.3-6.2
Dye dissolution and distribution	USD 100 000-400 000	4-5.7
Bulk powder dissolution and distribution	USD 76 000-600 000	3.8-7.5

Source: [ 84, Hasanbeigi A. 2010 ]

Cost savings can be derived from a reduction of consumption of chemicals and water, increase of reproducibility and decrease in staff costs. Savings of up to 30 % have been reported by [ 5, UBA 2001 ].

Liquid chemicals are the most commonly automatised (first option in existing companies) for health and safety reasons, but also due to the relatively low investment needed (limited number of chemicals used in the process) [ 176, Color Service 2002 ].

### Driving force for implementation

The main driving forces for implementation are increased reproducibility and productivity along with health and safety requirements defined by legislation.

### Example plants

Commonly applied in textile installations (in 51 out of 105 plants from the data collection).

Plants with automated dosing and dispensing systems represent more than 60 % of the existing dye and print houses in Europe. Automated systems for liquid chemicals are the most common (70 % of the plants), whereas automated dosing and dispensing for powder dyes and auxiliaries are present in 20 % of the European installations [ 176, Color Service 2002 ].

**Reference literature**

[ 5, UBA 2001 ], [ 28, GuT 2001 ], [ 44, ÖKOPOL 2011 ], [ 84, Hasanbeigi A. 2010 ], [ 175, Bunninger et al. 2016 ], [ 176, Color Service 2002 ]

**4.1.6.9 Substitution of hazardous substances****4.1.6.9.1 Substitution of alkylphenols and alkylphenol ethoxylates****Description**

Surfactants that are biodegradable and bioeliminable are used in pretreatment, dyeing, printing and finishing processes instead of alkylphenols and alkylphenol ethoxylates (AP/APEO).

**Technical description**

Many surfactants give rise to environmental concerns due to their poor biodegradability, their toxicity (including that of their metabolites) and their potential to act as endocrine disruptors.

Concerns in the textile sector focus on alkylphenol ethoxylates (APEO) and in particular on nonylphenol ethoxylates (NPE), which may be contained in the formulations of detergents and many other auxiliaries (e.g. softeners, desizing, fixing, wetting and dispersing agents, emulsifiers, spinning lubricants).

Some alkylphenol ethoxylates are endocrine disruptors with a known oestrogenic effect. More importantly, however, they produce metabolites which are many times more potent as endocrine disruptors than the parent compounds. The most potent of these are octyl- and nonylphenol [ 177, Acir et al. 2018 ].

APEO are listed in various voluntary (Manufacturing) Restricted Substances Lists ((M)RSLs) like ZDHC (see Section 8.9) as substances not to be used.

In addition, nonylphenol (NP) and nonylphenol ethoxylates (NPE) are subject to restriction (Annex XVII entries 46 and 46a) under the REACH Regulation [ 7, EU 2006 ]. In particular, their use on textiles and as substances or in mixtures in concentrations equal to or greater than 0.01 % by weight of the textile article or mixture is banned. Furthermore, NPE are included in Annex XIV to REACH, entry 4 and, therefore, subject to authorisation, due to its endocrine-disrupting properties for the environment.

Legal restrictions for biodegradation of surfactants in detergents are imposed by Regulation (EC) No 648/2004 on Detergents. The Regulation introduced stricter rules, allowing only the use of such surfactants in the detergents, which are readily biodegradable (Article 4). Annex VIII to the Regulation defines the test and analytical methods to determine the biodegradability of surfactants [ 178, EU 2004 ].

The ability to replace NPE as a detergent and emulsifier with other alternatives will depend on a formulation's performance demands and needs to be evaluated on a case-by-case basis. It is therefore difficult to replace NPE with one alternative formulation for all uses. The alternatives must have the characteristics of a true surfactant and many physical properties need to match [ 179, ECHA 2014 ].

The main alternative to NPE are (mostly linear) alcohol ethoxylates (AE). The properties of these non-ionic surfactants can be adjusted by the alcohol selection and by the length of the hydrophilic polyethylene glycol chain. The properties of AEs are affected by the length and the structure of the alkyl chain and the length of the polyoxyethylene chain. The challenge of replacing NPE with AE is to balance their good wetting and detergent properties with sometimes inferior emulsifying and dispersion properties, which are additionally needed in most applications. Selection of appropriate AE is therefore often a compromise, and not a straight replacement of NPE.

The most effective are AE mixtures comprising AE of different alkyl chain lengths and single cut alcohols (from C6 to C22) [ 180, Sasol 2019 ].

No concern is expected due to exposure of AE to health nor have endocrine-disrupting properties been shown [ 179, ECHA 2014 ]. However, there may be some concerns for aquatic environment for fatty alcohol ethoxylates (FAE) and ethoxylated dodecyl alcohol [ 181, SUBSPORT 2013 ].

Other non-ionic surfactants are glucose-based sugar esters, alkanol fatty acid amides, or quaternary ammonium compounds. In these groups there are also many different kinds of surfactants depending on the chemical structure [ 179, ECHA 2014 ].

Tests for biodegradability and bioeliminability are listed in [ 182, ISO 2006 ] and include *inter alia* the Zahn-Wellens Test (ISO-EN 9888:1999 comparable to OECD guideline 302 B). More details on biodegradability are provided in Regulation (EC) No 648/2004 on Detergents.

Safety Data Sheets are a source of information to select less hazardous surfactants.

More information on surfactants can be found in Section 8.1.1.

### **Achieved environmental benefits**

The use of APEO-free auxiliaries reduces the toxicity of waste waters. Moreover, the treatability and biodegradability of the effluent are improved.

### **Environmental performance and operational data**

Sites using exclusively APEO-free auxiliaries report no operational or processing difficulties [ 184, ENco 2001 ].

For the substitution of APEO in detergents, the substituting washing formulations are reported to be applied in concentrations similar to the conventional ones [ 183, Spain 2001 ].

According to other sources (e.g. [ 15, INTERLAINE 1999 ]), AE are slightly less effective detergents than APEO, which means that higher concentrations and feed rates may be required for equivalent effects. Investigations carried out in the wool scouring sector showed that mills using alkylphenol ethoxylates used an average of 7.6 g detergent per kg of greasy wool (range 4.5-15.8 g/kg), while the users of alcohol ethoxylates consumed an average of 10.9 g detergent per kg of greasy wool (range 3.5-20 g/kg).

### **Cross-media effects**

None identified.

### **Technical considerations relevant to applicability**

This technique is generally applicable. However, as long as surfactants containing APEO are used in fibre and yarn preparation agents, a large fraction of potentially hazardous surfactants in wet-processing effluents cannot be controlled by the textile finisher.

### **Economics**

Table 4.17 below gives a comparison of the costs of various alternatives to NPE, having set the price at 100 for NPE.

**Table 4.17: Comparison of prices between NPE and alternatives**

Product, calculated to 100 % active material	Price index
NPE	100
Alcohol ethoxylates, (natural based source)	90-120
Alcohol ethoxylates, (petrochemical based source)	80-120
Glucose-based surfactants	180-260
Alkanolamides	80-130
<i>Source: [ 179, ECHA 2014 ]</i>	

**Driving force for implementation**

Chemical legislation (REACH).

**Example plants**

A total of 29 plants reported using APEO-free surfactants (e.g. linear AEs).

**Reference literature**

[ 7, EU 2006 ], [ 15, INTERLAINE 1999 ], [ 32, Bettens L. 1999 ], [ 108, Derden et al. 2010 ], [ 177, Acir et al. 2018 ], [ 178, EU 2004 ], [ 179, ECHA 2014 ], [ 180, Sasol 2019 ], [ 181, SUBSPORT 2013 ], [ 183, Spain 2001 ], [ 184, ENco 2001 ]

**4.1.6.9.2 Substitution of poorly biodegradable phosphorus- or nitrogen-containing complexing agents****Description**

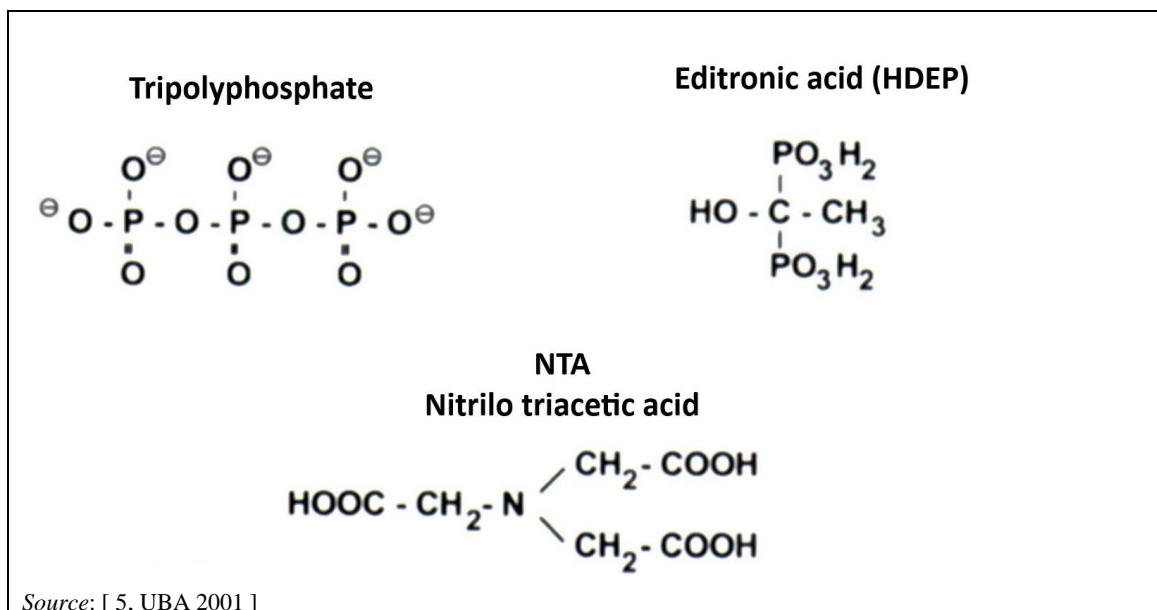
Complexing agents containing phosphorus (e.g. tripolyphosphate) or nitrogen (e.g. polycarboxylic acids such as EDTA or DTPA) used in the wet processes (e.g. pretreatment, dyeing and finishing) are substituted by biodegradable/bioeliminable substances, e.g.:

- polycarboxylates (e.g. polyacrylates);
- salts of hydroxy carboxylic acids (e.g. gluconates, citrates);
- sugar-based acrylic acid copolymers:
  - methylglycinediacetic acid (MGDA);
  - L-glutamic acid N,N-diacetic acid (GLDA);
  - iminodisuccinic acid (IDS);
  - phosphonates (e.g. aminotris methylene phosphonic acid (ATMP), diethylenetriamine pentamethylene phosphonic acid (DTPMP) and 1-hydroxyl ethylidene-1,1-diphosphonic acid (HEDP)).

**Technical description**

Complexing agents are applied as sequestering agents to mask hardening alkaline-earth cations and transition-metal ions in aqueous solutions in order to eliminate their damaging effect, especially in pretreatment processes (e.g. catalytic destruction of hydrogen peroxide), but also during dyeing operations.

Typical sequestering agents are polyphosphates (e.g. tripolyphosphate), phosphonates (e.g. etidronic acid also called 1-hydroxyethane 1,1-diphosphonic acid (HEDP), aminotris methylene phosphonic acid (ATMP), diethylenetriamine pentamethylene phosphonic acid (DTPMP)), hydrocarboxylic, amino carboxylic acids (e.g. EDTA or DTPA) (see Figure 4.15 below) and compounds such as methylglycinediacetic acid (MGDA), L-glutamic acid N,N-diacetic acid (GLDA) or iminodisuccinic acid (IDS) [ 324, TWG 2020 ].

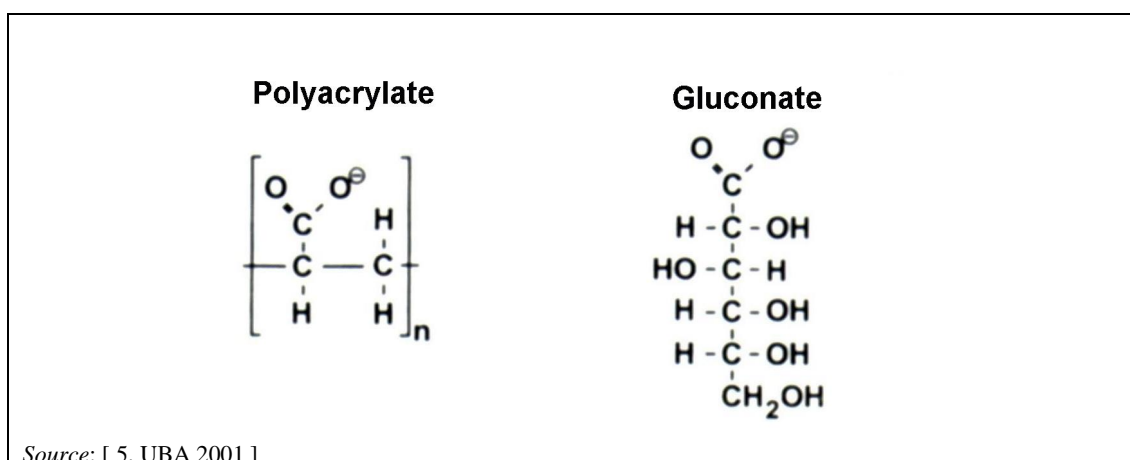


**Figure 4.15: Chemical structure of some N- or P-containing complexing agents**

The main concerns associated with the use of these substances arise from their N and P content, their often low biodegradability and bioeliminability, their toxicity and their ability to form stable complexes with metals, which may lead to remobilisation of heavy metals (see also Section 8.1.5).

Softening of fresh water, to remove the iron and the hardening alkaline-earth cations from the process water, and the techniques described in Section 4.4.7.2 are available options for minimising or avoiding the use of complexing agents in various applications (e.g. in hydrogen peroxide bleaching, rinsing after reactive dyeing of cotton).

When complexing agents are used, polycarboxylates or substituted polycarboxylic acids (e.g. polyacrylates and polyacrylate-maleic acid copolymerisates), hydroxy carboxylic acids (e.g. gluconates, citrates), some sugar-acrylic acid copolymers or polyaspartic acids are convenient alternatives to the conventional sequestering agents. None of these products contain N or P in their molecular structure (see Figure 4.16). In addition, the hydroxy carboxylic acids and sugar-acrylic acid copolymers are readily biodegradable.



**Figure 4.16: Chemical structure of some N- and P-free complexing agents**

Iminodi-succinic acid or salts are used for the finishing of keratine textile fibre material in oxidant-free treatment stages at pH values of 4 to 7.

The best complexing agent (in a technical, economical and ecological sense) is one that also achieves a good balance of ecological properties and effectiveness and has no detrimental effect on dyeing (demetallisation of dyes).

Effectiveness is measured as the capacity to complex alkaline-earth cations, the dispersing capacity and the capacity of stabilising hydrogen peroxide.

On the ecological side, the following factors are to be considered:

- biodegradability;
- bioeliminability;
- remobilisation of heavy metals;
- nitrogen content (eutrophication potential);
- phosphorus content (eutrophication potential).

A qualitative assessment of the ecological properties of most common classes of complexing agents is given in Table 4.18, while Table 4.19 gives an analysis of the aspects related to their effectiveness.

**Table 4.18: Qualitative assessment of commercially available complexing agents**

Ecological property	EDTA, DTPA	NTA	Poly-phosphate	Phosphonates	Poly-carboxylates	Hydroxy carboxylic acid	Sugar copolymers
Biodegradability	No	Yes	Inorganic	No	No	Yes	Yes
Bioeliminability	No	Yes	NI	Yes <sup>(1)</sup>	Yes	NI	NI
N-content	Yes	Yes	No	No	No	No	No
P-content	No	No	Yes	Yes	No	No	No
Remobilisation of heavy metals	Yes	No	No	No	No	No	No

(<sup>1</sup>) Under UV photocatalytic degradation is observed.  
 NB: NI: No information.  
 Source: [ 5, UBA 2001 ]

Regarding the use of phosphonates (e.g. DTPMP, HEDP). as substitutes, it is to be noted that the majority of phosphonates are not biodegradable, but bioeliminable (see Figure 4.17) [ 188, Rott et al. 2017 ].

OECD test	Analytical parameter	PBTC	HEDP	NTMP	EDTMP	DTPMP	Reference
302 B	COD	-	-	60-80 <sup>a</sup>	-	50	Held (1989)
	DOC	-	-	20 <sup>b</sup>	-	-	Bachus (2003)
	DOC	-	-	45 <sup>c</sup>	-	-	Bachus (2003)
	DOC	-	33	23	-	-	Steber and Wierich (1986, 1987)
	DOC	-	-	-	-	50	Cegarra et al. (1994)
	DOC	17	-	-	-	-	BADSR (1989)
	DOC	0	0	5	20	0	Reichert (1996)
	Primary substance	0	0	80	50	30	Reichert (1996)
302 A	DOC	<20	100	85	65	0	Horstmann and Grohmann (1988)
	<sup>14</sup> CO <sub>2</sub> /C	-	6.7	2.0	-	3.5	Saeger et al. (1978)
301 E	n.i.	-	-	90	-	-	Bachus (2003)
	DOC	-	-	No biodegradability	-	-	Horstmann and Grohmann (1988)
	<sup>14</sup> CO <sub>2</sub> /C	-	<3	20	-	-	Steber and Wierich (1986, 1987)
301 D	DOC	-	-	0	-	-	AAW (1984)
	BOD <sub>30</sub> /COD	0	-	-	-	-	BADSR (1976)
301 F	BOD <sub>30</sub> /COD	-	<10	<38	-	-	Steber and Wierich (1986, 1987)
	O <sub>2</sub> consumption	-	No consumption	-	-	-	Huber (1975)
301 B	O <sub>2</sub> consumption	n.c.	-	-	-	-	Metzner and Nägerl (1982)
	CO <sub>2</sub> evolution	-	<10	<10	-	-	Schöberl and Huber (1988)

OECD 302 B: Zahn-Wellens test, OECD 302 A: modified semi-continuous activated sludge test (SCAS test), OECD 301 D: closed bottle test, OECD 301 E: static modified OECD screening test, OECD 301 F: manometric respiration test (sapromat), OECD 301 B: carbon dioxide evolution test (modified Sturm test), n.i.: no information, n.c.: no consumption, COD: chemical oxygen demand, DOC: dissolved organic carbon, BOD<sub>30</sub>: biochemical oxygen demand after 30 days.  
<sup>a</sup> Use of technical solutions without specification of the phosphonate.  
<sup>b</sup> Pure mineralization.  
<sup>c</sup> 15% mineralization and 30% adsorption with a 20-fold sludge excess.

**Figure 4.17: Elimination of phosphonates in OECD tests (in %)**

Due to the very slow degradation and the small number of phosphonate-utilising species of microorganisms, it is thus assumed that phosphonates cannot be mineralised in conventional biological WWTPs, aerobically or anaerobically. Accordingly, phosphonates remain in adsorbed form in the sewage sludge in their original form and can only be completely oxidised ('mineralised') and thereby removed from the environment by combustion of the sewage sludge. Figure 4.18 shows the removal efficiencies of phosphonates in sludge adsorption [188, Rott et al. 2017].

Phosphonate (mg/L)	DS (g/L)	PBTC	HEDP	NTMP	EDTMP	DTPMP	Reference
Adsorption experiments with activated sludge:							
500	1.5	40 <sup>a</sup>	60 <sup>a</sup>	60 <sup>a</sup>	45 <sup>a</sup>	70 <sup>a</sup>	A
50	1.5	50 <sup>b</sup>	>90 <sup>a</sup>	>95 <sup>a</sup>	>90 <sup>a</sup>	>90 <sup>c</sup>	A
5.0–200	n.i.	40–50	–	–	–	–	B
0.7–21	2–3	–	>90 <sup>a</sup>	–	–	–	C
1.0–300	3.0	–	–	>90	–	–	D
1.1	1.0	–	–	80–100 <sup>d</sup>	–	–	E
1.1	1.0	–	–	40–60 <sup>e</sup>	–	–	E
Adsorption experiments with digested sludge:							
100	1.8	10 <sup>c</sup>	65 <sup>c</sup>	85 <sup>c</sup>	>95 <sup>c</sup>	80 <sup>c</sup>	A

A: Reichert (1996), B: Metzner and Nägerl (1982), C: Steber and Wierich (1986), D: Steber and Wierich (1987), E: Nowack (2002b), DS: dry substance, n.i.: no information.  
<sup>a</sup> After 1 day.  
<sup>b</sup> After 1 week.  
<sup>c</sup> After 1 h.  
<sup>d</sup> pH 3–5.  
<sup>e</sup> pH 6–9, in the presence of 0.5–2 mmol/L Ca<sup>2+</sup>; >60% removal rates.

**Figure 4.18: Removal efficiencies of phosphonates in sludge adsorption (in %)**

### Achieved environmental benefits

The substitution of conventional complexing agents with the products mentioned above has the following positive effects:

- reduced eutrophication in the receiving water;
- improved biodegradability of the final effluent;
- reduced risk of remobilisation of the heavy metals from sediments.

### Environmental performance and operational data

Complexing agents are applied in many different fields in textile chemistry. Recipes and application techniques are therefore process-specific. However, the use of the optimised products mentioned above does not imply major differences with respect to conventional complexing agents.

[ 5, UBA 2001 ]

Bioelimination and biodegradation rates for some commercial products that do not contain P and N in their molecular structure are:

- sugar-acrylic acid copolymer: readily biodegradable, (OECD 301F, mineralisation: 100 %; COD: 194 mg/g; BOD<sub>5</sub>: 40 mg/g);
- sugar acrylic acid copolymer: readily biodegradable (OECD 301C; COD: 149 mg/g);
- hydroxy carboxylic acid: bioeliminable (OECD 302B, elimination: 92 %; COD: 144 mg/g; BOD<sub>5</sub>: 51 mg/g);
- carboxylates: bioeliminable (OECD 302B, elimination > 90 %; COD: 280 mg/g; BOD<sub>5</sub>: 125 mg/g);
- modified polysaccharide: readily biodegradable (OECD 301E, biodegradability: 80 %; COD: 342 mg/g; BOD<sub>5</sub>: 134 mg/g).

NTA is biodegradable when treated in waste water treatment plants under nitrifying conditions (OECD 302B, elimination 98 % COD: 370 mg/g; BOD<sub>30</sub>: 270 mg/g – 'BASF, 2000'). Recent studies have shown that NTA plays a minor role, if any, in the remobilisation of heavy metals in aquatic sediments [185, Germany 2001]. Phosphonates are not biodegradable, but they are bioeliminable and they do not contribute to the remobilisation of heavy metals (see also Section 4.4.7.1).

The effectiveness of the various products in different processes has, however, to be considered when replacing conventional complexing agents with more environmentally friendly ones (see the table below).

**Table 4.19: Effectiveness of complexing agents**

Property	EDTA, DTPA	NTA	Poly-phosphate	Phosphonate	Poly-carboxylates	Hydroxy carboxylic acid	Sugar copolymers
Softening	+	+	+	++	+	0	+
Dispersing	-	-	0	+	+	-	+
Stabilisation of peroxide	+	-	-	++	0	-	+ (special products)
Demineralisation	++	+	0	++	0	0	0

NB: Effectiveness increases in the following order -, 0, +, ++.  
 Source: [ 5, UBA 2001 ]

### Cross-media effects

Taking as a reference the application of conventional complexing agents, there are no cross-media effects of concern. With polyacrylate-based complexing agents, the residual monomer content in the polymer should be taken into account (note that acrylates are also widely used in large volumes in other sectors as detergent builders, thus overloading the waste water treatment plants more significantly than textile effluents do).

### Technical considerations relevant to applicability

The complexing agents described in this section can be used in continuous and discontinuous processes.

Generally, there are no technical restrictions to the applicability of this technique.

### Economics

Costs for sugar-acrylic copolymers are about 30-50 % higher than using amino carboxylic acids like EDTA, DTPA or NTA because of the higher quantities needed (for the same effect) and higher costs [ 44, ÖKOPOL 2011 ].

### Driving force for implementation

The enforcement of regulations at national and European level, together with the PARCOM recommendations and the ecolabelling schemes, are the main driving forces.

### Example plants

N- and P-free complexing agents are applied in many plants worldwide. Consumption of polycarboxylates is significantly higher than for sugar-acrylic copolymers and hydrocarboxylic acids [ 5, UBA 2001 ].

Plant SE119 reported using saccharides instead of EDTA and UK127 uses NTA-free complexing products.

### Reference literature

[ 5, UBA 2001 ], [ 32, Bettens L. 1999 ], [ 35, RICARDO 2019 ], [ 44, ÖKOPOL 2011 ], [ 112, COM 2014 ], [ 189, Lanxess 2019 ]



### 4.1.6.9.3 Substitution of mineral-oil-based antifoaming agents

#### Description

Mineral-oil-based antifoaming agents used in wet processes (e.g. pretreatment, dyeing and finishing) are substituted by biodegradable substances, e.g. antifoaming agents based on synthetic ester oil.

#### Technical description

Excessive foaming causes uneven dyeing of yarn or fabric. There is a trend towards higher consumption of antifoaming agents because of the growing preference for high-speed and high-temperature processing, reduction in water usage and the use of continuous processes. Due to the increasing usage of dosing systems, more pumps and feeding pipes are used, which in turn increases the foam formation by shear forces and high flow rates. Antifoaming agents are commonly applied in pretreatment, dyeing (especially when dyeing in jet machines) and finishing operations, but also in printing pastes.

Antifoaming agents (also called 'defoamers') are used in the processes where liquors, formulations or chemicals are handled under high pressure or high velocities. An example of this is dyeing with jet machines, where agitation is severe. Furthermore, foam formation for the most part does not occur in the bath, but during the spraying of liquor on the fabric with air, through the nozzles in the head of the jet machines. If foam formation is not prevented in this step, the resulting dyeing will be uneven.

Products that are insoluble in water and have a low surface tension are suitable for providing an antifoaming effect. They displace foam-producing surfactants from the air/water boundary layer. Nevertheless, antifoaming agents contribute to the organic load of the final effluent. Their consumption should therefore be reduced in the first place. Possible measures in this respect are:

- using bath-less air-jets, where the liquor is not agitated by fabric rotation (see Section 4.5.1.7.2.1);
- reusing treated baths (see Section 4.5.1.8).

However, these techniques are not always applicable and cannot completely avoid the use of antifoaming agents. Therefore, the selection of auxiliaries with an improved ecological performance is important. Antifoaming agents are often based on mineral oils (hydrocarbons). The presence of PAH contaminants must also be taken into account when poorly refined oils are present in the formulation.

Environmentally improved products are free of mineral oils and are characterised by high bioelimination rates.

Sometimes active ingredients of alternative products are silicones (e.g. copolymers of silicone like polydimethylsiloxane (PDMS) with glycols), high-molecular-weight alcohols, fluorine derivatives, and mixtures of these components [44, ÖKOPOL 2011].

#### Achieved environmental benefits

Thanks to the use of mineral-oil-free antifoaming agents, the hydrocarbon load in the effluent, which is often limited in national or regional regulations, is minimised. Furthermore, these alternative antifoaming agents have a lower specific COD and higher bioelimination rate than hydrocarbons. For example, a product based on triglycerides of fatty acid and fatty alcohol ethoxylates (COD: 1 245 mg/l; BOD<sub>5</sub>: 840 mg/l) has a degree of bioeliminability higher than 90 % (determined in the modified Zahn-Wellens Test, according to OECD 302 B Test method or EN 29888, respectively) [5, UBA 2001].

For emissions to air, due to the substitution of mineral-oil-based compounds, it is possible to reduce VOC emissions during high-temperature processes (caused by the carry-over of antifoaming agents on the fabric after wet operations).

### **Environmental performance and operational data**

The mineral-oil-free antifoaming agents can be used in a way similar to conventional products.

The treatment of the effluents containing silicones requires additional abiotic pretreatment (i.e. prior to biological treatment).

### **Cross-media effects**

- Antifoaming agents contribute to the organic load of the final effluent; therefore, their consumption should be reduced.
- Effluents containing silicone oils (silicones) above certain concentrations may hinder the efficiency of biological waste water treatment (e.g. lowering the transfer/diffusion of oxygen into the activated sludge).
- Odour emissions (e.g. from using tributylphosphates and high-molecular-weight alcohols).

### **Technical considerations relevant to applicability**

There are no particular limitations concerning the application of mineral-oil-free formulations. However, the effectiveness of the various alternative products has to be borne in mind [ 5, UBA 2001 ].

### **Economics**

The cost of mineral-oil-free products is comparable to the cost of conventional ones [ 5, UBA 2001 ].

### **Driving force for implementation**

Minimisation of hydrocarbons in the effluent is the main reason for substituting mineral-oil-containing antifoaming agents.

### **Example plants**

Many plants in Europe. There are various suppliers for antifoaming agents free of mineral oils.

Plants IT064, IT 068, IT069, IT077 and IT091 report using silicone antifoaming agents instead of antifoaming agents with mineral oils.

### **Reference literature**

[ 5, UBA 2001 ], [ 44, ÖKOPOL 2011 ]

## **4.1.7 Prevention and reduction of emissions to water**

This section contains techniques used in the textiles sector to prevent, reduce or control the emissions to water.

This section only covers those techniques most relevant to the textiles sector. These techniques have already been described and analysed in the CWW BREF [ 77, COM 2016 ]. For this reason, it is not intended in this section to provide a complete analysis of each of the different techniques. Instead, only a short description of the techniques is given as well as examples of plants from the data collection where these techniques are applied.

### 4.1.7.1 Waste water management and treatment strategy

#### Description

Implementation of an integrated strategy for waste water management and treatment that includes an appropriate combination of the techniques given below with the following order of priority:

- process-integrated techniques (see Section 4.1.3, and others related to optimisation and low-water use equipment in Chapter 4);
- techniques to recover and reuse process liquors (see sections related to resource efficiency in Chapter 4);
- separate collection of waste water streams and pastes (e.g. printing and coating) containing high loads of pollutants that cannot be adequately treated by biological treatment; these waste water streams and pastes are either pretreated (see Section 4.1.7.2) or handled as waste (see Section 4.1.9.2);
- (final) waste water treatment techniques.

#### Technical description

The strategy for waste water management and treatment is based on the information provided by the inventory of waste water streams (see Section 4.1.1.2). The effluents from textile processes are characterised and the pollutants present in them are evaluated.

Based on this information, the appropriate treatment options are selected. Usually the goal is to find a cost-effective combination of treatment methods offering an optimum environmental performance. Special pretreatment may be needed to remove the compounds that are insufficiently abated during biological treatment (e.g. toxic compounds, poorly or non-biodegradable and/or non-bioeliminable organic compounds, organic compounds that are present in high concentrations, or metals) and to protect the biological waste water treatment plant (e.g. against inhibitory or toxic compounds).

An appropriate choice normally requires treatability and/or pilot studies. Many 'local' factors, varying from site to site, may influence the selection, e.g. plant location, size and layout of the processes, type of discharge (direct, indirect), quality of the receiving water body, limitations and constraints on an installation imposed by other legislation.

Source reduction options and/or special pretreatment considered for hazardous and poorly or non-biodegradable and/or non-bioeliminable substances present in the effluents (waste water streams) will be selected by considering the options for:

- reduction at the source (e.g. by use of process-integrated techniques, choice of raw materials, auxiliary chemicals, etc.);
- collection (drainage) system (e.g. suitable for segregation and separate pretreatment of different tributary waste water streams);
- treatment methods (e.g. suited to abate a specific pollutant or generic, suitable for abatement of many pollutants).

Examples of effluents from textile treatments which may need to be pretreated include the following [ 108, Derden et al. 2010 ]:

- Washing water from yarns and/or textiles when preparing dyeing processes.
- Rinsing water from washed, dyed and/or printed textile materials.
- Residues of (concentrated) process baths (e.g. residual baths and residual pastes from dyeing, printing and finishing, responsible for 1-2 % of the total waste water volume). These may also be handled as hazardous liquid wastes; see Section 4.1.7.2).
- Exhausted process baths in discontinuous process (dyeing).

- Rinsing water from cleaning the process baths (e.g. rinsing water from dye baths, responsible for 1-2 % of the total waste water volume).

Descriptions of individual treatment techniques are given in Section 4.1.7.3 and examples of typical configurations or combinations of these techniques used for waste water treatment in textile plants are given in Section 4.1.7.4.

#### Achieved environmental benefits

- Reduction of the waste water volume.
- Reduced pollutant loads sent to the waste water treatment plant.
- Reduction of emissions to water.

#### Environmental performance and operational data

Physico-chemical treatments are commonly used before biological treatment in textile plants (see Section 3.4 for textile plants from the data collection) to ensure appropriate abatement levels.

In the case of indirect discharge, it is ensured that the level of emission of the remaining pollutants in the effluent leaving the textile plant does not have a negative impact on the downstream WWTP or on the efficiency of this downstream installation at treating those remaining pollutants.

The following table summarises data on the applicability/efficiency of certain waste water treatment techniques to remove certain pollutants of concern from textile effluents.

**Table 4.20: Overview of applicable waste water purification techniques for the removal of NP/NPE, PAHs, brominated flame retardants, Sb<sub>2</sub>O<sub>3</sub>, and PFAS**

Waste water treatment technique	Parameter/pollutant				
	NP/NPE	PAHs	Brominated flame retardants	Sb <sub>2</sub> O <sub>3</sub>	PFAS (e.g. PFOA)
Anaerobic treatment	ND	ND	ND	0	ND
Biological (active sludge) treatment	0	x	(x) <sup>(1)</sup>	0	0
Active carbon dosage in biological treatment (PACT)	(x)	x	ND	0	x
Membrane bioreactor (MBR)	ND	(x)	x	(x) <sup>(2)</sup>	ND
Chemical precipitation (with coagulation-flocculation)	ND	x	x	x	ND
Microfiltration, ultrafiltration	ND	x	(x)	x	ND
Nanofiltration, reverse osmosis	(x)	x	(x)	x	ND
Sand filtration	ND	x	x	x	ND
Adsorption (e.g. active carbon filtration)	X	x	x	0	ND
Chemical oxidation	(x)	x	ND	0	ND
Ozonisation	ND	(x)	ND	0	ND
Evaporation	ND	ND	ND	0	ND
Incineration	ND	ND	ND	ND <sup>(3)</sup>	ND

NB:  
x: Parameter (group) removed.  
(x): Parameter (group) possibly / potentially partly removed.  
0: Parameter (group) not removed.  
ND: No data.  
<sup>(1)</sup> Adsorbed on sludge.  
<sup>(2)</sup> Increased concentration and toxicity of Sb<sub>2</sub>O<sub>3</sub> on the UF membrane prevent MBR from functioning.  
<sup>(3)</sup> Would need to be removed from waste gases due to high-temperature volatility and toxicity of Sb<sub>2</sub>O<sub>3</sub>.  
Source: [ 108, Derden et al. 2010 ], DE 408 and CZ\_B 36 comments from [ 324, TWG 2020 ]

The typical environmental performance of the plants using an appropriate combination of waste water treatment techniques is given in Table 5.3 and Table 5.4.

### **Cross-media effects**

See the CWW BREF [ 77, COM 2016 ].

### **Technical considerations relevant to applicability**

See the CWW BREF [ 77, COM 2016 ].

### **Economics**

See the CWW BREF [ 77, COM 2016 ].

### **Driving force for implementation**

- Environmental legislation (reducing and effectively abating the pollutant load).
- Economics (savings due to lower discharge fees).

### **Example plants**

According to the data collection, some plants using various combinations of process-integrated and waste water treatment techniques with a performance within the concentration ranges of Table 4.20 are: for direct discharge BE009, DE025, DE034, IT076 , IT082, IT097 and PT098 and for indirect discharge (i.e. without the COD/TOC, TN, TSS and TP which are abated in the WWTP downstream) IT084 and PT115. More details on the performance and combinations of WWT used in these plants are available in Section 4.1.7.5.

### **Reference literature**

[ 77, COM 2016 ], [ 93, Austrian EPA 2016 ], [ 108, Derden et al. 2010 ]

#### 4.1.7.2 Pretreatment of waste waters containing poorly biodegradable compounds

##### Description

Waste water streams and pastes (e.g. printing and coating) containing high loads of pollutants that cannot be treated adequately by biological treatment (e.g. toxic and/or poorly or non-biodegradable and/or bioeliminable compounds in spent process baths and rinsing waters) are separately collected and pretreated before discharging.

##### Technical description

Such waste water streams and pastes include:

- spent dyeing, coating or finishing padding liquors from continuous and/or cold semi-continuous treatments;
- desizing liquors;
- spent printing and coating pastes.

The pretreatment is carried out as part of an integrated strategy for waste water management and treatment (see Section 4.1.7.1) and is generally necessary to:

- protect the biological waste water treatment against inhibitory or toxic compounds;
- remove compounds that are insufficiently abated during biological waste water treatment (e.g. toxic compounds, poorly biodegradable organic compounds, organic compounds that are present in high loads, adsorbable organic halogenated compounds, oils, or metals);
- remove compounds that could otherwise be stripped to air from the collection system or during biological waste water treatment (e.g. sulphide);
- remove compounds that have other negative effects (e.g. corrosion of equipment; unwanted reaction with other substances; contamination of waste water sludge).

The above-mentioned compounds to be removed include organophosphorus and brominated flame retardants, PFAS, phthalates and chromium-(VI)-containing compounds.

Spent padding dyeing liquors, spent printing pastes and spent padding finishing liquors with high pollutant loads are collected separately and pretreated or disposed of as waste. While in the case of residual printing pastes this is easy to achieve, separating residual padding liquors from dyeing and finishing requires additional efforts as the residual padding liquor has to be pumped from the padder to an intermediate bulk container (IBC) or another type of appropriate container. This can either be done automatically by controlling valves or manually by pumping residues out of the padder and the padding liquor preparation tank.

The pretreatment of these waste water streams is generally carried out as close as possible to the source in order to avoid dilution. The pretreatment techniques used depend on the pollutants targeted and may include adsorption, filtration, precipitation, chemical oxidation or chemical reduction (see Section 4.1.7.3).

The various treatment options are indicated in Table 4.21.

**Table 4.21: Technical options for treatment and disposal of spent padding liquors and printing pastes**

Type of residue	Technical options for treatment and/or disposal
Residual dyeing padding liquor	The residual dyeing padding liquor is oxidised (at least to fragments which are biodegradable) by means of a wet oxidation process (see Section 4.1.7.4.1). This is possible for all relevant groups of dyestuffs such as reactive, direct, vat, sulphur and disperse dyestuffs.
	In the case of reactive dyestuffs, the dyestuffs can be precipitated/flocculated by means of an organic cationic flocculant. The sludge formed is separated by dewatering (e.g. in a chamber filter press) and disposed of by incineration.
	In the case of sulphur dyestuffs in their oxidised form as well as in case of vat dyestuffs, the dyestuffs can be separated by precipitation/flocculation by means of a combination of inorganic precipitating agents (iron or aluminium salts) and a polyelectrolyte. The sludge is separated by dewatering (e.g. in a chamber filter press) and disposed of by incineration.
Residual printing paste	In the case of pigment printing paste, inorganic precipitating agents can be used. The sludge formed is separated by dewatering (e.g. in a chamber filter press) and disposed of by incineration. The residual pigment printing paste may also be incinerated directly.
	Residual paste containing reactive dyestuffs can be fed to an anaerobic digester as most (but not all) reactive dyestuffs are azo dyestuffs, which can be cleaved in anaerobic conditions. However, the resulting aromatic amines are non-biodegradable and may therefore ultimately end up in the environment. (See Section 4.1.7.4.5.)
Residual finishing padding liquor	There are many different chemical compounds used and each has its individual chemical properties. In general, it is best to directly incinerate the residual final finishing padding liquors unless the compounds exclusively consist of readily biodegradable compounds such as fatty acid esters applied as softeners.
<i>Source:</i> [ 142, HAZBREF 2019 ]	

**Achieved environmental benefits**

- Reduction of the load of non-biodegradable compounds in the disposed-of waste water.
- Reduced emissions to water.

**Environmental performance and operational data**

Figure 4.19 and Figure 4.20 show two examples of collection of spent padding liquor.



Source: [ 142, HAZBREF 2019 ]

**Figure 4.19: Example 1 - Padder (left) and IBC (right) equipped with a pump and pipes to manually empty the padder**



Source: [ 142, HAZBREF 2019 ]

**Figure 4.20: Example 2 - Automated system for the collection of spent padding liquor (left) and IBC receiving the spent padding liquor (right)**

The waste water load is limited and the operation of the waste water treatment plant is not disrupted if rinsing waters from process baths containing brominated flame retardants (e.g. DBDPE),  $Sb_2O_3$  and PFOA are collected and reused. Indirectly, this may also reduce the use of products (e.g. chemicals) needed to operate the WWTP.

When those separate waste water streams are treated before being indirectly discharged or treated on site and directly discharged, the bioeliminability/biodegradability of the waste water streams and pastes before they are sent to biological treatment is at least:

- 80 % after 7 days (for adapted sludge), when determined according to standard EN ISO 9888 (as required in some Member States, e.g. DE, BE), [ 44, ÖKOPOL 2011 ], [ 108, Derden et al. 2010 ],; or
- 70% after 28 days when determined according to standard EN ISO 7827 (as required in other Member States, e.g. SE; see Section 3.4.21).



See Section 3.4.21 for more information about bioeliminability/biodegradability measurements on the segregated textile effluents.

### **Cross-media effects**

The technique leads to a higher volume of hazardous waste.

As the spent padding liquors and printing pastes are incinerated (possibly after precipitation/flocculation), this generates emissions to air. However, in general the benefits of technical measures for treatment and disposal of these waste streams should outweigh the cross-media effects and environmental effects of not implementing the technique.

It is nevertheless important that the quantity of residues is minimised prior to disposal [ 142, HAZBREF 2019 ].

### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

### **Economics**

For a padder, the investment costs for an automated system for the separate collection of residual padding liquors (valves, tank below the padder from where the residual padding liquor is pumped to an IBC) are in the range of EUR 20 000-30 000. Investment costs for the manually operated separation system (flexible pipes and a flexible pump) are around EUR 5 000. Operating costs are negligible.

The costs for the treatment of residual printing pastes and residual padding liquors depend on the techniques applied and may be in the range of a few euro per tonne (in the case of anaerobic treatment) to EUR 300-500/t in the case of direct incineration [ 142, HAZBREF 2019 ].

### **Driving force for implementation**

Environmental legislation.

### **Example plants**

Cilander AG, Herisau, Switzerland (direct incineration of residual padding liquors).  
Textilveredlung an der Wiese (Plant DE047) and Lauffenmühle, both located in Lörrach, Germany (anaerobic co-fermentation of residual dyeing padding liquors in the municipal anaerobic digester).

Plants from the data collection:

Plants DE024, DE030, DE039, DE40 and FR133 handle spent dye baths as waste.

Plants DE025, DE032 and DE049 handle spent printing pastes as waste.

Plants DE022, DE024, DE025, DE030, DE032, DE046, DE047, DE049, FR135 and SE119 handle finishing baths as waste.

Plants which have indirect releases and pretreat their discharges: DE051, AT006 and DE022 (see Section 4.1.7.5.2, for example Table 4.34).

### **Reference literature**

[ 44, ÖKOPOL 2011 ], [ 108, Derden et al. 2010 ], [ 142, HAZBREF 2019 ]

## **4.1.7.3 Individual waste water treatment techniques**

This section introduces the individual waste water treatment techniques as described in [ 77, COM 2016 ]. It is not exhaustive; instead, only a short descriptions relevant for the textile sector and examples of plants from the data collection applying these techniques are given.

#### 4.1.7.3.1 Equalisation / Buffer storage

##### **Description**

Balancing of flows and pollutant loads by using tanks, basins or other management techniques.

##### **Technical description**

Equalisation and buffering facilities ensure reasonably constant conditions of certain parameters, especially pH, hydraulic load (or flow rate) and contaminant loads/concentrations for the effective operation of downstream waste water treatment plants (WWTPs).

##### **Achieved environmental benefits**

This technique enables downstream treatment techniques to operate at the optimum efficiency. It makes use of mixing effects to offset extremes of important WWTP operating parameters (e.g. temperature, pH).

##### **Environmental performance and operational data**

The retention times of equalisation tanks in the textile sector are typically 12-24 hours; in adverse climatic or other local conditions the retention times may be even longer.

##### **Cross-media effects**

Excessive retention of waste water in the equalisation tank may lead to odour emissions.

##### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to applicability of this technique.

##### **Economics**

The cost of constructing and operating an equalisation tank needs to be compared with the savings associated with the smooth operation of the downstream treatment techniques and compliance with environmental standards.

Equalisation / buffer storage may reduce waste water discharge costs (fees, taxes) in case of indirect (sewer) discharge due to lower daily inflow of effluent. The discharged flow can be spread to 7 days instead of 5 (working) days per week.

##### **Driving force for implementation**

- Compliance with environmental standards.
- Protection and proper operation of downstream treatment techniques.

##### **Example plants**

Equalisation tanks are widely used in the textile sector [ 50, TWG 2019 ]

##### **Reference literature**

[ 50, TWG 2019 ], [ 77, COM 2016 ]

#### 4.1.7.3.2 Neutralisation

##### **Description**

Neutralisation is the process by which the pH of the incoming waste water is adjusted to the neutral pH level (approximately 7) by the addition of chemicals. Sodium hydroxide (NaOH) or calcium hydroxide (Ca(OH)<sub>2</sub>) is generally used to increase the pH, whereas sulphuric acid (H<sub>2</sub>SO<sub>4</sub>), hydrochloric acid (HCl) or carbon dioxide (CO<sub>2</sub>) is used to decrease the pH. The precipitation of some substances may occur during neutralisation.

##### **Achieved environmental benefits**

Neutralisation avoids the effects of strongly acidic or alkaline waste waters, e.g. corrosion or lowering of the efficiency of biological treatment downstream.

### **Environmental performance and operational data**

The neutralisation of process waste water requires a tank of sufficient volume to assure the appropriate hydraulic retention time. The mixing capacity should be sufficient to keep the tank completely mixed.

The CO<sub>2</sub> from flue-gases is often introduced to neutralise waste waters with a high pH in the textile sector.

### **Cross-media effects**

Increased concentration of salts in the waste waters (as a result of chemical neutralisation) and the solid waste generated (e.g. precipitate) may need to be disposed of.

### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to applicability of this technique.

### **Economics**

No information provided.

### **Driving force**

Compliance with legal requirements to limit pollution to a receiving water body.

### **Example plants**

Neutralisation is widely used in the textile sector [ 50, TWG 2019 ].

Plants from the data collection [ 50, TWG 2019 ] using CO<sub>2</sub> as a neutralising agent: IT059, PT099, PT109 and SE118.

### **Reference literature**

[ 50, TWG 2019 ], [ 77, COM 2016 ]

#### **4.1.7.3.3 Insoluble contaminants / mechanical separation**

##### **4.1.7.3.3.1 Screening**

### **Description**

Screening is the mechanical separation/removal of insoluble contaminants such as fibre and fluff from textile effluent by coarse or fine screens.

### **Technical description**

Screening devices are classified based on the size of the material they remove (the screenings).

Fine screens (with openings as small as 100-200 µm) typically used for textile effluents are fixed parabolic (curved), rotary drum and rotary disk. Fine screens can be either movable or fixed in a vertical, inclined or horizontal position and must be cleaned by rakes, teeth or brushes.

### **Achieved environmental benefits**

Reduced suspended solids and BOD/COD emission levels.

### **Environmental performance and operational data**

The use of fine screens produces effects similar to primary sludge removal in primary sedimentation. Fine screens are capable of removing 20-35 % of suspended solids and BOD<sub>5</sub>.

The screens must be mechanically cleaned; the cleaning of oils and grease from fine screens may cause some difficulties.

Typical pollutants targeted are gross solids, suspended solids, oil/grease.

**Example plants**

Plants from the data collection using screening: BE009, DE030, IT084, PT099, PT110, PT114, PT115 and UK129 [ 50, TWG 2019 ].

**Reference literature**

[ 50, TWG 2019 ], [ 77, COM 2016 ]

## 4.1.7.3.3.2 Grit separation

**Description**

[ 77, COM 2016 ]

Grit separation is the removal of sand and gravel from rainwater. Grit chambers are part of the WWTP and are usually situated immediately downstream of the screen installed as protection for downstream techniques (equipment) from coarse and fibrous material.

**Example plants**

Plants from the data collection using grit separation before other waste water treatment techniques: BE008, CZ015, DE032, FR134, FR135, FR136, IT084, PT110 and UK129 [ 50, TWG 2019 ].

**Reference literature**

[ 50, TWG 2019 ], [ 77, COM 2016 ]

## 4.1.7.3.3.3 Hydrocyclone

**Description**

[ 77, COM 2016 ]

A hydrocyclone is used to separate suspended solids with a diameter of 5  $\mu\text{m}$  to 1 000  $\mu\text{m}$  that are likely to sink and resistant to shearing forces. It separates the particles by using the centrifugal force generated as the liquid enters the cyclone tangentially at high speeds and is accelerated by the conical middle section. This creates a liquid vortex in the cyclone. The smaller the diameter of the cyclone, the greater the centrifugal force that will be generated as the liquid is forced to turn sharply. Light components leave the hydrocyclone through the top, while heavier components are collected at the bottom.

**Example plants**

According to the data collection [ 50, TWG 2019 ], Plant UK129 is using a hydrocyclone.

**Reference literature**

[ 50, TWG 2019 ], [ 77, COM 2016 ]

## 4.1.7.3.3.4 Oil-water separation

**Description**

[ 77, COM 2016 ]

An oil-water separator is a piece of plumbing equipment designed to intercept most greases (by gravitation) before they enter the biological waste water treatment.

The typical oil-water separators are: the American Petroleum Institute (API) separator (an open rectangular basin and a flight scraper), the parallel plate interceptor (PPI) (equipped with plates parallel to the current to enlarge the active surface area and oil skimming device) and the corrugated plate interceptor (CPI) (equipped with corrugated plate packs placed countercurrently and an oil skimming device). The skimmer device has to be regularly maintained. Skimmed oil is handled as waste.

### Example plants

Plants from the data collection: DE022, PT099, PT109, SE120 and UK129 [[50, TWG 2019](#)].

### Reference literature

[[50, TWG 2019](#)], [[77, COM 2016](#)]

#### 4.1.7.3.3.5 Coagulation and flocculation

##### Description

[[77, COM 2016](#)]

Coagulation and flocculation occur in successive steps which are intended to overcome the forces stabilising the suspended particles, allowing particle collision and growth of floc.

Coagulation is the first step. It aims at destabilising the particles' charge by neutralising their electrical surface charge. This is carried out by adding coagulants with charges opposite to those of the suspended solids to the waste water. This allows the particles to stick together into slightly larger particles.

Flocculation is a gentle mixing stage which aims at increasing the particle size. Collisions of microfloc particles cause them to bond to produce larger floc. This occurs in the presence of inorganic (formed by the coagulant) or added organic polymers. Contact times for flocculation range from 15 or 20 minutes to an hour or more.

Once the floc has reached the optimum size and strength, the waste water can be brought to sedimentation (see Section 4.1.7.3.3.6).

Typical pollutants targeted are suspended solids and particulate-bound non-biodegradable or inhibitory pollutants (e.g. metals in dyestuffs).

### Example plants

Plants from the data collection using coagulation and flocculation are BE009, BE011, CZ020, DE025, DE032, DE051, IT075, IT076, IT084, PT110, PT114, UK124, UK128 and UK129 [[50, TWG 2019](#)].

### Reference literature

[[50, TWG 2019](#)], [[77, COM 2016](#)]

#### 4.1.7.3.3.6 Sedimentation

##### Description

[[77, COM 2016](#)]

Sedimentation, or clarification, is the separation of suspended particles and floating material by gravitational settling.

The settled solids are removed as sludge from the bottom, whereas floated material is skimmed from the water surface. When the particles cannot be separated by simple gravitational means, e.g. when they are too small and their density is too close to that of water or they form colloids, special chemicals are added to cause the solids to settle, such as aluminium sulphate (alum); ferric sulphate; ferric chloride; lime; polyaluminium chloride; polyaluminium sulphate; cationic organic polymers.

Typical pollutants targeted are suspended solids and particulate-bound metals or non-biodegradable or inhibitory pollutants.

**Example plants**

Plants from the data collection using sedimentation: BE009, CZ015, CZ020, DE025, DE032, IT067, IT075, IT076, IT082, IT084, IT092, IT096, IT097, PT098, PT110, PT111, PT114 and SE118 [ 50, TWG 2019 ].

**Reference literature**

[ 50, TWG 2019 ], [ 77, COM 2016 ]

## 4.1.7.3.3.7 Flotation

**Description**

[ 77, COM 2016 ]

Flotation is a process in which solid or liquid particles or particulates are separated from the waste water phase by attaching to fine gas bubbles, usually air. The buoyant particles accumulate at the water surface and are collected with skimmers. Flocculant additives, such as aluminium and ferric salts, activated silica and various organic polymers, are commonly used to support the flotation process. Their function, besides coagulation and flocculation, is to create a surface or a structure able to absorb or entrap the gas bubbles.

There are three methods of flotation: vacuum flotation, induced gas flotation (IGF) / induced air flotation (IAF) and dissolved gas flotation (DGF) / dissolved air flotation (DAF).

Typical pollutants targeted are suspended solids and particulate-bound non-biodegradable or inhibitory pollutants.

**Example plants**

Plants from the data collection using flotation: AT006, BE009, IT076, UK124 and UK129 [ 50, TWG 2019 ].

**Reference literature**

[ 50, TWG 2019 ], [ 77, COM 2016 ]

## 4.1.7.3.3.8 (Sand) filtration

**Description**

[ 77, COM 2016 ]

Filtration is the separation of solids from waste water effluents passing through a porous medium. In the case of sand filtration, this medium is sand (or a similar granular medium). This technique is rarely used as a stand-alone treatment and is generally combined with the sedimentation of solids (see Section 4.1.7.3.3.6) or flotation (see Section 4.1.7.3.3.7).

Typical pollutants targeted are suspended solids and particulate-bound non-biodegradable or inhibitory pollutants.

**Example plants**

Plants from the data collection using sand filtration: BE007, BE009, BE011, DE032, PT098, PT108, PT111 and PT114 [ 50, TWG 2019 ].

**Reference literature**

[ 50, TWG 2019 ], [ 77, COM 2016 ]

### 4.1.7.3.3.9 Microfiltration and ultrafiltration

#### Description

[ 77, COM 2016 ]

Microfiltration (MF) and ultrafiltration (UF) are membrane processes that retain certain substances contained in waste waters on one side of the membrane. The liquid that permeates through the membrane is referred to as the permeate. The liquid that is retained is referred to as the concentrate. The driving force of the process is the pressure difference across the membrane. Both are special and elaborate filtration techniques using 'pore-type' membranes which operate like sieves. The solvent and particles of molecular size can pass through the pores, whereas suspended particles, colloidal particles, bacteria, viruses, and even larger macromolecules are held back.

#### Example plants

According to the data collection [ 50, TWG 2019 ], Plant BE009 uses microfiltration and Plant UK129 uses ultrafiltration.

#### Reference literature

[ 50, TWG 2019 ], [ 77, COM 2016 ]

### 4.1.7.3.4 Soluble non-biodegradable or inhibitory contaminants / physico-chemical treatment

#### 4.1.7.3.4.1 Chemical oxidation

#### Description

[ 77, COM 2016 ]

Chemical oxidation is the conversion of pollutants by chemical oxidising agents other than oxygen/air or bacteria into similar but less harmful or hazardous compounds and/or to short-chained and more easily degradable or biodegradable organic components. Chemical oxidation is used for the treatment of selected segregated waste water streams containing non-biodegradable/bioeliminable substances (i.e. with high COD loads) which might disturb the biological process in a downstream biological WWTP, or which have properties which are too harmful to allow them to be released into an ordinary sewer.

Chemical oxidising agents include:

- chlorine;
- sodium or calcium hypochlorite;
- chlorine dioxide;
- ozone (with or without UV light);
- hydrogen peroxide;
- hydroxyl radicals generated by hydrogen peroxide (known as the Advanced Oxidation Process) in combination with:
  - ferrous salts (Fenton's agent); see [ 77, COM 2016 ] for a detailed description of an oxidation technique involving hydrogen peroxide and a ferrous ion catalyst;
  - ozone;
  - UV light;
  - pressure;
  - temperature.

A special type of chemical oxidation is wet oxidation (WO). It is the reaction of oxygen in the aqueous phase at a high pressure and temperature, and is used to increase the solubility of oxygen in water.

Alkaline hydrolysis is widely practised by hank dyers on the first yarn scour bowl spent liquors. The first bowl of the yarn scour is where most of the dirt and spinning oils are washed away from yarn and if the yarn has been pretreated with permethrin (which sometimes occurs in Europe and Türkiye) then this can also be partially washed into the liquor. As source control of permethrin-containing raw materials is very hard to achieve in practice (e.g. by better control of the supply chain or extensive testing of every incoming hank), most operators chose to use alkaline hydrolysis to control and prevent emissions of permethrin [ 190, Seaman S. 2019 ].

The alkaline treatment process is as follows: set up an alkaline treatment bath for the first bowl liquor which comprises 4 g/litre of sodium hydroxide dissolved into the liquor followed by a minimum 2-hour boil (at 98-100 °C) in a sealed stainless steel tank. This destroys any residual permethrin in the liquor which should then be mixed back into the predominantly acidic main effluent to give the final effluent balanced pH with minimal or zero permethrin (well below any relevant discharge consent limit) [ 190, Seaman S. 2019 ].

Typical pollutants targeted are oxidisable dissolved non-biodegradable or inhibitory pollutants (e.g. optical brighteners and azo dyestuffs, and sulphide).

#### **Example plants**

According to the data collection [ 50, TWG 2019 ], Plants BE009, BE011 and UK123 use chemical oxidation. In particular, at Plant UK123, boiling of effluent with caustic soda is used to destroy the permethrin.

#### **Reference literature**

[ 50, TWG 2019 ], [ 77, COM 2016 ], [ 190, Seaman S. 2019 ]

#### 4.1.7.3.4.2 Chemical reduction

##### **Description**

[ 77, COM 2016 ]

Chemical reduction is the conversion of pollutants by chemical reducing agents into similar but less harmful or hazardous compounds. Common chemical reducing agents include sulphur dioxide; sodium hydrogen sulphite/metabisulphite; ferrous sulphate; sodium sulphide and sodium hydrogen sulphide; urea or amidosulphonic acid (at low pH).

These chemicals are brought into contact with the waste species under appropriate pH and concentration conditions. Chemical reduction normally results in products that can be treated more easily in downstream treatment facilities such as a chemical precipitation unit.

Typical pollutants targeted are reducible dissolved non-biodegradable or inhibitory pollutants (e.g. hexavalent chromium (Cr(VI))).

##### **Example plants**

According to the data collection [ 50, TWG 2019 ], Plant BE009 uses chemical reduction.

##### **Reference literature**

[ 50, TWG 2019 ], [ 77, COM 2016 ]

#### 4.1.7.3.4.3 Phosphorus removal by chemical precipitation

##### **Description**

[ 77, COM 2016 ]

The chemical precipitation of phosphorus is accomplished by the addition of the salts of multivalent metal ions that form precipitates of sparingly soluble phosphates. The multivalent metal ions most commonly used are calcium (Ca<sup>2+</sup>), aluminium (Al<sup>3+</sup>) and iron (Fe<sup>3+</sup>).



Chemical addition occurs in primary clarifiers (when present) or in the secondary process, in the aeration basin or upstream of the secondary clarifiers, or in tertiary clarifiers or other treatment processes. Feeding chemicals to the primary clarifiers usually requires less chemical than feeding to the secondary or tertiary process. Feeding chemicals at both the primary and secondary clarifiers results in less chemical use than feeding to the secondary process alone, allowing some phosphorus to be removed in the primary clarifiers and polishing to occur in the secondary process. The resulting chemical precipitate will settle to the tank bottom where it can be removed as a sludge.

Apart from phosphorus, other typical pollutants targeted by this technique are precipitable dissolved non-biodegradable or inhibitory pollutants (e.g. metals in dyestuffs).

### **Example plants**

According to the data collection [[50, TWG 2019](#)], Plant BE010 uses chemical precipitation by  $\text{FeCl}_3$  for phosphorus removal.

### **Reference literature**

[[50, TWG 2019](#)], [[77, COM 2016](#)]

#### 4.1.7.3.4.4 Nanofiltration (NF) and reverse osmosis (RO)

##### **Description**

[[77, COM 2016](#)]

A very specific membrane filtration process is the permeation of a liquid through a membrane, to be segregated into permeate that passes through the membrane and concentrate that is retained. The driving force of this process is the pressure difference across the membrane.

Nanofiltration (NF) and reverse osmosis (RO) membranes can hold back all particles down to the size of organic molecules and even ions. Provided that the feed is particle-free, these membranes are mainly used when complete recycling of permeate and/or concentrate is desired.

A large proportion (e.g. more than 90 %) of waste waters from the textile industry can be recycled by using this technique, thereby improving the overall life cycle impact of textiles [[11, Beton et al. 2014](#)].

### **Example plants**

According to the data collection [[50, TWG 2019](#)], Plant BE011 uses nanofiltration and Plants BE009 and IT092 reverse osmosis.

### **Reference literature**

[[50, TWG 2019](#)], [[77, COM 2016](#)]

#### 4.1.7.3.4.5 Adsorption

##### **Description**

[[77, COM 2016](#)]

Adsorption is the transfer of soluble substances (solutes) from the waste water phase to the surface of solid, highly porous particles (the adsorbent). The adsorbent has a finite capacity for each compound to be removed. When this capacity is exhausted, the adsorbent is 'spent' and has to be replaced by fresh material. The spent adsorbent either has to be regenerated or incinerated.

Potential adsorbents for adsorptive waste water purification are activated carbon, lignite coke, aluminium oxide and adsorber resins.

Typical pollutants targeted are adsorbable dissolved non-biodegradable or inhibitory pollutants (e.g. AOX in dyestuffs, organophosphorus flame retardants).

#### **Example plants**

According to the data collection [ 50, TWG 2019 ], Plants IT082 and PT114 use adsorption.

#### **Reference literature**

[ 50, TWG 2019 ], [ 77, COM 2016 ]

#### 4.1.7.3.4.6 Evaporation

##### **Description**

[ 77, COM 2016 ]

Evaporation of waste water is a distillation process where water is the volatile substance, leaving the concentrate as bottom residue to be handled (e.g. recycled or disposed of). The aim of this operation is to reduce the volume of waste water or to concentrate mother liquors. The volatile steam is collected in a condenser and the condensed water is, if necessary after subsequent treatment, recycled.

There are many types of evaporators: natural circulation evaporators; short-tube vertical evaporators; basket-type evaporators; falling film evaporators; agitated thin film evaporators.

Typical pollutants targeted are soluble contaminants (e.g. salts).

#### **Example plants**

According to the data collection [ 50, TWG 2019 ], Plants CZ016, DE022 and FR133 use evaporation. Plant FR 133 indicates that the evaporators on its site are 'long tube vertical evaporators (falling film)'.

#### **Reference literature**

[ 50, TWG 2019 ], [ 77, COM 2016 ]

#### 4.1.7.3.4.7 Distillation/rectification

##### **Description**

[ 77, COM 2016 ], [ 96, Pinasseau et al. 2018 ]

Distillation or rectification is the separation of waste water from its contaminants by transferring them into the vapour phase. The enriched vapour phase is condensed afterwards.

Waste water distillation or rectification has a limited application. It is often used as a process-integrated measure to recover starting material and/or product from mother liquors. As a waste water treatment operation, it is applied for the following reasons:

- to recover solvent after waste water extraction;
- to recover solvent from waste water, e.g. separation of alcohols from methyl cellulose production;
- to treat oil emulsions;
- as a pretreatment to remove the main contaminant content from the waste water stream in order to recover it and afterwards discharge the waste water to further downstream treatment;
- to recover organics from scrubbing liquors.

#### **Example plants**

According to the data collection [ 50, TWG 2019 ], Plant BE013 uses distillation for ammonia recovery from mercerisation with ammonia.

### Reference literature

[ 50, TWG 2019 ], [ 77, COM 2016 ], [ 96, Pinasseau et al. 2018 ]

#### 4.1.7.3.4.8 Stripping

##### Description

[ 77, COM 2016 ], [ 96, Pinasseau et al. 2018 ]

Waste water stripping is an operation in which waste water is brought into contact with a high flow of a gas current in order to transfer volatile pollutants from the water phase to the gas phase.

Stripping is applied to separate volatile contaminants from water, e.g.:

- chlorinated hydrocarbons, such as trichloroethene, perchloroethene, trichloromethane, dichloroethane, trichloroethane;
- ammonia and hydrogen sulphide; their volatility is strongly dependent on temperature and pH, thus pH control is essential (pH > 9.5 with ammonia, pH 2-3 with hydrogen sulphide);
- organic solvents, petrol, diesel fuel, lower aromatics, phenol, mercaptans.

##### Example plants

According to the data collection [ 50, TWG 2019 ], Plants CZ016 and IT074 use stripping for treatment of effluents from dry cleaning.

### Reference literature

[ 50, TWG 2019 ], [ 77, COM 2016 ], [ 96, Pinasseau et al. 2018 ]

#### 4.1.7.3.5 Soluble biodegradable contaminants / biological treatment

##### Description

Biological treatment processes have repeatedly been shown to be effective for the elimination of biodegradable organic compounds, nitrogen compounds and phosphorus. In contrast to other treatment techniques, biological treatment makes use of microorganisms that can react to the manifold boundary conditions of their existence and are therefore able to adjust optimally to the compounds that are to be degraded (adaptation).

##### 4.1.7.3.5.1 Aerobic treatment

##### Description

Aerobic treatment is the biological oxidation of dissolved organic substances using the metabolism of microorganisms. In the presence of dissolved oxygen – injected as air or pure oxygen – the organic components are converted (mineralised) into carbon dioxide, water or other metabolites and biomass (i.e. the activated sludge).

Aerobic waste water treatment generally represents the final biological step. It offers the advantage of a high rate of sludge growth, which not only enables the handling of the various components of toxic waste water but also provides a COD removal efficiency that is normally superior to that of anaerobic treatment.

Aerobic biological treatment techniques commonly used in the textile sector are the activated sludge process with sedimentation and recirculation or with a membrane bioreactor. Less commonly used aerobic biological treatment techniques are the trickling or percolating filter process, the expanded-bed process and the fixed-bed biofilter process.

The complete mix process is operated with several variants, depending on the amount of waste water, the availability of space, the requirements for emissions to air, etc. Examples of variants are:

- the oxidant agent: air or pure oxygen, the latter having the advantage of fewer stripping effects and a reduced odorous release, because less gas is blown through the waste water, and of faster and more effective biological reaction;
- the aeration chamber: a more or less flat tank or a tower, the latter taking into account the higher degradation efficiency because of smaller air bubbles ascending in a high column of waste water and thus considerably increasing the air/waste water mass transfer;
- the clarification step: sedimentation or membrane filtration (membrane bioreactor, see below), the latter requiring less space, the former probably supported by a final flotation stage.

In general, the complete mix activated sludge process is applicable to all biodegradable waste water streams, be it as a high-load pretreatment of tributary streams or as the main part of a central WWTP.

### Example plants

Plants from the data collection using the activated sludge process or a membrane bioreactor are listed in Sections 4.1.7.3.5.1.1 and 4.1.7.3.5.1.2, respectively.

Plant UK124 uses an aerobic biofilter treatment.

#### 4.1.7.3.5.1.1 Activated sludge system with a low sludge loading

### Description

The increase of the biodegradability of poorly biodegradable substances in the effluents by the use of activated sludge systems with a low sludge loading (i.e. food to microorganisms (F/M) ratio).

### Technical description

[ 77, COM 2016 ], [ 96, Pinasseau et al. 2018 ]

In the activated sludge process, the microorganisms are maintained as suspension in the waste water and the whole mixture is mechanically aerated. The activated sludge mixture is sent to a separation facility from which the sludge is recycled to the aeration tank. The separation facility can be a sedimentation or settling tank (see Section 4.1.7.3.3.6); an air flotation facility (see Section 4.1.7.3.3.7); or a MF or UF membrane (see Section 4.1.7.3.3.9; more common for a membrane bioreactor).

The complete mix process is operated with several variants, depending on the amount of waste water, the availability of space, the requirements for emissions to air, etc. Operational variations concern the following:

- the oxidant agent: air or pure oxygen, the latter having the advantage of fewer stripping effects and a reduced odorous release, because less gas is blown through the waste water, and of faster and more effective biological reaction;
- the aeration chamber: a more or less flat tank or a tower, the latter taking into account the higher degradation efficiency because of smaller air bubbles ascending in a high column of waste water and thus considerably increasing the air/waste water mass transfer;
- the clarification step: sedimentation or membrane filtration (membrane bioreactor, see next technique below), the former probably supported by a final flotation stage and the latter requiring much less space.

In general, the complete mix activated sludge process is applicable to all biodegradable waste water streams, be it as a high-load pretreatment of tributary streams or as the main part of a central WWTP.

In activated sludge systems, easily biodegradable compounds are mineralised, whereas poorly biodegradable compounds need special conditions, such as low sludge loading also referred to as 'food to microorganisms' ratio (F/M) (i.e.  $< 0.15$  expressed in kg BOD<sub>5</sub> per kg of MLSS (mixed liquor suspended solids) per day, or even  $< 0.05$  for mineralisation below optimum temperatures) in the aeration tank, adaptation (when the compounds are discharged very regularly) and a temperature higher than 15 °C (which is normally the case for textile waste water).

For example, poorly biodegradable chemicals, such as nitrilotriacetate (NTA), m-nitrobenzene sulphonate and its corresponding amine, polyvinyl alcohol (PVA) and phosphonates are degraded and mineralised in such conditions [5, UBA 2001].

The low F/M ratio conditions in an activated sludge treatment can be achieved not only by increasing the hydraulic retention time but also for example by:

- removing the food from the activated sludge, (e.g. see the technique described in Section 4.1.7.4.1);
- reducing the load by pretreatment of selected concentrated streams (see Section 4.1.7.3.4.1);
- increasing the biomass and increasing the sludge concentration in the activated sludge system (e.g. bio-membrane reactor, bio-flotation); this design variant makes it possible to increase the sludge concentration in the activation basin from normal values around 3 g/l to 6-10 g/l.

Today, many activated sludge systems meet these system conditions (see the examples in Section 4.1.7.3.5.4), which also enables almost complete nitrification. In contrast, effluents containing non-biodegradable compounds should be pretreated at the source (see Section 4.1.7.3.4.1).

In this example, the plant mainly finishes cotton fabric, including pretreatment (desizing, scouring, bleaching), dyeing (cold pad-batch and exhaust dyeing), printing (mainly with pigment printing pastes) and finishing. About 5 % of the treated waste water is recycled for washing and cleaning operations (floor washing, cleaning of printing equipment such as pumps, pipes, squeegees and screens). The retention time in the activated sludge system is very high. Decolourisation is achieved through reductive cleavage of azo groups of dyestuffs by an iron(II)-salt. Figure 4.21 shows the layout of the waste water treatment plant.

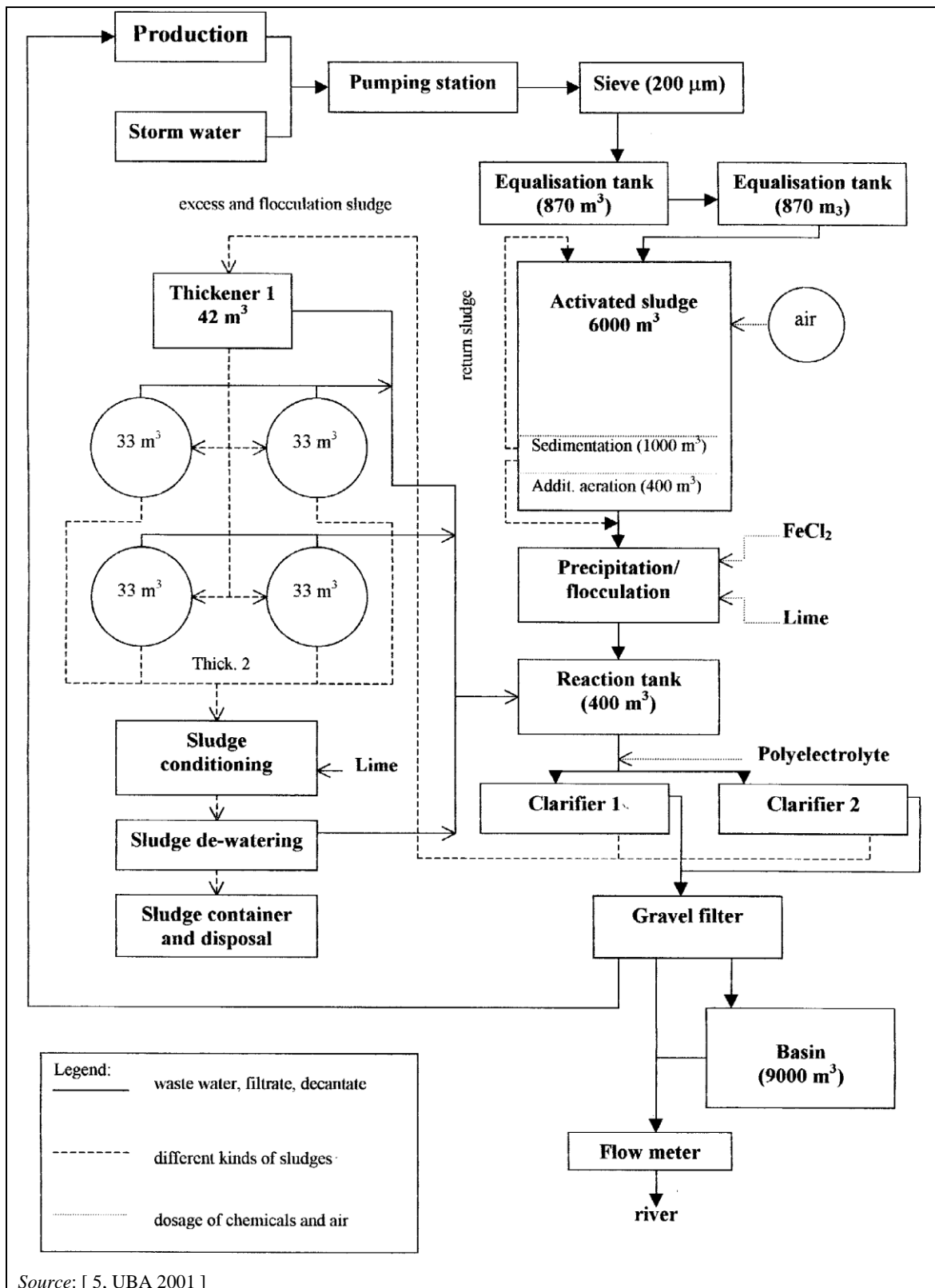


Figure 4.21: Treatment of waste water from one textile finishing mill with 5 % water recycling

#### Achieved environmental benefits

Reduction of emissions of poorly biodegradable pollutants to water.

#### Environmental performance and operational data

The table below shows the influent and effluent values and F/M ratios of six treatment plants. In some cases of combined treatment, textile waste water and municipal waste water are

discharged to the plant via different sewer lines. For these plants, the influent values are presented separately. Where textile and municipal waste water are already mixed in the sewer, the influent values are given under the heading 'influent (textile ww)'.

F/M ratios below 0.15 kg BOD<sub>5</sub>/kg MLSS·d enable almost complete nitrification (residual ammonia concentrations lower than 0.5 mg/l).

Plant 4 has a F/M ratio of 0.2, resulting in higher ammonia concentrations and a lower BOD<sub>5</sub> removal efficiency.

**Table 4.22: Characteristics of waste water parameters (input and output) for six treatment plants**

Aspect/component	unit	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6
		Annual average values for 2000	Annual average values for 1999	Annual average values for 2000	Annual average values for 1998	Annual average values for 2000	Annual average values for 2000
Total flow	(m <sup>3</sup> /d)	8377±1431	47770±24500	6690	25000	2070	38750±16790
Municipal ww flow	(m <sup>3</sup> /d)	4562±2018	NI	4865	NI	NI	NI
Textile ww flow	(m <sup>3</sup> /d)	3685±1431	NI	1825	NI	NI	NI
Food to microorganisms ratio (F/M)	kg BOD <sub>5</sub> /(kg MLSS x d)	0.1	0.1	1.1 and 0.05	0.2	0.1	0.1
<b>Influent (municipal ww)</b>							
pH		8±0.4	NI	8.1	NI	NI	NI
COD	(mg O <sub>2</sub> /l)	443±200	NI	336	NI	NI	278±86
BOD <sub>5</sub>	(mg O <sub>2</sub> /l)	114±50	NI	144	NI	NI	138±49
NH <sub>4</sub> -N	(mg N/l)	30±14	NI	31	NI	NI	12.5±4.8
N-org	(mg N/l)	18±7	NI	15.9	NI	NI	n.a.
P total	(mg P/l)	6±2	NI	6.2	NI	NI	3.7±1.2
<b>Influent (textile ww)</b>							
pH		9.2±0.8	8.4±0.4	8.7	n.a.	9 - 9.5	NI
COD	(mg O <sub>2</sub> /l)	791±281	349±129	967	950	1200 - 1500	NI
BOD <sub>5</sub>	(mg O <sub>2</sub> /l)	157±57	145±49	336	400	400 - 500	NI
NH <sub>4</sub> -N	(mg N/l)	2.6±2.0	26±8	5.6	n.a.	11 - 25	NI
N-org	(mg N/l)	19.5±7.0	6±3	9.5	50	30 - 40	NI
P total	(mg P/l)	3.8±1.2	5±2	2.2	n.a.	10 - 25	NI
PVA	(mg/l)	28 - 138	n.a.	53	n.a.	n.a.	NI
<b>Effluent</b>							
pH		7.2±0.2	8.2±0.3	7.4	n.a.	7.8 - 8.6	6.8 - 7.5
COD	(mg O <sub>2</sub> /l)	59±16	46±23	54	60 - 110	90 - 110	11±1.3
BOD <sub>5</sub>	(mg O <sub>2</sub> /l)	3±2	4.4±3.8	3	10 - 40	<5	3±0.7
NH <sub>4</sub> -N	(mg N/l)	0.1±0.2	0.2±0.9	0.12	5 - 15	0.3 - 1.6	0.4±0.3
NO <sub>3</sub> -N	(mg N/l)	2.9±1.9	3.6±1.1	5.4	1 - 10	<2	6.8±1.0
N-org	(mg N/l)	1.7±0.5	n.a.	n.a.	8 - 15	5 - 10	n.a.
P total	(mg P/l)	0.2±0.2	0.9±0.7	0.6	n.a.	1 - 2.5	0.15±0.015
AOX	(mg Cl/l)	0.06 - 0.08	0.06 - 0.1	n.a.	n.a.	<0.04 - 0.15	n.a.
PVA	(mg/l)	0.6 - 7.8	n.a.	3	n.a.	n.a.	n.a.
SAC (435 nm)	(1/m)	8.3±3	n.a.	2.4	0.02	5 - 7	0.42±0.08
SAC (525 nm)	(1/m)	6.8±2.9	n.a.	0.9	n.a.	1.5 - 5	0.31±0.08
SAC (620 nm)	(1/m)	2.9±1.4	n.a.	0.9	n.a.	1 - 3.5	0.18±0.05
<b>Removal efficiencies</b>							
COD	(%)	90±4	84.4	89	91	92.5	96
BOD <sub>5</sub>	(%)	97±2	96.2	98	93.5	99	98
Nitrogen	(%)	88±6	88	78	77	82	47
Phosphorus	(%)	96±3	79	88	n.a.	90	96
NB:							
NI: No information; n.a.: Not applicable.							
Source: [ 5, UBA 2001 ]							

**Cross-media effects**

None identified.

**Technical considerations relevant to applicability**

Activated sludge systems with low F/M ratios are applicable to both new and existing plants for all kinds of textile waste water. They can also be applied to municipal waste water treatment plants with low and high percentages of textile waste water as well as to purely industrial plants in which the waste water of one or more finishing mills is treated.

**Economics**

When low F/M ratio conditions are achieved by increasing the retention time, this means bigger aeration tanks, resulting in higher investment costs. Broadly speaking, the size of activated sludge systems is inversely proportional to the F/M ratio. Precise data on investment costs are not available.

**Driving force for implementation**

Environmental legislation.

**Example plants**

Plants 1 to 6 [ 5, UBA 2001 ].

Plants from the data collection using the activated sludge process: BE007, BE010, BE011, BE014, CZ019, CZ020, DE032, DE034, IT067, IT075, IT076, IT082, IT092, IT096 and IT097 [ 50, TWG 2019 ].

**Reference literature**

[ 5, UBA 2001 ], [ 50, TWG 2019 ], [ 77, COM 2016 ], [ 96, Pinasseau et al. 2018 ]

*4.1.7.3.5.1.2 Membrane bioreactor***Description**

[ 77, COM 2016 ], [ 96, Pinasseau et al. 2018 ]

The membrane bioreactor process, as a combination of biological activated sludge treatment and membrane separation, is a biological treatment process used for urban and industrial waste water (see the CWW BREF [ 77, COM 2016 ] for more details on membrane bioreactors). The different variations of this process are:

- an external recirculation loop between the activated sludge tank and the membrane module;
- immersion of the membrane module in the aerated activated sludge tank, where the effluent is filtered through the hollow fibre membrane, and the biomass remains in the tank; this variant consumes less energy and results in a more compact plant.

These variants together with the conventional activated sludge process are shown in Figure 4.22.



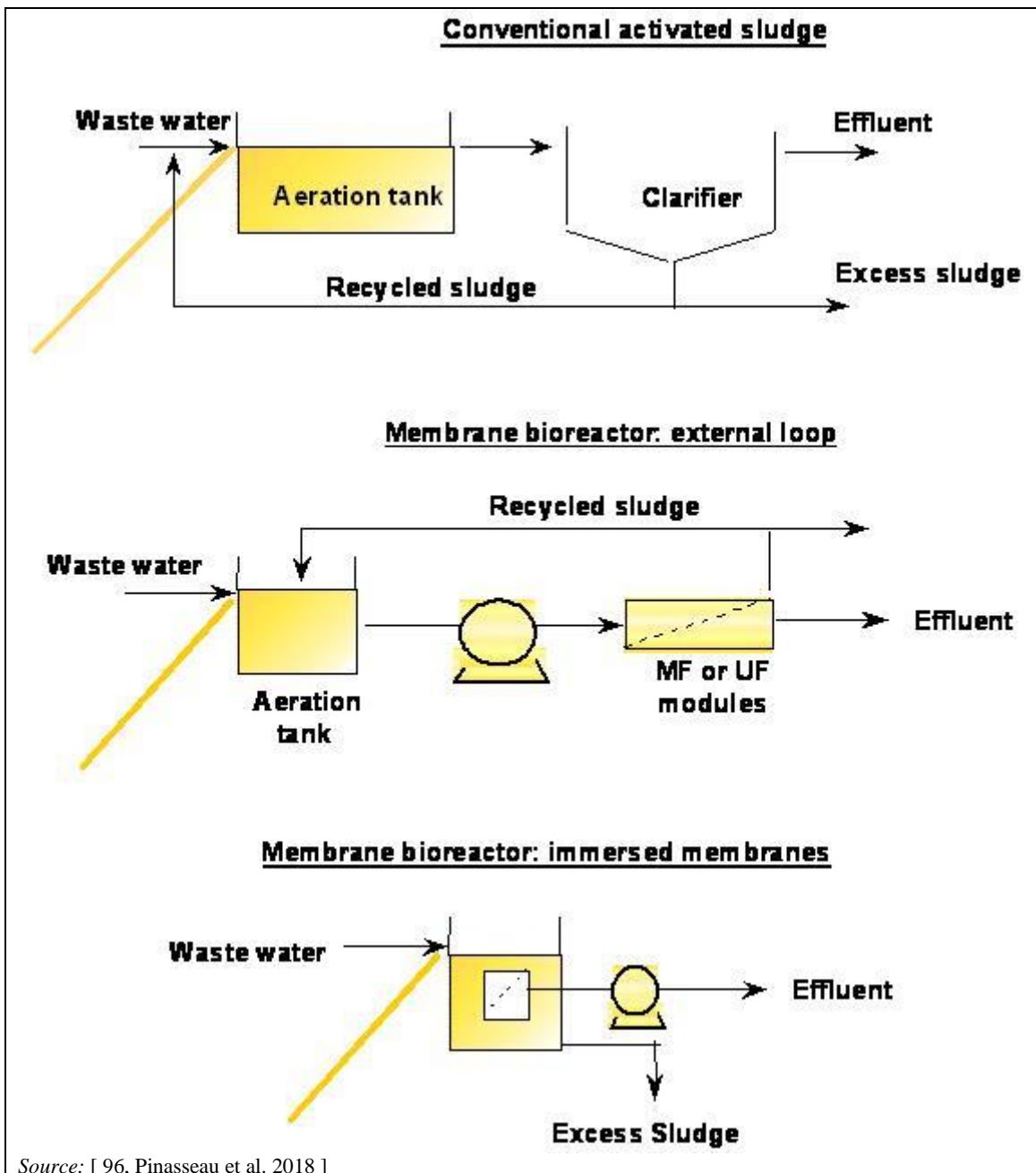


Figure 4.22: Variants of membrane bioreactor, compared with a conventional activated sludge process

**Example plants**

According to the data collection [ 50, TWG 2019 ], Plant IT076 uses a membrane bioreactor (IT075 plans to invest in one in 2020).

**Reference literature**

[ 50, TWG 2019 ], [ 77, COM 2016 ], [ 96, Pinasseau et al. 2018 ]

## 4.1.7.3.5.2 Anaerobic treatment

**Description**

[ 77, COM 2016 ], [ 96, Pinasseau et al. 2018 ]

Anaerobic waste water treatment converts the organic content of waste water, with the help of microorganisms and without entry of air, to a variety of products such as methane, carbon dioxide, and sulphide.

Anaerobic waste water treatment is essentially used only as a pretreatment for waste water which is characterised by a high organic load ( $> 2$  g/l) and a more or less constant quality. It is used mostly in sectors with effluents with consistently high BOD loads.

The biogas consists of about 70 % methane and 30 % carbon dioxide and other gases such as hydrogen and hydrogen sulphide, the quantity of which depends on the sulphate content in the waste water. The process is carried out in an airtight stirred tank reactor, and the microorganisms are retained in the tank as biomass (sludge).

There are several reactor types available. The most commonly used are:

- anaerobic contact reactor;
- upflow anaerobic sludge blanket (UASB);
- fixed-bed reactor;
- expanded-bed reactor.

Anaerobic bioreactors are used to treat textile effluents with a high COD concentration and dyestuff pollutants (high colour).

Typical pollutants targeted are biodegradable organic compounds (e.g. azo dyestuffs, printing pastes).

**Environmental performance and operational data**

An anaerobic bioreactor combined with an activated sludge system (with tilted plate separators) removes nearly 90 % of COD as well as most of the colour and toxicity [ 191, TenCate 2015 ], [ 192, Paques 2019 ].

**Example plants**

According to the data collection [ 50, TWG 2019 ], Plants CZ019 and FR134 use anaerobic treatment.

**Reference literature**

[ 50, TWG 2019 ], [ 77, COM 2016 ], [ 96, Pinasseau et al. 2018 ]

## 4.1.7.3.5.3 Nitrogen removal by nitrification/denitrification

**Description**

[ 77, COM 2016 ], [ 96, Pinasseau et al. 2018 ]

Nitrogen, or more precisely organic nitrogen compounds (e.g. urea, ammonium), is removed by a special biological treatment that consists of two steps:

- Aerobic nitrification, where special microorganisms oxidise ammonium ( $\text{NH}_4^+$ ) to the intermediate nitrite ( $\text{NO}_2^-$ ) which is further converted to nitrate ( $\text{NO}_3^-$ ). Ammonium can also be oxidised to nitrite without further conversion to nitrate.
- Anoxic denitrification, where microorganisms convert nitrate into nitrogen gas.

Nitrification may not be applicable in the case of high chloride concentrations (i.e. around 10 g/l) and when the reduction of the chloride concentration prior to nitrification would not be justified by the environmental benefits. Nitrification is not applicable when the temperature of the waste water is low (e.g. below 12 °C).

### Example plants

Plants from the data collection using nitrification/denitrification: BE007, BE010, BE011, BE014, CZ019, CZ020, DE032, DE034, IT067, IT075, IT076, IT082, IT092, IT096 and IT097 [ 50, TWG 2019 ].

### Reference literature

[ 50, TWG 2019 ], [ 77, COM 2016 ], [ 96, Pinasseau et al. 2018 ]

#### 4.1.7.3.5.4 Combinations of biological waste water treatment techniques

Recent developments of process variants and combinations are based on detailed knowledge and control of microbiological, hydraulic and aeration conditions (biotic and abiotic), which significantly increase the efficiency of microorganisms' activity. The processes that may be used for textile effluent treatment are as follows:

- Simultaneous nitrification/denitrification (also called biological double-efficiency process) is possible due to the control of the dissolved oxygen concentration at a very low level (at an average of 0.3 mg/l), and the formation of an oxygen concentration gradient across the flocs of bacteria. The nitrification occurs at the surface of the activated sludge flocs (aerobic zones) and denitrification occurs within the flocs (anoxic zones). A high sludge concentration with a low food to microorganisms (F/M) ratio, results in smaller sludge flocs that maintain just sufficient aerobic conditions. The process can work at a carbon to nitrogen (C/N) ratio as low as 0.17. Such conditions are achieved in a single basin (treatment tank) [ 193, US EPA 2013 ], [ 194, BDP Envirotech 2016 ], [ 195, BDP Envirotech 2016 ].
- Multistage treatment is based on the establishment of the food chain of biota (from microorganisms to worms and insects) in different compartments of the reactor where different compounds of the effluent are degraded. Typically the reactor has 8-12 compartments with different conditions – aerobic (for nitrification) or anoxic (for denitrification). Due to the establishment of a food chain, the amounts of sludge are significantly reduced [ 196, US EPA 2013 ].

The most commonly used combinations of biological waste water treatment techniques used in the textile sector are presented below.

#### 4.1.7.4 Combinations and variations of waste water treatment techniques in the textiles industry

The waste water treatment techniques used to achieve ambitious environmental performance of textile finishing plants are presented in [ 52, Schönberger H. 2018 ], [ 197, ZDHC 2016 ], [ 198, ZDHC 2019 ]. An extensive overview study and measurement campaign was conducted in France to study the emissions of pollutants from the textile treatment sector including the waste water treatments effective in its reduction and abatement [ 199, FR Ministry of Ecology, Sustainable Development and Energy 2016 ].

##### 4.1.7.4.1 Adsorption and advanced oxidation treatment integrated with activated sludge treatment

###### Description

Adsorption and advanced oxidation treatment are integrated with activated sludge treatment to degrade or destroy the non-biodegradable compounds in textile waste waters.

###### Technical description

After biological treatment, e.g. treatment in activated sludge systems under low food to microorganism (F/M) ratio conditions (Section 4.1.7.3.5.1.1), effluents containing non-biodegradable compounds need additional treatments to remove or destroy these substances.

The performance of the activated sludge treatment can be complemented by integrating adsorption on powdered activated carbon (PAC) and advanced oxidation treatment of the sludge produced by adsorption.

Powdered activated carbon is added to the aerobic aerator together with iron, which is used as a coagulant to precipitate phosphate and increase the binding of dyes into the sludge. Activated carbon and bacteria are maintained in aerobic conditions, thus allowing simultaneous biodegradation, adsorption and coagulation.

The excess sludge (a mixture of spent powdered carbon, iron and biomass) generated in the aerobic aerator is treated (regenerated) by means of advanced oxidation: either hydrothermal treatment (wet oxidation) or oxidation with hydrogen peroxide at low temperature (below 130 °C) which is referred to as ‘catalytic active carbon wet peroxidation’.

Wet oxidation is a liquid-phase reaction in water using dissolved oxygen (or air) to oxidise soluble and suspended oxidisable contaminants in the aqueous environment. When air is used as the source of oxygen, the process is referred to as ‘Wet Air Oxidation’ (WAO). The oxidation reaction is carried out at moderate temperatures of 150-315 °C and at pressures from 10 bar to 207 bar. The process destroys the large molecules in waste water, converting them predominantly to carbon dioxide, water and short-chain organic acids, which are highly biodegradable and more suitable for biological treatment. This regeneration process provides continual reuse of the activated carbon and ensures high levels of waste treatment [ 200, Zimpro 2019 ].

Advanced oxidation using hydrogen peroxide destroys concentrated or adsorbed substances by creating the conditions for the Fenton reaction ( $\text{H}_2\text{O}_2$ ,  $\text{Fe}^{2+}$  at pH 3). The principle of this process is described in [ 77, COM 2016 ]. Both the reactivated carbon and the iron are recycled back to the aerobic system.

###### Achieved environmental benefits

Reduction of emissions of poorly and non-biodegradable pollutants to water.

###### Environmental performance and operational data

The pretreatment techniques described improve the performance of the activated sludge treatment.

The addition of the adsorbent (activated carbon) and coagulant can be done at any point where the utilisation is most effective (cost, performance) and they do not necessarily need to be added directly in the aerobic aerator. This is because the countercurrent flow from coagulation, adsorption and filtration has the effect of returning to the biological system the adsorbent and coagulant containing the substances removed from the water.

Reactivation of powdered carbon using hydrogen peroxide allows the reuse of carbon and iron. The technique is most interesting for pretreating hot concentrates and for reactivating sludges from biological, physical and coagulation processes (somewhat comparable with chemical oxidation described in Section 4.1.7.3.4.1, but simpler because there is no need to inject oxygen gas).

The main advantages of these treatments being integrated with the biological step over sequential tertiary treatments are:

- the production of excess sludge in biological treatment is reduced (by recirculation through chemical oxidation treatment);
- substances that are potentially hazardous (non-biodegradable, accumulatable, toxic) are preferentially removed and destroyed;
- the activated sludge system is better protected against shock loading, and, as the adsorbed material is degraded, the risk of displacement of dyes and other adsorbed substances is much lower than with post-adsorption (e.g. granular activated carbon);
- the excess solids produced are dense and retain the remaining substances, which can therefore be sent to easier dewatering (anaerobic) and incineration;
- mineralisation of the organic pollutants is improved;
- energy use in aeration is lower.

With PAC treatments, good filtration is very important in order to efficiently separate the sludge from the treated effluent. The following additional equipment is needed:

- dosing systems for powdered carbon and iron sulphate;
- dosing system for peroxide;
- microfiltration;
- reactor for reactivation of concentrated streams.

Consumption of powdered activated carbon is less than 100 g/m<sup>3</sup> of waste water when reactivation of the activated carbon is carried out.

Hydrogen peroxide is consumed in stoichiometric amounts to transform the concentrated substances into bioeliminable substances (under conditions of optimal pH and temperature).

Iron is added as iron sulphate. It is introduced as a coagulant but it also serves as a catalyst, nutrient and precipitant for sulphides and phosphates.

### **Cross-media effects**

The chemical oxidation treatment requires electricity and chemicals.

### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

The technique is applicable to existing and new installations where a biological treatment is available and where solids are fully retained in the clarification system. A microfilter is to be added when there is a risk that solids could escape with the effluent.

**Economics**

Investment and operational costs for additional treatments could be offset in the long term by savings in sludge treatment and energy costs and due to the increased efficiency of biological treatment.

**Driving forces for implementation**

Environmental legislation.

**Example plants**

Different PAC processes to treat dyestuff-containing effluents are in place worldwide.

**Reference literature**

[ 77, COM 2016 ], [ 200, Zimpro 2019 ]

**4.1.7.4.2 Waste water treatment by precipitation, coagulation and flocculation****Description**

A combination of precipitation, coagulation and flocculation is used to degrade or destroy the non-biodegradable compounds in textile waste waters.

**Technical description**

Dissolved heavy metal compounds (e.g. dyestuffs) and other non-biodegradable substances (e.g. organic thickeners, binders, fixation agents from pigment pastes) are removed from textile waste waters by a combination of precipitation, flocculation and coagulation. These processes can take place simultaneously in the same step either before or after biological treatment.

For precipitation, aluminium and iron sulphate are used. Although at high concentrations (> 500 mg/l) sulphates become aggressive against concrete, the use of sulphates is preferred to chlorides. Sulphates are easier to remove from water than chlorides. Moreover, the use of sulphates avoids the introduction of chlorides in the waste water and in the sludge to be incinerated [ 22, TWG 2002 ].

Iron sulphate is equally effective for the removal of COD and can also be considered as a coagulant (e.g. it is particularly effective for removing acrylates and other substances from pigment printing waste water). The introduction of iron has advantages (it is responsible for the activation of redox processes, it can be recycled, etc.), but it forms coloured complexes that remain in the solution, giving it a yellowish or brownish tint [ 22, TWG 2002 ].

The precipitate is separated from the aqueous phase by sedimentation, dissolved air flotation, flocculation, coagulation or filtration (e.g. micro- or ultrafiltration). Precipitation, flocculation and/or coagulation agents are specifically selected in order to maximise COD and colour removal, and to minimise sludge formation. In most cases, the best performance is obtained with a combination of aluminium sulphate (precipitation), cationic organic flocculant and very low amounts of an anionic polyelectrolyte (also used for flocculation).

Membrane filtration techniques (e.g. micro-, ultra-, nanofiltration) can be used to separate the precipitate from the waste water.

For more detailed descriptions of coagulation and flocculation, see Section 4.1.7.3.3.5 and for filtration, see Sections 4.1.7.3.3.9 and 4.1.7.3.4.4

**Achieved environmental benefits**

Reduction of emissions of non-biodegradable substances like heavy metals, COD and colour (dyes and pigments) to water.

### **Environmental performance and operational data**

Before precipitation, flocculation and coagulation, the textile waste water is equalised. However, the equalisation time can be shorter (about 12 hours) than with biological treatment. Fibres are removed by a sieve.

The dosage of precipitation agent and flocculants (e.g. for a mixed textile effluent with a COD of around 1 000 mg/l) is about:

- aluminium sulphate: 400-600 mg/l;
- cationic organic flocculant: 50-200 mg/l;
- anionic polyelectrolyte: 1-2 mg/l.

Typically, COD removal is only about 40-50 %. When the effluent has a high content of water-insoluble compounds (e.g. in waste water from pigment printing sections), COD removal is higher. Decolouration is high, typically 50-90 %, and for some dyes even more than 90 %.

The quantity of sludge produced is about 0.7-1 kg dry matter/m<sup>3</sup> of treated waste water. Usually, the sludge is dewatered in a chamber filter press to reach a dry matter content of about 35-40 % (3 kg of sludge are therefore produced for 0.5 kg of COD removed).

### **Cross-media effects**

- Additional energy and chemicals are consumed for these waste water treatments.
- Sludge generated in these treatments could be considered hazardous waste and needs appropriate handling (including disposal).

### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

### **Economics**

No information provided. For more information, see [\[ 77, COM 2016 \]](#).

### **Driving force for implementation**

Environmental legislation.

### **Example plants**

See Section 4.1.7.3.3.5.

### **Reference literature**

[\[ 22, TWG 2002 \]](#), [\[ 77, COM 2016 \]](#)

#### 4.1.7.4.3 Waste water treatment of segregated streams in a membrane biological reactor

##### **Description**

Effluents containing poorly biodegradable compounds (e.g. polyvinyl alcohol (PVA) removed from fabric during desizing) are treated in a membrane biological reactor.

##### **Technical description**

PVA is only biodegradable under certain conditions. These include a waste water temperature of more than 15 °C, a food to microorganisms ratio of less than 0.15 kg BOD<sub>5</sub>/kg MLSS x d and adaptation of the biomass [ 142, HAZBREF 2019 ]. If in an industrial or municipal biological waste water treatment plant these conditions cannot be maintained over the entire year (e.g. due to very low waste water temperature in winter or very high in the summer), additional treatment is required.

A membrane biological reactor (MBR) (see Section 4.1.7.3.5.1.2) equipped with an ultrafiltration membrane, preventing residual PVA from leaving the reactor, can be used for treatment at unfavourable temperatures by using adapted microorganisms. The membrane can either be separately installed or directly submerged in the activated sludge tank.

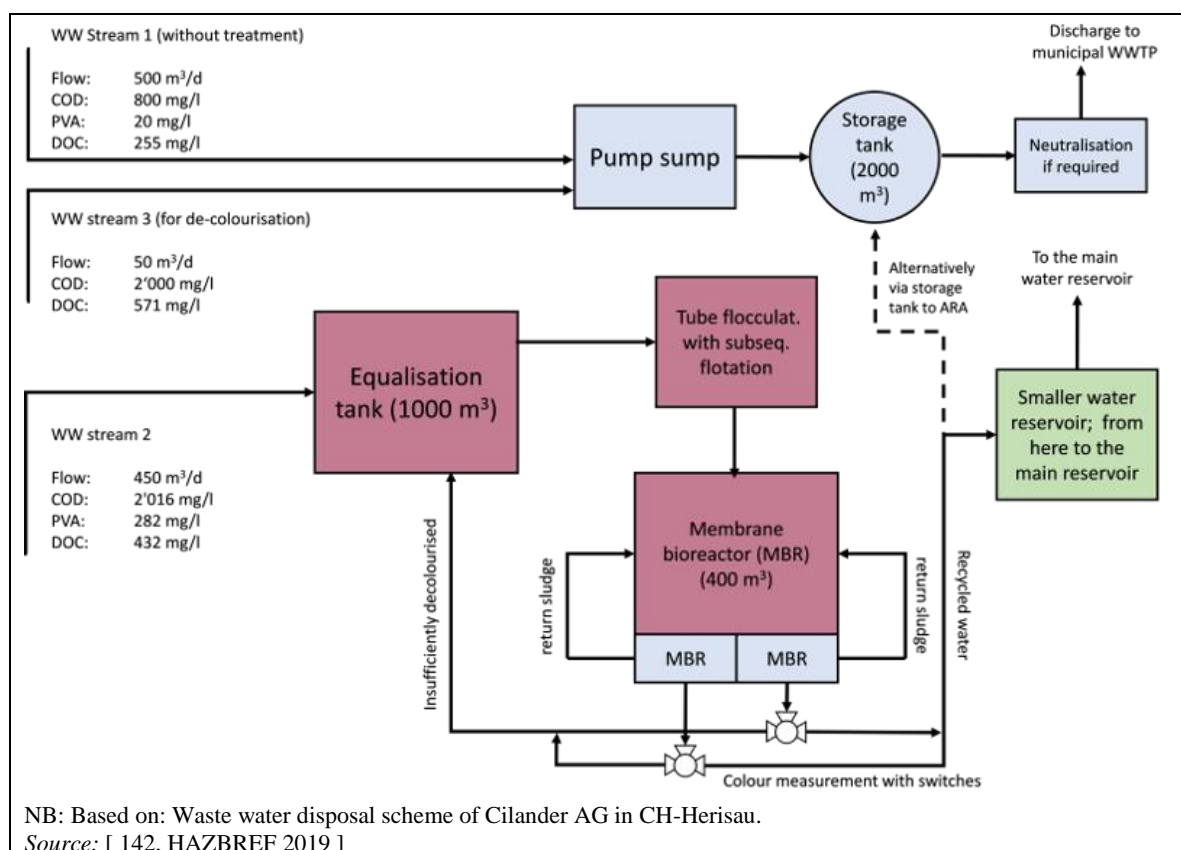
##### **Achieved environmental benefits**

The emission of PVA to water bodies is drastically minimised over the entire year, including wintertime with low waste water temperatures.

##### **Environmental performance and operational data**

Figure 4.23 shows a waste water treatment plant with PVA-containing streams originating from desizing machines. The waste water streams are then segregated by automated valves and directed to an equalisation tank from where the streams are fed to the tube flocculator and subsequently to the membrane bioreactor (MBR). The food to microorganisms ratio is about 0.2 kg BOD<sub>5</sub>/kg MLSS x d. PVA is degraded between 95 % and 98 %, even at temperatures of 40 °C. To still enable biodegradation, the PVA-degrading microorganisms have been adapted to elevated temperature levels.





**Figure 4.23: Scheme of a waste water pretreatment plant with a membrane bioreactor (MBR) for biological PVA degradation**

### Cross-media effects

Compared to the treatment in a conventional activated sludge system or in a municipal waste water treatment plant, biological treatment in a MBR requires additional energy as the energy consumption of a MBR plant is higher than that of conventional activated sludge systems.

### Technical consideration relevant to applicability

The technique is applicable to both new and existing plants. However, in existing plants, sufficient space for equalisation tanks and the MBR plant is a prerequisite. Furthermore, in existing plants additional waste water pipes have to be retrofitted to enable proper segregation of the different waste water streams. It can be expected that low waste water temperatures (where PVA degradation is low) usually only occur in colder parts of Europe (e.g. central and northern Europe).

### Economics

The investment costs for the plant shown in Figure 4.23 were around EUR 1.5 million. The treatment costs are about EUR 1-1.5/m<sup>3</sup>.

### Driving force for implementation

- Environmental regulation (emission limit values).
- Reduction of waste water fees (in the case of indirect discharge).

### Example plants

Cilander AG, Herisau, Switzerland.

### Reference literature

[ 142, HAZBREF 2019 ]

#### 4.1.7.4.4 Waste water treatments for optimised waste water recycling and reuse

##### Description

Polluted waste water streams (effluents) are segregated (e.g. based on pollutants and pollution level), and treated with a combination of appropriate techniques (e.g. filtration techniques like micro-, ultra-, nanofiltration, reverse osmosis, membrane bioreactor (MBR), advanced oxidation processes (AOP) (UV/H<sub>2</sub>O<sub>2</sub>) and/or evaporation. The treated water (e.g. permeate) is recycled in the processes and the evaporation concentrate is either reused or further treated to recover auxiliary chemicals (e.g. sizing agents, dispersants, acids, salts) which can be reused in textile treatment processes.

##### Technical description

Waste water streams are segregated in high and low concentrated streams. Streams concentrated with pollutants are typically from pretreatment (e.g. desizing), dyeing, printing and finishing operations; low concentrated streams are typically from rinsing and washing operations.

Membrane techniques are applied in various combinations for the treatment of segregated streams to allow water reclamation and reuse closely integrated with the process.

Low concentrated streams are typically pretreated with ultrafiltration, followed by or in combination with other treatments (e.g. nanofiltration, advanced oxidation processes, membrane bioreactor). Highly concentrated streams are typically pretreated with evapo-concentration. For more treatment combinations, see the description below.

The concentrates from treatment with the membrane techniques can be further treated with evaporation and/or crystallisation to further separate the water content for reuse and the remaining concentrated liquids (e.g. acids or alkalis) or solid substances (e.g. salts) for reuse in the processes (e.g. in dyeing). The combination of techniques used depends on the load and nature of the pollutants in the waste water effluent.

In some cases (depending on the driving factors/circumstances), ‘Zero Liquid Discharge (ZLD)’ (almost no discharge of waste waters from the textile plant) can be achieved with the combination of UF, nano-filtration, reverse osmosis, evaporation, or crystallisation treatments, alone or coupled with the primary and secondary WWT (i.e. neutralisation, equalisation, coagulation/flocculation, activated sludge process, filtration, etc.) [ 35, RICARDO 2019 ], [ 92, Inayath Hussain et al. 2018 ], [ 201, Telgmann et al. 2019 ], [ 202, Tamil Nadu PCB 2019 ].

When closing the water cycle, the main challenge is in attaining the ‘right water quality’ without negative effects on the product quality. According to [ 203, Vajnhandl et al. 2014 ], it is common practice for operators to use water of too high a quality, often drinking water, just to be on the safe side.

According to [ 203, Vajnhandl et al. 2014 ], three types of water quality are already suggested for use in the textile industry – high-, moderate-, and low-quality waters:

- High-quality water can be used for all processes, such as dye baths, print pastes, finishing baths, and final rinse baths. The consumption of such water is typically 10-20 % of the total water consumption. In Table 4.23 criteria for water reuse from four different sources are presented: fresh softened water, recycled effluent (proposed by [ 203, Vajnhandl et al. 2014 ]), mains drinking water of prescribed concentrations or values (PCVs), and of Confederation of British Wool Textiles (CBWT) water specifications.
- Moderate-quality water used for washing-off stages after scouring, bleaching, dyeing/printing and finishing. Typically, around 50-70 % of total water consumption consists of such water needs. The final rinse bath in the washing processes should always be high-quality water to ensure that the material is free from traces of contamination (Table 4.24).

- Low-quality water can be used for cleaning the equipment, screen washing in print work, the general washing-down of print paste containers and floors (Table 4.25). The typical quantity of this type of water required represents only 10-20 % of total water consumption. It would be wasteful to use high-quality water for such operations.

**Table 4.23: High-quality water standards for water reused for all textile finishing processes**

Parameter	Fresh softened water	Recycled effluent (maximum recommended level)	Mains water PVCs	CBWT specification
Colour <sup>(1)</sup> (mg/l Pt scale)	Non-visible	Non-visible	20	Non-visible
COD (mg/l O <sub>2</sub> )	–	20-50	–	–
pH	6.5-7.5	6.5-7.5	5.5-9.5	6.0-8.0
Total hardness (mg/l)	50 <sup>(2)</sup>	90 <sup>(2)</sup>	250 (Ca), 50 (Mg)	60-80 <sup>(2)</sup>
Chloride (mg/l)	300	500	400	–
Sulphate (mg/l)	–	–	250	–
Fe (mg/l)	0.05	0.1	0.2	0.1
Cu (mg/l)	0.05	0.005	3	0.1
Cr (mg/l)	–	0.01	0.05	–
Al (mg/l)	–	0.02	0.2	–
Mn (mg/l)	–	–	0.05	0.05
Zn (mg/l)	–	–	5	0.1

<sup>(1)</sup> Suggested specification for water with no visible colour absorbance in 10 mm cell: 450 nm 0.02-0.04; 500 nm 0.02-0.05; 550 nm 0.01-0.03; 600 nm 0.01–0.02.  
<sup>(2)</sup> Measured as ppm CaCO<sub>3</sub>.  
Source: [ 203, Vajnhandl et al. 2014 ]

**Table 4.24: Moderate-quality water standards for water reused for washing-off stages after scouring, bleaching, dyeing/printing and finishing**

Parameter	Maximum recommended level
Colour	Non-visible
COD (mg/l)	200
pH	7.0-8.0
Total hardness (ppm CaCO <sub>3</sub> )	100
Chloride (mg/l)	500-2 000
Fe (mg/l)	0.1
Cu (mg/l)	0.05
Cr (mg/l)	0.1

Source: [ 203, Vajnhandl et al. 2014 ]

**Table 4.25: Low-quality water standards for water reuse for cleaning (e.g. equipment, floor)**

Parameter	Maximum recommended level
Colour	Non-visible
COD (mg/l)	500-2 000
pH	6.5-8.0
Total hardness (ppm CaCO <sub>3</sub> )	100
Chloride (mg/l)	3 000-4 000
Fe (mg/l)	0.1
Cu (mg/l)	0.05
Cr (mg/l)	0.1

Source: [ 203, Vajnhandl et al. 2014 ]

**Achieved environmental benefits**

- Reduced discharge of waste water.
- Reduced water consumption.
- Recovery of auxiliary chemicals (e.g. sizes, salts, dispersion agents).

**Environmental performance and operational data**

To avoid membranes scaling and fouling, fibres and particles (e.g. dust from singeing) need to be removed (e.g. by upstream pretreatment like sieving). Also, the chemicals that cause scaling of the membranes need to be neutralised. In the case of ultrafiltration, spiral modules are much less sensitive to scaling than ceramic tubular modules. Polymer membranes have a proven lifetime of 2-3 years [ 44, ÖKOPOL 2011 ].

As a filter cake is produced that needs to be cleaned, self-cleaning membranes are preferred (e.g. transverse current filtration).

Waste water is circulated over membranes, producing a coating on the surface of the membrane where the transverse flow of waste water takes place. The coating can be kept a specific thickness by regulating the transverse current or by backflushing [ 44, ÖKOPOL 2011 ].

The filtrate/permeate amount depends on the pressure and on the thickness of the coating on the membrane. Waste water is circulated into the system according to the amount of drained-off filtrate. Permeate fluxes achieved by membrane techniques are:

- ultrafiltration (UF), cut-off around 50 daltons: 85-130 l/m<sup>2</sup> x h;
- nanofiltration (NF), cut-off around 200 daltons: 12-17 l/m<sup>2</sup> x h;
- reverse osmosis (RO), cut-off around 50 daltons: 11-17 l/m<sup>2</sup> x h.

For the ZLD approach, combinations of different types of evaporators are used including agitated thin-film, falling-film, forced-circulation, mechanical vapour recompression, multiple-effect, etc. ZLD systems can achieve water recycling rates of more than 98 % and recovery rates for salt from dyeing effluents of up to 90 % [ 35, RICARDO 2019 ], [ 201, Telgmann et al. 2019 ].

Energy consumption for ultrafiltration, reverse osmosis, evaporation or crystallisation can be substantial. According to [ 92, Inayath Hussain et al. 2018 ], the operation of a typical WWTP (pretreatment, biological treatment, settling, filtration) with additional ultrafiltration/reverse osmosis/evaporation/crystallisation unit consumes up to 28 kWh/m<sup>3</sup> of electrical power and steam, with around 50 % consumed in the evaporation/crystallisation step.

The use of different combinations and/or variations of waste water treatment techniques to improve recycling and reuse of waste waters is an important area of research and development in the textile sector. Examples of recent LIFE, Eco-innovation and Horizon 2020 projects demonstrating these approaches are presented in Table 4.26 below.

Table 4.26: Examples of LIFE, Eco-innovation and Horizon 2020 projects on recycling and reuse of textile waste waters

Project name	Description
BATTLE - Best Available Technique for water reuse in TextiLE SMEs	<p>The demonstration plant was the medium-sized textile finishing plant Stamperia di Martinengo (IT) – with 500 m<sup>3</sup>/day of effluent treated, of which 374 m<sup>3</sup>/day were recovered/reused.</p> <p>The treatment technique used was membrane UF. A high recovery rate was enabled by an innovative water management system, which integrated online effluent characterisation, stream segregation, final effluent treatability evaluation and impact control, reclaimed water reusability and cost analysis [ 204, ENEA 2019 ].</p>
PROWATER - Sustainable water management in the textile wet treatment industry through an innovative treatment process for waste water reuse	<p>The demonstration plants were 4 textile finishing plants from Prato (IT). The effluent recycling system was composed of a sequence of treatments: physico-chemical pretreatment (coagulation + lammelar sedimentation or flotation), cross-flow ultrafiltration and ozonation. The removal efficiency of surfactants was 62 % and of colour 98 %. Operating costs in 4 demonstration plants were in a range between EUR 0.78 and EUR 2.37 per m<sup>3</sup>. Fresh water consumption was reduced by 40 % on an industrial scale [ 205, Tecnotessile 2019 ].</p>
PURIFAST - Advanced Purification Of Industrial And Mixed Waste Water By Combined Membrane Filtration And Sonochemical Technologies	<p>Pre-industrial-scale prototype of advanced waste water treatment system based on ultrafiltration (UF) and an ultrasonic Advanced Oxidation Process (AOP) on textile and mixed waste waters. For textile waste waters, a reduction efficiency of more than 90 % was achieved for colour and around 80 % for COD and TSS. As much as 60 % of textile effluent has proven to be reusable. An ex-post study revealed that the technique was not implemented on demonstration sites (in IT and DE) due to the large capital investments needed [ 206, Tecnotessile 2019 ].</p>
Water-Saving Processes for Textile Production (WASATEX)	<p>A combination of techniques like a membrane bioreactor, nanofiltration, filtration (resin bleaching and softener), reverse osmosis and UV chemical oxidation was implemented in Benetton Tekstil company in Osijek (HR). A reuse/recycling rate of 62 % (1 000 out of 1 600 m<sup>3</sup>/day of fresh water) was acheived in the plant (theoretically up to 90 % is possible). The energy recovery reduced the natural gas consumption for heating the fresh water. The brine recovery reduced the NaCl consumption. The estimated return on investment (ROI) was 5 years [ 207, ASPEL 2019 ].</p>

European consortium to demonstrate EColoRO concept for waste water reuse in the textile industry	Waste water treatment by electrocoagulation followed by membrane filtration (ultrafiltration and reverse osmosis) allowed the reuse of up to 90 % of textile waste waters. The electrocoagulation removes 93-96 % of dyes and pigments. The technology was demonstrated on an industrial scale in textile plants in BE and IT [ 208, S-ISPT 2019 ], [ 209, ECWRTI 2019 ].
Aquatfite4use – The project for sustainable water use in industry	The combination of treatment techniques tested in plants in SI (Tekstina, Sivilanit) and CZ (Inotex) included: flocculation, membrane bioreactor (MBR), ultrafiltration, nanofiltration (NF), evapo-concentration and AOP (UV/H <sub>2</sub> O <sub>2</sub> ). The textile effluent streams were segregated and treated separately based on their pollution level. The highly concentrated streams were treated by evapo-concentration (COD removal 96-98 %). The low-medium concentrated streams were treated by MBR/AOP or MBR/NF (COD removal 93-98 %, conductivity removal 70-80 %, turbidity removal 99 %). Mixed textile waste waters were treated with flocculation/biological treatment/AOP (UV/H <sub>2</sub> O <sub>2</sub> ) as end-of-pipe treatment without any effluents segregation [ 210, TNO 2019 ].
ElectroChemical technique combined with UV irradiation for the treatment and reuse of dyeing textile waste waters: Industrial marketing (ECUVal)	Photo(UV)-electrochemical treatment is used for degradation of dyes contained in the textile effluents. The salts in the effluent serve as electrolyte. Residual dyes are removed by the addition of chemical reagents. The final effluent contains salt and can be reused for dyeing. Water consumption for the dyeing process was reduced by 70-100 %, dye removal > 90 %, lower salt consumption (15-60 %). Industrial pilot and scale-up in plants in ES [ 211, UPC 2019 ].

### Cross-media effects

- Increased energy consumption (e.g. for pumps and evaporation).
- Solid or liquid waste generated (e.g. remaining impurities and liquid concentrates).

The extent of cross-media effects is different depending on whether the techniques are applied only to some segregated streams or the whole plant (e.g. like the ZLD approach). In the latter case they are bigger (e.g. the energy consumption of the plant can increase by up to 20% per year) [ 92, Inayath Hussain et al. 2018 ], [ 209, ECWRTI 2019 ].

### Technical consideration relevant to applicability

The membrane techniques are applicable to all textile plants, provided that proper waste water segregation is practised and membrane-compatible single waste water streams are selected for treatment. Recipes have to be checked in terms of membrane compatibility and have to be changed if necessary (see Description above).

Additional piping, buffer tanks connecting waste water recovery units with process machines, and/or filtration/evaporation/crystallisation equipment are needed. In existing installations, space availability may be limited.

### Economics

The investment for a 10 m<sup>3</sup>/h membrane bioreactor is about EUR 1 million. Taking into account the capital cost and operating costs (labour, energy, chemicals for membrane cleaning, maintenance and concentrate disposal), the specific costs are EUR 4.5/m<sup>3</sup> of recycled water (capital cost: EUR 1.3/m<sup>3</sup>, operating cost: EUR 3.2/m<sup>3</sup>) [5, UBA 2001].

[92, Inayath Hussain et al. 2018] reports the running (operation and maintenance) costs of the waste water treatment in the ZLD approach (no discharge), specific for the Indian circumstances (energy/chemicals market), as EUR 4.5-6/m<sup>3</sup>.

The yearly operational costs of these techniques for smaller plants (<< 50m<sup>3</sup>/day of waste water) are estimated to be around EUR 100 000 (including energy costs, maintenance, chemicals and potential sludge treatment from ZLD) [212, EURATEX 2019].

An economic feasibility study of electrocoagulation with ultrafiltration and a reverse osmosis system (EC+EF+RO) conducted within the Life project EColoRO [213, Feyaerts M. 2017] presents the economic case for real industrial cases in the EU (Belgium and Italy). In particular, there is a reduction of water costs (from EUR 2.4/m<sup>3</sup> to EUR 1.9/m<sup>3</sup>) and relatively short payback period (less than 5 years). Table 4.27 presents the CAPEX and OPEX data and Table 4.28 economic costing analysis of the (EC+EF+RO) system.

Nevertheless, whether the business case can be realised for the application of the extended water reuse concepts (e.g. such as EColoRO or ZLD) depends largely on textile plant typology (technologies), the variability of the effluent composition (e.g. may be more challenging to achieve for commission plants), cross-media effects related to water, energy and waste treatment pricing and local discharge policies and regulations [209, ECWRTI 2019], [212, EURATEX 2019].

**Table 4.27: CAPEX and OPEX costs of the EC+UF+RO system**

EC+UF+RO		
CAPEX	Total = Equipment + installation / building	EUR 564 k [EUR 500 k + EUR 64 k]
OPEX	Metal electrodes	0.45 EUR/kg
	Energy costs	EUR 72.15 (2018) – EUR 83.2 (2017) /MWh
	Disposal of brine	EUR 0.87/m <sup>3</sup>
	Disposal of sludge	EUR 0.1/kg dry sludge
	Water recovery	75 %
	Sludge generation	1.5 kg dry sludge/m <sup>3</sup>
	Energy consumption of electrocoagulation	5 kWh/m <sup>3</sup>
	Energy consumption of UF/RO	1.2 kWh/m <sup>3</sup>
<i>Source:</i> [213, Feyaerts M. 2017]		

**Table 4.28: Economic costing analysis of EC+UF+RO system**

EC+UF+RO		Comment
Payback time (years)	4.7	Internal target > 3 years
Net Present Value (EUR)	112919.2	NPV > 0 = positive investment
Internal Rate of Return (%)	19.8	IPR > discount rate (15 %) = positive investment
Water costs (EUR/m <sup>3</sup> )	1.87	Water cost before investment: 2.37
NB: Water costs before investment, EUR 2.37/m <sup>3</sup> , consist of the costs of groundwater EUR 0.61/m <sup>3</sup> (Walloon Region, Belgium), WWT of process water EUR 0.41/m <sup>3</sup> and disposal of certain waste water EUR 1.50/m <sup>3</sup> .		
Source: [ 213, Feyaerts M. 2017 ]		

**Driving force for implementation**

- Environmental legislation.
- Savings in water consumption.
- Savings in chemicals.

**Example plants**

Membrane techniques for treatment of segregated waste water streams are applied in many plants in Europe.

IDEAL Floorcoverings, Wielsbeke, Belgium (BE009) uses filtration (ultrafiltration and reverse osmosis to recycle waste water [ 214, EIPPCB 2019 ].

According to the data collection, Plants FR130, FR133 and DE022 use evapo-concentration to recycle waste water (e.g. Plants FR130 and FR133 report no waste water discharge; in Plant FR130 85 % of waste water is recycled and the rest is treated as waste by a third party) [ 50, TWG 2019 ].

**Reference literature**

[ 5, UBA 2001 ], [ 35, RICARDO 2019 ], [ 44, ÖKOPOL 2011 ], [ 50, TWG 2019 ], [ 92, Inayath Hussain et al. 2018 ], [ 157, Danish EPA 2001 ], [ 201, Telgmann et al. 2019 ], [ 202, Tamil Nadu PCB 2019 ], [ 204, ENEA 2019 ], [ 205, Tecnotessile 2019 ], [ 206, Tecnotessile 2019 ], [ 207, ASPEL 2019 ], [ 208, S-ISPT 2019 ], [ 209, ECWRTI 2019 ], [ 210, TNO 2019 ], [ 211, UPC 2019 ], [ 212, EURATEX 2019 ], [ 213, Feyaerts M. 2017 ], [ 214, EIPPCB 2019 ], [ 215, Dasgupta et al. 2015 ]

**4.1.7.4.5 Anaerobic removal of residual dyestuffs from padding liquors and printing paste residues****Description**

Residual printing pastes and padding liquors for continuous and semi-continuous dyeing, which contain high concentrations of dyestuffs, are treated in anaerobic digesters (see Section 4.1.7.3.5.2), preferably in co-fermentation with primary and excess sludge from biological treatment.

**Technical description**

When azo dyestuffs are treated under anaerobic conditions, the azo groups (characteristic of this type of dyestuffs) are irreversibly destroyed, causing the dyestuffs to lose their colour. However, the remaining aromatic systems still absorb light, so some slight yellowish colour often remains.

The water-soluble cleavage products (the ones with sulphonic groups) are present in the water phase and reach the activated sludge treatment both as overflow from the anaerobic digester and as filtrate from sludge dewatering. Some naphthalene derivatives are poorly biodegradable and



may still be present in the final effluent. For this reason, the supernatant needs to be subsequently treated in an activated sludge system.

### **Achieved environmental benefits**

Anaerobic treatments reach colour removal efficiencies of more than 90 % with azo dyes (determined as reduction of spectral absorption coefficients at the wavelengths 436 nm, 525 nm and 620 nm) [5, UBA 2001].

Also with printing pastes containing natural thickeners, such as alginates or galactomannans, there is a conversion to biogas thanks to degradation of these biopolymers.

Although the quantity of the concentrates mentioned represents a small percentage of the total discharged waste water (only a few tonnes per week even for large mills), there are cases in which the total residual colour in the effluent of treatment plants could be reduced by about 50 %.

### **Environmental performance and operational data**

In order to derive the most benefit from anaerobic treatment, this technique should be applied in combination with process-integrated techniques aimed at minimising padding liquors and printing paste residues. Moreover, it is important to separate at source the residual padding liquors from other streams in order to keep them concentrated.

The dosage of reactive printing paste should not exceed 10 g/kg of sludge because of possible inhibition effects on the anaerobic process. Laboratory tests may assist with determination of inhibition effects.

Padding liquors and printing pastes with heavy-metal-containing dyestuffs are separated unless the sludge resulting from the anaerobic treatment is incinerated or disposed of in appropriate landfill.

### **Cross-media effects**

The reductive cleavage of the azo bonds leads to aromatic amines. As for the potential for release of carcinogenic aromatic amines, investigations carried out so far have not confirmed this fear [5, UBA 2001]. Moreover, the supernatant from the anaerobic treatment is normally treated with activated sludge.

### **Technical considerations relevant to applicability**

The technique can be applied to both new and existing installations.

Anaerobic treatment is particularly suitable for azo dyestuffs, which represent 50 % of the colourants currently available on the market.

However, other chromophoric systems cannot be treated substantially. Vat dyes for example are reduced to the colourless form, but this process is reversible.

Pigment printing pastes cannot be treated in anaerobic digesters because all components are non-biodegradable and scaling problems occur because of polymer binders.

In conclusion, even if anaerobic treatments reach efficiencies of 90 % with azo dyes, for companies using a broader range of dyes this technique has an average overall efficiency.

### **Economics**

The known cost for anaerobic treatment in municipal anaerobic digesters varies between EUR 30 and EUR 60 per tonne of padding liquor or printing paste [5, UBA 2001].

### **Driving force for implementation**

Compliance with existing environmental standards for emissions to water (e.g. for colour).

**Example plants**

Residual padding liquors for dyeing are treated in the anaerobic digester of the municipal waste water treatment plant of Heidenheim, D-Heidenheim.

Plants CZ019 (printing and dyeing) and FR134 (dyeing and functional finishing) report using anaerobic treatment for waste water treatment.

**Reference literature**

[ 5, UBA 2001 ]

**4.1.7.5 Environmental performance of plants using different combinations of waste water treatment techniques****4.1.7.5.1 Direct discharge**

The tables below present the environmental performance (emissions to water) of plants treating textile effluents with combinations of waste water treatment techniques and directly discharging to the receiving water body. The environmental performance for chemical oxygen demand (COD) is presented in Table 4.29, for total organic carbon (TOC) in Table 4.30, for total nitrogen (TN) in Table 4.31, for total phosphorus (TP) in Table 4.32 and for total suspended solids (TSS) in Table 4.33.

Table 4.29: Environmental performance of combinations of waste water treatment techniques for chemical oxygen demand (COD) emissions to water

Emission point	Associated processes	Minimum concentration over 3 years (mg/l)	Average concentration over 3 years (mg/l)	Maximum concentration over 3 years (mg/l)	Maximum load over 3 years (g/day)	Combination of techniques	Maximum amount of waste water discharged (m <sup>3</sup> /t of textile)	Maximum specific water consumption at plant level (m <sup>3</sup> /t of textile)	% of recycled/reused water in total water consumed
IT082_w{1}	Dyeing - Singeing - Functional finishing - Thermal treatment (e.g drying, thermofixation, curing) - Wool Fulling	12.0	24.7	43.0	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Adsorption (e.g. powdered/granular activated carbon, lignite coke, etc.) - Other	117.0	142.0	20.0
IT096_w{1}	Dyeing - Other	29.0	38.7	49.0	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Other	65.0	54.8	NI
BE010_w{1}	Bleaching - Dyeing - Bleaching - Scouring - Functional finishing	31.0	45.4	53.0	8.4	Equalisation - - Activated sludge process - Nitrification/denitrification - Other	67.7	92.9	2.0
DE032_w{1}	Washing synthetic fibre - Desizing - Bleaching - Dyeing - Printing	43.0	51.3	58.0	NI	Equalisation - Neutralisation - Grit separators - Coagulation and flocculation - Sedimentation - Sand filtration - Nitrification/denitrification - Activated sludge process	NI	47.1	NI
BE011_w{1}	Dyeing	36.0	46.1	59.0	44.2	Equalisation - Neutralisation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sand filtration - Nanofiltration - Chemical oxidation (incl. Advanced oxidation)	62.9	70.2	20.3
CZ020_w{1}	Dyeing	21.0	34.4	65.0	NI	Sedimentation - Nitrification/denitrification - Neutralisation - Coagulation and flocculation - Activated sludge process	494.2	0.00001	NI

CZ019_w{1}	Bleaching - Dyeing - Printing - Functional finishing - Desizing	0.0	71.0	0.0	NI	Equalisation - Neutralisation - Anaerobic treatment - Nitrification/denitrification - Activated sludge process	NI	NI	NI
IT092_w{1}	Dyeing - Other	7.6	23.4	73.8	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Reverse osmosis	99.4	196.9	NI
IT097_w{1}	Dyeing - Shrink-proof finishing - Printing - Other	28.0	53.1	80.0	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation	258.6	292.7	NI
PT111_w{1}	Desizing - Dyeing - Fabric production - Wool Fulling - Functional finishing - Shrink-proof finishing - Dry cleaning - Thermal treatment (e.g drying, thermofixation, curing)	35.0	56.7	80.0	51.3	Equalisation - Neutralisation - Activated sludge process - Sedimentation - Sand filtration - Other	225.3	267.3	100.0
PT098_w{1}	Wool Fulling - Functional finishing - Dyeing - Thermal treatment (e.g drying, thermofixation, curing)	27.0	58.3	91.0	39.3	Equalisation - Neutralisation - Sedimentation - Sand filtration - Activated sludge process - Other	328.2	259.0	NI
BE007_w{1}	Dyeing	0.0	92.9	0.0	23.6	Equalisation - Neutralisation - Sand filtration - Activated sludge process - Nitrification/denitrification	10.7	14.3	5.4
DE034_w{1}	Washing synthetic fibre - Desizing - Bleaching - Dyeing	0.0	59.0	97.0	44.4	Activated sludge process - Nitrification/denitrification	38.0	41.4	NI
NB: NI: No information. Source: [ 50, TWG 2019 ]									

Table 4.30: Environmental performance of combinations of waste water treatment techniques for total organic carbon (TOC) emissions to water

Emission point	Associated processes	Minimum concentration over 3 years (mg/l)	Average concentration over 3 years (mg/l)	Maximum concentration over 3 years (mg/l)	Maximum load over 3 years (g/day)	Combination of techniques	Maximum amount of waste water discharged (m <sup>3</sup> /t of textile)	Maximum specific water consumption at plant level (m <sup>3</sup> /t of textile)	% of recycled/reused water in total water consumed
IT092_w{1}	Dyeing - Other	10.4	10.4	10.4	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Reverse osmosis	99.4	196.9	NI
IT097_w{1}	Dyeing - Shrink-proof finishing - Printing - Other	10.5	10.5	10.5	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation	258.6	292.7	NI
DE032_w{1}	Washing synthetic fibre - Desizing - Bleaching - Dyeing - Printing	12.5	16.8	22.0	NI	Equalisation - Neutralisation - Grit separators - Coagulation and flocculation - Sedimentation - Sand filtration - Nitrification/denitrification - Activated sludge process	NI	47.1	NI
NB: NI: No information. Source: [ 50, TWG 2019 ]									

Table 4.31: Environmental performance of combinations of waste water treatment techniques for total nitrogen (TN) emissions to water

Emission point	Associated processes	Minimum concentration over 3 years (mg/l)	Average concentration over 3 years (mg/l)	Maximum concentration over 3 years (mg/l)	Maximum load over 3 years (g/day)	Combination of techniques	Maximum amount of waste water discharged (m <sup>3</sup> /t of textile)	Maximum specific water consumption at plant level (m <sup>3</sup> /t of textile)	% of recycled/reused water in total water consumed
DE034_w{1}	Washing synthetic fibre - Desizing - Bleaching - Dyeing	1.9	2.1	2.2	1.3	Activated sludge process - Nitrification/denitrification	38.0	41.4	NI
PT098_w{1}	Wool Fulling - Functional finishing - Dyeing - Thermal treatment (e.g drying, thermofixation, curing)	1.0	2.2	4.6	1.9	Equalisation - Neutralisation - Sedimentation - Sand filtration - Activated sludge process - Other	328.2	259.0	NI
BE007_w{1}	Dyeing	NI	5.7	NI	1.4	Equalisation - Neutralisation - Sand filtration - Activated sludge process - Nitrification/denitrification	10.7	14.3	5.4
DE025_w{1}	Washing synthetic fibre - Dyeing - Printing	0.4	2.5	6.4	NI	Equalisation - Neutralisation - Coagulation and flocculation - Sedimentation - Activated sludge process	25.8	139.0	NI
CZ019_w{1}	Bleaching - Dyeing - Printing - Functional finishing - Desizing	NI	7.6	NI	NI	Equalisation - Neutralisation - Anaerobic treatment - Nitrification/denitrification - Activated sludge process	NI	NI	NI

BE009_w{2}	Printing - Coating (also back-coating) and laminating	3.0	4.1	7.7	NI	Screening - Sedimentation - Equalisation - Activated sludge process - Sand filtration - Coagulation and flocculation - Flotation - Chemical oxidation (incl. Advanced oxidation) - Sand filtration - Chemical reduction - Microfiltration - Reverse osmosis	25.2	28.8	20.0
BE011_w{1}	Dyeing	2.0	4.9	9.7	6.8	Equalisation - Neutralisation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sand filtration - Nanofiltration - Chemical oxidation (incl. Advanced oxidation)	62.9	70.2	20.3
PT110_w{1}	Dyeing	4.0	7.4	15.0	NI	Equalisation - Grit separators - Screening - Coagulation and flocculation - Sedimentation - Activated sludge process - Other	101.1	102.3	NI
NB: NI: No information. Source: [ 50, TWG 2019 ]									

Table 4.32: Environmental performance of combinations of waste water treatment techniques for total phosphorus (TP) emissions to water

Emission point	Associated processes	Minimum concentration over 3 years (mg/l)	Average concentration over 3 years (mg/l)	Maximum concentration over 3 years (mg/l)	Maximum load over 3 years (g/day)	Combination of techniques	Maximum amount of waste water discharged (m <sup>3</sup> /t of textile)	Maximum specific water consumption at plant level (m <sup>3</sup> /t of textile)	% of recycled/reused water in total water consumed
BE007_w{1}	Dyeing	0.17	0.14	0.35	NI	Equalisation - Neutralisation - Sand filtration - Activated sludge process - Nitrification/denitrification	10.7	14.3	5.4

DE025_w{1}	Washing synthetic fibre - Dyeing - Printing	NI	0.13	0.47	NI	Equalisation - Neutralisation - Coagulation and flocculation - Sedimentation - Activated sludge process	25.8	139.0	NI
CZ020_w{1}	Dyeing	0.08	0.21	0.65	NI	Sedimentation - Nitrification/denitrification - Neutralisation - Coagulation and flocculation - Activated sludge process	494.2	0.0	NI
BE010_w{1}	Bleaching - Dyeing - Bleaching - Scouring - Functional finishing	0.20	0.57	0.91	0.16	Equalisation - - Activated sludge process - Nitrification/denitrification - Other	67.7	92.9	2.0
IT082_w{1}	Dyeing - Singeing - Functional finishing - Thermal treatment (e.g drying, thermofixation, curing) - Wool Fulling	0.20	0.53	1.00	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Adsorption (e.g. powdered/granular activated carbon, lignite coke, etc.) - Other	117.0	142.0	20.0
CZ019_w{1}	Bleaching - Dyeing - Printing - Functional finishing - Desizing	NI	1.20	NI	NI	Equalisation - Neutralisation - Anaerobic treatment - Nitrification/denitrification - Activated sludge process	NI	NI	NI
DE032_w{1}	Washing synthetic fibre - Desizing - Bleaching - Dyeing - Printing	0.35	0.81	1.40	NI	Equalisation - Neutralisation - Grit separators - Coagulation and flocculation - Sedimentation - Sand filtration - Nitrification/denitrification - Activated sludge process	NI	47.1	NI
BE009_w{2}	Printing - Coating (also back-coating) and laminating	NI	0.56	1.67	NI	Screening - Sedimentation - Equalisation - Activated sludge process - Sand filtration - Coagulation and flocculation - Flotation - Chemical oxidation (incl. Advanced oxidation) - Sand filtration - Chemical reduction - Microfiltration - Reverse osmosis	25.2	28.8	20.0



BE011_w{1}	Dyeing	0.33	0.77	1.70	1.19	Equalisation - Neutralisation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sand filtration - Nanofiltration - Chemical oxidation (incl. Advanced oxidation)	62.9	70.2	20.3
NB: NI: No information. Source: [ 50, TWG 2019 ]									

**Table 4.33: Environmental performance of individual or combinations of waste water treatment techniques for total suspended solids (TSS) emissions to water**

Emission point	Associated processes	Minimum concentration over 3 years (mg/l)	Average concentration over 3 years (mg/l)	Maximum concentration over 3 years (mg/l)	Maximum load over 3 years (g/day)	Combination of techniques	Maximum amount of waste water discharged (m <sup>3</sup> /t of textile)	Maximum specific water consumption at plant level (m <sup>3</sup> /t of textile)	% of recycled/reused water in total water consumed
IT082_w{1}	Dyeing - Singeing - Functional finishing - Thermal treatment (e.g. drying, thermofixation, curing) - Wool Fulling	NI	0.3	1.0	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Adsorption (e.g. powdered/granular activated carbon, lignite coke, etc.) - Other	117.0	142.0	20.0
BE011_w{1}	Dyeing	2.0	3.9	6.0	3.9	Equalisation - Neutralisation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sand filtration - Nanofiltration - Chemical oxidation (incl. Advanced oxidation)	62.9	70.2	20.3
CZ019_w{1}	Bleaching - Dyeing - Printing - Functional finishing - Desizing	NI	7.5	NI	NI	Equalisation - Neutralisation - Anaerobic treatment - Nitrification/denitrification - Activated sludge process	NI	NI	NI

IT097_w{1}	Dyeing - Shrink-proof finishing - Printing - Other	5.0	8.0	11.0	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation	258.6	292.7	NI
IT096_w{1}	Dyeing - Other	10.0	12.7	15.0	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Other	65.0	54.8	NI
BE009_w{2}	Printing - Coating (also back-coating) and laminating	5.9	9.9	17.0	NI	Screening - Sedimentation - Equalisation - Activated sludge process - Sand filtration - Coagulation and flocculation - Flotation - Chemical oxidation (incl. Advanced oxidation) - Sand filtration - Chemical reduction - Microfiltration - Reverse osmosis	25.2	28.8	20.0
FR132_w{1}	NI	2.0	5.1	20.0	3.1	Sedimentation	0.045	216.0	NI
FR132_w{2}	Bleaching - Dyeing	2.0	11.3	20.0	10.2	Screening - Activated sludge process	0.14	216.0	NI
BE007_w{1}	Dyeing	NI	22.2	NI	5.6	Equalisation - Neutralisation - Sand filtration - Activated sludge process - Nitrification/denitrification	10.7	14.3	5.4
BE010_w{1}	Bleaching - Dyeing - Bleaching - Scouring - Functional finishing	10.0	14.3	27.0	3.3	Equalisation - - Activated sludge process - Nitrification/denitrification - Other	67.7	92.9	2.0
CZ020_w{1}	Dyeing	2.0	7.0	28.0	NI	Sedimentation - Nitrification/denitrification - Neutralisation - Coagulation and flocculation - Activated sludge process	494.2	0.0000098	NI
PT110_w{1}	Dyeing	1.0	10.2	29.0	NI	Equalisation - Grit separators - Screening - Coagulation and flocculation - Sedimentation - Activated sludge process - Other	101.1	102.3	NI

PT111_w{1}	Desizing - Dyeing - Fabric production - Wool Fulling - Functional finishing - Shrink-proof finishing - Dry cleaning - Thermal treatment (e.g drying, thermofixation, curing)	5.0	12.7	29.0	18.6	Equalisation - Neutralisation - Activated sludge process - Sedimentation - Sand filtration - Other	225.3	267.3	100.0
<p>NB: NI: No information. Source: [ 50, TWG 2019 ]</p>									

#### 4.1.7.5.2 Direct and indirect discharge

The tables below present the environmental performance (emissions to water) of plants treating textile effluents with individual or combinations of waste water treatment techniques and discharging either directly to the receiving water body or to the sewerage system with downstream waste water treatment. The environmental performance for adsorbable organically bound halogens (AOX) is presented in Table 4.34, for hydrocarbon oil index (HOI) in Table 4.35, for antimony (Sb) in Table 4.36, for chromium (Cr) in Table 4.37, for copper (Cu) in Table 4.38, for nickel (Ni) in Table 4.39, for zinc (Zn) in Table 4.40 and for sulphides ( $S^{2-}$ ) in Table 4.41.

Table 4.34: Environmental performance of individual or combinations of waste water treatment techniques for adsorbable organically bound halogens (AOX) emissions to water

Emission point	Type of discharge	Associated processes	Type of fibre	Minimum concentration over 3 years (mg/l)	Average concentration over 3 years (mg/l)	Maximum concentration over 3 years (mg/l)	Maximum load over 3 years (g/day)	Combination of techniques	Maximum amount of waste water discharged (m <sup>3</sup> /t of textile)	Maximum specific water consumption at plant level (m <sup>3</sup> /t of textile)	% of recycled/reused water in total water consumed
CZ017_w{1}	INDIR	Spinning - Fabric production - Singeing - Functional finishing - Shrink-proof finishing - Thermal treatment (e.g drying, thermofixation, curing) - Other	polyester-wool	0.00019	0.00023	0.00026	0.0004	Equalisation - Other	172.8	190.4	NI
CZ020_w{1}	DIR	Dyeing	acrylic-elastane-flax-polyamide-polyester-wool-other	0.00003	0.00014	0.001	NI	Sedimentation - Nitrification/denitrification - Neutralisation - Coagulation and flocculation - Activated sludge process	494.2	0.00001	NI

IT060_w{1}	INDIR	Dyeing - Spinning - Fabric production - Desizing - Mercerising - Thermal treatment (e.g drying, thermofixation, curing) - Shrink- proof finishing - Singeing - Coating (also back- coating) and laminating	cotton	0.010	0.010	0.010	NI	No information	NI	NI	NI
DE046_w{1}	INDIR	Washing synthetic fibre - Dyeing	polyamide- polyester	0.015	0.015	0.015	NI	No information	32.0	32.0	NI
BE013_w{1}	INDIR	Mercerising	blend cotton- synthetic- cotton	0.020	0.020	0.020	0.003	Distillation/ rectification - Equalisation - Neutralisation	9.7	12.7	NI
IT063_w{1}	INDIR	Dyeing - Fabric production - Dry cleaning - Printing - Printing - Functional finishing	elastane- polyamide	0.010	0.011	0.020	0.024	Equalisation	NI	198.5	NI

IT063_w{3}	INDIR	Dry cleaning	elastane-polyamide	0.010	0.015	0.030	0.0003	Adsorption (e.g. powdered/g ranular activated carbon, lignite coke, etc.)	NI	198.5	NI
DE023_w{1}	INDIR	Washing synthetic fibre - Mercerising - Bleaching - Dyeing	blend cotton-synthetic-cotton-polyamide-polyester-rayon (viscose)	0.010	0.024	0.050	NI	No information	72.0	72.0	NI
DE034_w{1}	DIR	Washing synthetic fibre - Desizing - Bleaching - Dyeing	cotton-elastane-polyamide-polyester-rayon (viscose)-other	0.015	0.026	0.050	0.026	Activated sludge process - Nitrification/denitrification	38.0	41.4	NI
DE050_w{1}	INDIR	Washing synthetic fibre - Desizing - Bleaching	blend cotton-synthetic-cotton-polyamide-polyester	0.051	0.051	0.051	NI	No information	15.8	16.6	NI
DE044_w{1}	INDIR	Desizing - Mercerising - Bleaching - Dyeing	blend cotton-synthetic-cotton-wool	0.060	0.060	0.060	NI	No information	200.0	103.0	NI
IT069_w{1}	INDIR	Scouring - Bleaching - Mercerising	blend cotton-synthetic-cotton-flax-rayon(viscose)	0.016	0.051	0.089	NI	Other	11.2	12.0	NI

AT006_w{1}	INDIR	Bleaching - Dyeing	-	0.023	0.047	0.090	0.035	Flotation	NI	NI	NI
IT090_w{1}	INDIR	Scouring - Dyeing - Thermal treatment (e.g drying, thermofixat ion, curing) - Other - Bleaching	acrylic- blend wool- synthetic- polyamide- polyester- rayon(visco se)-silk- wool	0.036	0.064	0.091	0.673	Other	42.3	41.9	NI
DE032_w{1}	DIR	Washing synthetic fibre - Desizing - Bleaching - Dyeing - Printing	blend cotton- synthetic- cotton- polyester	0.035	0.062	0.120	NI	Equalisatio n - Neutralisati on - Grit separators - Coagulatio n and flocculation - Sedimentati on - Sand filtration - Nitrificatio n/denitrific ation - Activated sludge process	NI	47.1	NI
BE010_w{1}	DIR	Bleaching - Dyeing - Bleaching - Scouring - Functional finishing	blend cotton- synthetic- cotton	0.080	0.103	0.120	NI	Equalisatio n - - Activated sludge process - Nitrificatio n/denitrific ation - Other	67.7	92.9	2.0



IT064_w{1}	INDIR	Scouring	blend cotton- synthetic- cotton- polyamide- polyester- wool	0.077	0.104	0.134	NI	Other	80.4	36.1	69.4
IT079_w{1}	INDIR	Scouring - Wool Fulling - Functional finishing - Thermal treatment (e.g drying, thermofixat ion, curing) - Other	blend wool- synthetic- wool	0.070	0.105	0.140	0.989	Other	41.9	41.9	100.0
IT073_w{1}	INDIR	Dyeing - Functional finishing	acrylic- blend cotton- synthetic- cellulose acetate- cotton- elastane- polyamide- polyester- rayon(mod al)- rayon(visco se)-wool	0.045	0.100	0.150	0.140	No technique used	129.6	147.7	48.0

ES058_w{1}	INDIR	Mergerising - Bleaching - Dyeing - Desizing - Fabric production - Printing - Thermal treatment (e.g drying, thermofixation, curing)	blend cotton-synthetic-cotton	NI	0.150	NI	0.344	No information	27.8	30.5	NI
BE014_w{1}	DIR	Bleaching - Dyeing - Functional finishing	cotton-wool-other	0.033	0.065	0.158	0.008	Equalisation - Activated sludge process - Nitrification/denitrification	20.9	23.7	10.0
DE025_w{1}	DIR	Washing synthetic fibre - Dyeing - Printing	polyamide-polyester	NI	0.022	0.160	NI	Equalisation - Neutralisation - Coagulation and flocculation - Sedimentation - Activated sludge process	25.8	139.0	NI

IT068_w{1}	INDIR	Washing synthetic fibre - Desizing - Scouring - Bleaching - Dyeing - Functional finishing - Other	blend cotton-synthetic-cotton-flax-polyamide-polyester-rayon (viscose)-rayon(lyocell)-silk	0.082	0.122	0.163	NI	Other	14.7	15.9	NI
SE118_w{1}	INDIR	Washing synthetic fibre - Scouring - Scouring - Bleaching - Dyeing - Singeing - Printing - Functional finishing - Shrink-proof finishing - Coating (also back-coating) and laminating - Thermal treatment (e.g drying, thermofixation, curing)	blend cotton-synthetic-cotton-polyester	0.050	0.087	0.170	NI	Sedimentation - Equalisation - Neutralisation	168.0	175.0	NI

BE009_w{2}	DIR	Printing - Coating (also back-coating) and laminating	other-polyamide	0.085	0.118	0.175	NI	Screening - Sedimentation - Equalisation - Activated sludge process - Sand filtration - Coagulation and flocculation - Flotation - Chemical oxidation (incl. Advanced oxidation) - Sand filtration - Chemical reduction - Microfiltration - Reverse osmosis	25.2	28.8	20.0
DE031_w{1}	INDIR	Dyeing	acrylic- blend wool- synthetic- blend cotton- synthetic- cotton-flax- polyester	0.023	0.082	0.190	NI	No information	33.7	18.0	NI

BE007_w{1}	DIR	Dyeing	polyamide- other	0.081	0.119	0.200	NI	Equalisation - Neutralisation - Sand filtration - Activated sludge process - Nitrification/ denitrification	10.7	14.3	5.4
IT078_w{1}	INDIR	Wool Fulling - Washing synthetic fibre - Dyeing	blend cotton- synthetic- blend wool- synthetic- cotton- polyester- rayon(visco se)-wool	0.075	0.151	0.211	NI	Other	88.7	94.2	NI
BE008_w{1}	INDIR	Printing - Dyeing	blend wool- synthetic- polyamide	0.160	0.187	0.220	NI	Equalisation - Grit separators - Other	45.6	48.2	NI
DE029_w{1}	INDIR	Dyeing	polyamide- polyester- other	0.010	0.068	0.260	NI	No information	18.0	21.0	NI
IT074_w{1}	INDIR	Washing synthetic fibre - Scouring - Functional finishing - Dry cleaning - Other	blend cotton- synthetic- blend wool- synthetic- cotton- polyester- silk	0.092	0.184	0.312	NI	Other - Other	NI	46.0	NI

IT097_w{1}	DIR	Dyeing - Shrink- proof finishing - Printing - Other	wool	0.280	0.315	0.350	NI	Equalisatio n - Neutralisati on - Activated sludge process - Nitrificatio n/denitrific ation - Sedimentati on	258.6	292.7	NI
AT004_w{1}	INDIR	Washing synthetic fibre	acrylic	NI	0.167	0.380	0.086	Neutralisati on	30.5	21.8	NI
BE011_w{1}	DIR	Dyeing	NI	0.080	0.168	0.380	0.116	Equalisatio n - Neutralisati on - Coagulatio n and flocculation - Activated sludge process - Nitrificatio n/denitrific ation - Sand filtration - Nanofiltrati on - Chemical oxidation (incl. Advanced oxidation)	62.9	70.2	20.3

DE022_w{1}	INDIR	Raw wool scouring - Washing synthetic fibre - Desizing - Scouring - Bleaching - Dyeing - Thermal treatment (e.g drying, thermofixation, curing) - Functional finishing - Coating (also back-coating) and laminating	acrylic-blend cotton-synthetic-blend wool-synthetic-cellulose acetate-cotton-polyamide-polyester-rayon (viscose)-other	0.010	0.099	0.391	NI	Neutralisation - Oil separation - Evaporation	65.0	80.0	NI
<p>NB: DIR: Direct discharge. INDIR: Indirect discharge. NI: No information. Source: [ 50, TWG 2019 ]</p>											

Table 4.35: Environmental performance of individual or combinations of waste water treatment techniques for hydrocarbon oil index (HOI) emissions to water

Emission point	Type of discharge	Associated processes	Type of fibre	Minimum concentration over 3 years (mg/l)	Average concentration over 3 years (mg/l)	Maximum concentration over 3 years (mg/l)	Maximum load over 3 years (g/day)	Combination of techniques	Maximum amount of waste water discharged (m <sup>3</sup> /t of textile)	Maximum specific water consumption at plant level (m <sup>3</sup> /t of textile)	% of recycled/reused water in total water consumed
IT092_w{1}	DIR	Dyeing - Other	wool	0.03	0.03	0.03	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrication - Sedimentation - Reverse osmosis	99.4	196.9	NI
IT097_w{1}	DIR	Dyeing - Shrink-proof finishing - Printing - Other	wool	0.03	0.03	0.03	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrication - Sedimentation	258.6	292.7	NI



ES058_w{1}	INDIR	Mercerising - Bleaching - Dyeing - Desizing - Fabric production - Printing - Thermal treatment (e.g drying, thermofixation, curing)	blend cotton- synthetic- cotton	0.00	0.32	0.00	0.64	No information	27.8	30.5	NI
BE007_w{1}	DIR	Dyeing	polyamide- other	0.82	0.88	0.93	NI	Equalisatio n - Neutralisati on - Sand filtration - Activated sludge process - Nitrificatio n/denitrific ation	10.7	14.3	5.4
PT115_w{1}	INDIR	Dyeing - Functional finishing	cotton	0.04	1.4	2.5	4.00	Equalisatio n - Neutralisati on - Screening	NI	106.7	NI
PT108_w{1}	INDIR	Fabric production - Fabric production	NI	0.30	2.6	4.0	3.24	Neutralisati on - Sand filtration - Sand filtration	99.3	96.5	37.0
IT063_w{1}	INDIR	Dyeing - Fabric production - Dry cleaning - Printing - Printing - Functional finishing	elastane- polyamide	0.50	1.7	5.7	2.40	Equalisatio n	NI	198.5	NI

PT099_w{1}	INDIR	Dyeing - Printing - Functional finishing	blend cotton- synthetic- cotton- elastane- polyamide- polyester- rayon(lyo- cell)- rayon(mod- al)- rayon(visco- se)-silk	1.0	1.6	5.7	NI	Screening - Oil separation - Other	127.0	140.0	NI
IT059_w{1}	INDIR	Scouring - Mercerising - Bleaching - Dyeing - Singeing - Dry cleaning	blend cotton- synthetic- cotton	3.2	4.4	6.0	4.68	Other	695.8	732.5	NI
PT104_w{1}	INDIR	Dyeing - Bleaching	cotton	0.2	2.5	7.0	1.34	Ultrafiltrati- on - Other	53.4	109.4	NI
PT113_w{1}	INDIR	Dyeing - Washing synthetic fibre - Bleaching - Functional finishing	cotton	2.0	3.7	7.0	7.61	Screening - Other	81.0	86.7	1.3
PT114_w{2}	INDIR	NI	NI	5.0	5.7	7.0	0.04	No information	NI	186.0	53.3
<p>NB: DIR: Direct discharge. INDIR: Indirect discharge. NI: No information. Source: [ 50, TWG 2019 ]</p>											

Table 4.36: Environmental performance of combinations of waste water treatment techniques for antimony (Sb) emissions to water

Emission point	Type of discharge	Associated processes	Type of fibre	Minimum concentration over 3 years (mg/l)	Average concentration over 3 years (mg/l)	Maximum concentration over 3 years (mg/l)	Maximum load over 3 years (g/day)	Combination of techniques	Maximum amount of waste water discharged (m <sup>3</sup> /t of textile)	Maximum specific water consumption at plant level (m <sup>3</sup> /t of textile)	% of recycled/reused water in total water consumed
IT067_w{1}	DIR	Dyeing - Printing - Other - Shrink-proof finishing	wool	0.0005	0.0005	0.0005	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation	43.7	48.6	NI
IT092_w{1}	DIR	Dyeing - Other	wool	0.0005	0.0005	0.0005	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Reverse osmosis	99.4	196.9	NI
BE008_w{1}	INDIR	Printing - Dyeing	blend wool-synthetic-polyamide	0.0033	0.003	0.0033	NI	Equalisation - Grit separators - Other	45.6	48.2	NI

DE031_w{1}	INDIR	Dyeing	acrylic- blend wool- synthetic- blend cotton- synthetic- cotton-flax- polyester	NI	0.007	0.014	NI	No information	33.7	18.0	NI
BE011_w{1}	DIR	Dyeing	-	0.01	0.013	0.02	0.010	Equalisation - Neutralisation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sand filtration - Nanofiltration - Chemical oxidation (incl. Advanced oxidation)	62.9	70.2	20.3
IT065_w{1}	INDIR	Desizing - Mercerising - Bleaching - Dyeing - Dyeing - Singeing - Singeing - Functional finishing	blend cotton- synthetic- cotton- polyester	0.0097	0.019	0.028	0.037	Other	0.14	147.0	NI

BE010_w{1}	DIR	Bleaching - Dyeing - Bleaching - Scouring - Functional finishing	blend cotton-synthetic-cotton	0.020	0.025	0.031	NI	Equalisation - - Activated sludge process - Nitrification/denitrification - Other	67.7	92.9	2.0
SE118_w{1}	INDIR	Washing synthetic fibre - Scouring - Scouring - Bleaching - Dyeing - Singeing - Printing - Functional finishing - Shrink-proof finishing - Coating (also back-coating) and laminating - Thermal treatment (e.g drying, thermofixation, curing)	blend cotton-synthetic-cotton-polyester	0.050	0.075	0.11	NI	Sedimentation - Equalisation - Neutralisation	168.0	175.0	NI

IT084_w{1}	INDIR	Bleaching - Dyeing - Thermal treatment (e.g drying, thermofixat ion, curing)	cotton- polyester- rayon(mod al)- rayon(visco se)	0.001	0.026	0.12	NI	Equalisatio n - Neutralisati on - Grit separators - Screening - Coagulation and flocculation - Sedimentati on	0.13	150.0	NI
BE014_w{1}	DIR	Bleaching - Dyeing - Functional finishing	cotton- wool-other	0.033	0.065	0.16	0.0081	Equalisatio n - Activated sludge process - Nitrificatio n/denitrific ation	20.9	23.7	10.0
<p>NB: DIR: Direct discharge. INDIR: Indirect discharge. NI: No information. Source: [ 50, TWG 2019 ]</p>											

Table 4.37: Environmental performance of individual or combinations of waste water treatment techniques for chromium (Cr) emissions to water

Emission point	Type of discharge	Associated processes	Type of fibre	Minimum concentration over 3 years (mg/l)	Average concentration over 3 years (mg/l)	Maximum concentration over 3 years (mg/l)	Maximum load over 3 years (g/day)	Combination of techniques	Maximum amount of waste water discharged (m <sup>3</sup> /t of textile)	Maximum specific water consumption at plant level (m <sup>3</sup> /t of textile)	% of recycled/reused water in total water consumed
SE118_w{1}	INDIR	Washing synthetic fibre - Scouring - Bleaching - Dyeing - Singeing - Printing - Functional finishing - Shrink-proof finishing - Coating (also back-coating) and laminating - Thermal treatment (e.g drying, thermofixation, curing)	blend cotton-synthetic-cotton-polyester	0.001	0.002	0.006	NI	Sedimentation - Equalisation - Neutralisation	168.0	175.0	NI
DE031_w{1}	INDIR	Dyeing	acrylic-blend wool-synthetic-blend cotton-synthetic-cotton-flax-polyester	0.005	0.006	0.007	NI	No information	33.7	18.0	NI

IT094_w{1}	INDIR	NI	acrylic- blend cotton- synthetic- blend wool- synthetic- cotton- flax-hemp- polyamide -polyester- rayon(visc ose)-silk	0.001	0.002	0.008	NI	Other	41.9	3.0	95.9
UK124_w{1}	DIR	Dyeing - Functional finishing - Washing synthetic fibre	polyamide -polyester- other	0.001	0.003	0.008	NI	Neutralisati on - Coagulatio n and flocculatio n - Flotation - Other	310.8	355.9	NI
FR131_w{1}	DIR	Washing synthetic fibre - Bleaching - Dyeing - Printing - Functional finishing - Coating (also back- coating) and laminating - Thermal treatment (e.g drying, thermofixati on, curing)	blend cotton- synthetic- cotton- polyester	NI	0.003	0.009	NI	Screening - Sedimentat ion - Activated sludge process - Sedimentat ion - Other	29.4	37.6	NI



DE042_w{1}	INDIR	Washing synthetic fibre - Desizing - Bleaching - Dyeing - Functional finishing	cotton-polyacrylonitrile-polyester-other	0.005	0.006	0.010	0.002	Neutralisation - Equalisation	NI	29.7	NI
DE045_w{1}	INDIR	Washing synthetic fibre - Desizing - Desizing	cotton-polyester	NI	0.010	NI	0.006	No information	NI	48.7	NI
DE039_w{1}	INDIR	Mercerising - Dyeing - Washing synthetic fibre - Bleaching - Desizing	blend cotton-synthetic-cotton-polyamide-polyester	0.008	0.011	0.013	NI	Equalisation - Neutralisation	36.0	36.0	NI
FR134_w{1}	DIR	Washing synthetic fibre - Desizing - Mercerising - Bleaching - Dyeing - Singeing - Functional finishing	cotton	0.003	0.005	0.013	0.006	Equalisation - Neutralisation - Grit separators - Activated sludge process - Anaerobic treatment	67.0	72.5	NI
IT059_w{2}	INDIR	Thermal treatment (e.g drying, thermofixation, curing) - Functional finishing	blend cotton-synthetic-cotton	0.001	0.006	0.014	NI	No technique used	36.6	732.5	NI

DE024_w{1}	INDIR	Desizing - Dyeing - Scouring - Singeing	blend cotton- synthetic- cotton- polyamide -polyester	0.010	0.011	0.020	0.001	Equalisation	3.9	4.7	NI
FR136_w{1}	INDIR	Desizing - Scouring - Bleaching - Mercerising - Dyeing - Singeing - Fabric production - Functional finishing	blend cotton- synthetic- cotton- polyester	0.006	0.012	0.021	0.016	Grit separators - Neutralisation	60.1	99.9	10.2
IT059_w{1} ( <sup>1</sup> ) ( <sup>2</sup> )	INDIR	Scouring - Mercerising - Bleaching - Dyeing - Singeing - Dry cleaning	blend cotton- synthetic- cotton	0.001	0.011	0.021	0.010	Other	695.8	732.5	NI
IT074_w{2}	INDIR	Washing synthetic fibre - Scouring	blend cotton- synthetic- blend wool- synthetic- cotton- polyester- silk	0.009	0.020	0.028	NI	Other - Other	NI	46.0	NI

IT076_w{1}	INDIR	Raw wool scouring	wool	0.030	0.030	0.030	NI	Equalisation - Flotation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sedimentation - Membrane bioreactor	58.3	52.9	NI
IT077_w{1}	INDIR	Desizing - Mercerising - Scouring - Bleaching - Singeing - Thermal treatment (e.g drying, thermofixation, curing)	blend cotton-synthetic- blend wool-synthetic-cotton-polyester-rayon(viscose)-wool	0.010	0.020	0.030	0.355	No information	NI	21.6	19.1

DE030_w{1}	INDIR	Washing synthetic fibre - Desizing - Mercerising - Bleaching - Singeing - Dyeing - Functional finishing - Thermal treatment (e.g drying, thermofixation, curing)	blend cotton-synthetic-cotton-rayon (viscose)	0.005	0.012	0.031	NI	Equalisation - Neutralisation - Screening	51.2	61.4	NI
FR135_w{1}	INDIR	Washing synthetic fibre	acrylic	NI	0.003	0.031	NI	Grit separators	11.5	17.6	NI
PT109_w{1}	INDIR	Mercerising - Desizing - Scouring - Bleaching - Dyeing - Shrink-proof finishing - Singeing - Functional finishing - Thermal treatment (e.g drying, thermofixation, curing)	blend cotton-synthetic-cotton-polyester-	0.034	0.034	0.034	0.061	Oil separation - Neutralisation	74.0	91.6	14.0

IT065_w{1}	INDIR	Desizing - Mercerising - Bleaching - Dyeing - Dyeing - Singeing - Singeing - Functional finishing	blend cotton- synthetic- cotton- polyester	0.012	0.022	0.040	0.053	Other	0.1	147.0	NI
CZ015_w{1}	INDIR	Dyeing - Functional finishing	polyester- other	0.007	0.036	0.050	0.027	Grit separators - Equalisatio n - Sedimentat ion	0.0	0.0	NI
DE023_w{1}	INDIR	Washing synthetic fibre - Mercerising - Bleaching - Dyeing	blend cotton- synthetic- cotton- polyamide -polyester- rayon (viscose)	0.010	0.034	0.050	NI	No information	72.0	72.0	NI
DE029_w{1}	INDIR	Dyeing	polyamide -polyester- other	0.050	0.050	0.050	NI	No information	18.0	21.0	NI
DE051_w{1} ( <sup>1</sup> ) ( <sup>2</sup> )	INDIR	Washing synthetic fibre - Scouring - Bleaching - Dyeing - Functional finishing	blend cotton- synthetic- blend wool- synthetic- cotton- polyacrylo nitrile- polyamide -polyester- wool-other	0.010	0.014	0.050	0.034	Neutralisati on - Coagulatio n and flocculatio n - Equalisatio n	60.0	60.0	NI

FR132_w{2}	DIR	Bleaching - Dyeing	cotton-flax	0.003	0.010	0.050	0.003	Screening - Activated sludge process	0.1	216.0	NI
SE120_w{1}	INDIR	Washing synthetic fibre - Desizing - Bleaching	acrylic- blend cotton- synthetic- cotton- flax- polyamide -wool	0.007	0.025	0.051	0.028	Neutralisati on - Oil separation - Sedimentat ion - Equalisatio n	123.0	85.7	8.0
IT082_w{1} ( <sup>1</sup> ) ( <sup>2</sup> )	DIR	Dyeing - Singeing - Functional finishing - Thermal treatment (e.g drying, thermofixati on, curing) - Wool Fulling	wool	NI	0.033	0.059	NI	Equalisatio n - Neutralisati on - Activated sludge process - Nitrificatio n/denitrific ation - Sedimentat ion - Adsorption (e.g. powdered/g ranular activated carbon, lignite coke, etc.) - Other	117.0	142.0	20.0
AT006_w{1}	INDIR	Bleaching - Dyeing	NI	0.019	0.036	0.062	0.032	Flotation	NI	NI	NI

IT069_w{1}	INDIR	Scouring - Bleaching - Mercerising	blend cotton-synthetic-cotton-flax-rayon(viscose)	0.018	0.033	0.065	NI	Other	11.2	12.0	NI
IT060_w{1}	INDIR	Dyeing - Spinning - Fabric production - Desizing - Mercerising - Thermal treatment (e.g drying, thermofixation, curing) - Shrink-proof finishing - Singeing - Coating (also back-coating) and laminating	cotton	0.050	0.051	0.070	NI	No information	NI	NI	NI
IT097_w{1}( <sub>2</sub> )	DIR	Dyeing - Shrink-proof finishing - Printing - Other	wool	0.005	0.038	0.070	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation	258.6	292.7	NI

BE009_w{2}	DIR	Printing - Coating (also back- coating) and laminating	other- polyamide	0.039	0.054	0.073	NI	Screening - Sedimentat ion - Equalisatio n - Activated sludge process - Sand filtration - Coagulatio n and flocculatio n - Flotation - Chemical oxidation (incl. Advanced oxidation) - Sand filtration - Chemical reduction - Microfiltrat ion - Reverse osmosis	25.2	28.8	20.0
IT091_w{1}	INDIR	Scouring - Dyeing - Functional finishing - Thermal treatment (e.g drying, thermofixati on, curing) - Other	cotton- flax- polyester- rayon(visc ose)	0.020	0.032	0.073	NI	No information	127.1	134.2	70.6



IT064_w{1}( 2)	INDIR	Scouring	blend cotton- synthetic- cotton- polyamide -polyester- wool	0.007	0.039	0.078	NI	Other	80.4	36.1	69.4
IT074_w{1}	INDIR	Washing synthetic fibre - Scouring - Functional finishing - Dry cleaning - Other	blend cotton- synthetic- blend wool- synthetic- cotton- polyester- silk	0.018	0.047	0.083	NI	Other - Other	NI	46.0	NI
UK127_w{1}	INDIR	Mercerising - Bleaching - Dyeing - Scouring - Singeing - Printing	blend cotton- synthetic- blend wool- synthetic- cotton	0.009	0.030	0.086	0.170	Neutralisati on	48.1	70.8	NI
AT003_w{1}	INDIR	Mercerising - Dyeing - Desizing - Bleaching	cotton	0.010	0.033	0.090	0.171	Neutralisati on	74.1	155.8	NI
DE026_w{1}	INDIR	Washing synthetic fibre - Desizing - Dyeing - Bleaching	cotton- flax- polyamide -polyester- other	0.005	0.013	0.090	0.002	No information	NI	NI	NI

DE049_w{1}	INDIR	Desizing - Bleaching - Bleaching - Dyeing - Singeing - Printing - Coating (also back- coating) and laminating - Scouring - Functional finishing	cotton- other	0.005	0.028	0.095	NI	Equalisatio n - Neutralisati on	43.4	54.0	7.0
IT092_w{1} ( <sup>1</sup> )	DIR	Dyeing - Other	wool	0.050	0.085	0.100	NI	Equalisatio n - Neutralisati on - Activated sludge process - Nitrificatio n/denitrific ation - Sedimentat ion - Reverse osmosis	99.4	196.9	NI
<p>Dyeing with chromium-containing dyes:  <sup>(1)</sup> Metal complex 1:1 dyes (some may contain chromium).  <sup>(2)</sup> Metal complex 1:2 dyes (some may contain chromium).  NB:  DIR: Direct discharge.  INDIR: Indirect discharge.  NI: No information.  Source: [50, TWG 2019]</p>											

Table 4.38: Environmental performance of individual or combinations of waste water treatment techniques for copper (Cu) emissions to water

Emission point	Type of discharge	Associated processes	Type of fibre	Minimum concentration over 3 years (mg/l)	Average concentration over 3 years (mg/l)	Maximum concentration over 3 years (mg/l)	Maximum load over 3 years (g/day)	Combination of techniques	Maximum amount of waste water discharged (m <sup>3</sup> /t of textile)	Maximum specific water consumption at plant level (m <sup>3</sup> /t of textile)	% of recycled/reused water in total water consumed
BE013_w{1}	INDIR	Mercerising	blend cotton-synthetic-cotton	0.005	0.007	0.008	0.001	Distillation/rectification - Equalisation - Neutralisation	9.7	12.7	NI
BE011_w{1}	DIR	Dyeing	NI	0.005	0.008	0.011	0.009	Equalisation - Neutralisation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sand filtration - Nanofiltration - Chemical oxidation (incl. Advanced oxidation)	62.9	70.2	20.3

BE007_w{1}	DIR	Dyeing	polyamide- other	NI	0.004	0.015	NI	Equalisation - Neutralisation - Sand filtration - Activated sludge process - Nitrification/ denitrification	10.7	14.3	5.4
BE008_w{1}	INDIR	Printing - Dyeing	blend wool- synthetic- polyamide	NI	0.007	0.015	NI	Equalisation - Grit separators - Other	45.6	48.2	NI
BE014_w{1}	DIR	Bleaching - Dyeing - Functional finishing	cotton- wool-other	0.010	0.013	0.016	0.003	Equalisation - Activated sludge process - Nitrification/ denitrification	20.9	23.7	10.0
DE042_w{1}	INDIR	Washing synthetic fibre - Desizing - Bleaching - Dyeing - Functional finishing	cotton- polyacrylon itrile- polyester- other	0.005	0.008	0.016	0.003	Neutralisation - Equalisation	NI	29.7	NI
DE034_w{1}	DIR	Washing synthetic fibre - Desizing - Bleaching - Dyeing	cotton- elastane- polyamide- polyester- rayon (viscose)- other	0.005	0.015	0.021	0.007	Activated sludge process - Nitrification/ denitrification	38.0	41.4	NI

IT059_w{2}	INDIR	Thermal treatment (e.g drying, thermofixation, curing) - Functional finishing	blend cotton-synthetic-cotton	0.004	0.014	0.023	NI	No technique used	36.6	732.5	NI
PT098_w{1}	DIR	Wool Fulling - Functional finishing - Dyeing - Thermal treatment (e.g drying, thermofixation, curing)	elastane-polyamide-polyester-rayon(viscose)-wool-other	0.008	0.016	0.027	0.014	Equalisation - Neutralisation - Sedimentation - Sand filtration - Activated sludge process - Other	328.2	259.0	NI
DE032_w{1}	DIR	Washing synthetic fibre - Desizing - Bleaching - Dyeing - Printing	blend cotton-synthetic-cotton-polyester	0.003	0.009	0.028	NI	Equalisation - Neutralisation - Grit separators - Coagulation and flocculation - Sedimentation - Sand filtration - Nitrification/denitrification - Activated sludge process	NI	47.1	NI

UK124_w{1}	DIR	Dyeing - Functional finishing - Washing synthetic fibre	polyamide- polyester- other	0.001	0.017	0.029	NI	Neutralisati on - Coagulation and flocculation - Flotation - Other	310.8	355.9	NI
IT074_w{2}	INDIR	Washing synthetic fibre - Scouring	blend cotton- synthetic- blend wool- synthetic- cotton- polyester- silk	0.020	0.025	0.029	NI	Other - Other	NI	46.0	NI
DE044_w{1}	INDIR	Desizing - Mercerising - Bleaching - Dyeing	blend cotton- synthetic- cotton- wool	0.030	0.030	0.030	NI	No information	200.0	103.0	NI
IT073_w{1}	INDIR	Dyeing - Functional finishing	acrylic- blend cotton- synthetic- cellulose acetate- cotton- elastane- polyamide- polyester- rayon(mod al)- rayon(visco se)-wool	0.010	0.020	0.030	0.030	No technique used	129.6	147.7	48.0

IT076_w{1}	INDIR	Raw wool scouring	wool	0.030	0.030	0.030	NI	Equalisation - Flotation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sedimentation - Membrane bioreactor	58.3	52.9	NI
IT069_w{1}	INDIR	Scouring - Bleaching - Mercerising	blend cotton-synthetic-cotton-flax-rayon(viscose)	0.023	0.027	0.031	NI	Other	11.2	12.0	NI
BE008_w{2}	INDIR	Dyeing - Printing	blend wool-synthetic-polyamide	0.007	0.010	0.034	0.006	Equalisation - Grit separators - Other	45.6	48.2	NI
IT082_w{2}	INDIR	Dyeing - Singeing - Functional finishing - Thermal treatment (e.g drying, thermofixation, curing) - Wool Fulling	wool	0.025	0.032	0.038	NI	Equalisation	NI	142.0	20.0

IT079_w{1}	INDIR	Scouring - Wool Fulling - Functional finishing - Thermal treatment (e.g drying, thermofixat ion, curing) - Other	blend wool- synthetic- wool	0.010	0.023	0.040	0.322	Other	41.9	41.9	100.0
ES058_w{1}	INDIR	Mercerisin g - Bleaching - Dyeing - Desizing - Fabric production - Printing - Thermal treatment (e.g drying, thermofixat ion, curing)	blend cotton- synthetic- cotton	NI	0.040	NI	0.073	No information	27.8	30.5	NI
PT109_w{1}	INDIR	Mercerisin g - Desizing - Scouring - Bleaching - Dyeing - Shrink- proof finishing - Singeing - Functional finishing - Thermal treatment (e.g drying, thermofixat ion, curing)	blend cotton- synthetic- cotton- polyester-	0.044	0.044	0.044	0.081	Oil separation - Neutralisati on	74.0	91.6	14.0



IT084_w{1}	INDIR	Bleaching - Dyeing - Thermal treatment (e.g drying, thermofixat ion, curing)	cotton- polyester- rayon(mod al)- rayon(visco se)	0.001	0.008	0.045	NI	Equalisatio n - Neutralisati on - Grit separators - Screening - Coagulatio n and flocculation - Sedimentati on	0.1	150.0	NI
AT006_w{1}	INDIR	Bleaching - Dyeing	-	0.019	0.035	0.048	0.043	Flotation	NI	NI	NI
DE023_w{1}	INDIR	Washing synthetic fibre - Mercerisin g - Bleaching - Dyeing	blend cotton- synthetic- cotton- polyamide- polyester- rayon (viscose)	0.010	0.030	0.050	NI	No information	72.0	72.0	NI
AT005_w{1}	INDIR	Dyeing	blend wool- synthetic- wool	0.010	0.021	0.053	0.040	Neutralisati on	97.2	98.8	NI
DE046_w{1}	INDIR	Washing synthetic fibre - Dyeing	polyamide- polyester	0.010	0.025	0.055	NI	No information	32.0	32.0	NI
IT074_w{1}	INDIR	Washing synthetic fibre - Scouring - Functional finishing - Dry cleaning - Other	blend cotton- synthetic- blend wool- synthetic- cotton- polyester- silk	0.028	0.039	0.057	NI	Other - Other	NI	46.0	NI

IT090_w{1}	INDIR	Scouring - Dyeing - Thermal treatment (e.g drying, thermofixat ion, curing) - Other - Bleaching	acrylic- blend wool- synthetic- polyamide- polyester- rayon(visco se)-silk- wool	0.016	0.034	0.062	0.550	Other	42.3	41.9	NI
IT061_w{1}	INDIR	Scouring - Wool Carbonisin g	wool	0.021	0.043	0.065	NI	Other	6.3	NI	100.0
IT091_w{1}	INDIR	Scouring - Dyeing - Functional finishing - Thermal treatment (e.g drying, thermofixat ion, curing) - Other	cotton-flax- polyester- rayon(visco se)	0.030	0.050	0.067	NI	No information	127.1	134.2	70.6

BE009_w{1}	DIR	Printing - Coating (also back- coating) and laminating	other- polyamide	0.010	0.071	0.019	0.014	Screening - Sedimentati on - Equalisatio n - Activated sludge process - Sand filtration - Coagulatio n and flocculation - Flotation - Chemical oxidation (incl. Advanced oxidation) - Sand filtration - Chemical reduction - Microfiltrat ion - Reverse osmosis	25.2	28.8	20.0
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FR131_w{1}	DIR	Washing synthetic fibre - Bleaching - Dyeing - Printing - Functional finishing - Coating (also back-coating) and laminating - Thermal treatment (e.g drying, thermofixation, curing)	blend cotton-synthetic-cotton-polyester	0.01	0.03	0.08	NI	Screening - Sedimentation - Activated sludge process - Sedimentation - Other	29.4	37.6	NI
IT089_w{1}	INDIR	Scouring - Dyeing - Thermal treatment (e.g drying, thermofixation, curing) - Other - Bleaching	acrylic-blend wool-synthetic-polyamide-polyester-rayon(viscose)-silk-wool	0.02	0.03	0.08	0.247	Other	25.8	25.8	NI

BE009_w{2}	DIR	Printing - Coating (also back- coating) and laminating	other- polyamide	NI	0.01	0.08	NI	Screening - Sedimentati on - Equalisatio n - Activated sludge process - Sand filtration - Coagulatio n and flocculation - Flotation - Chemical oxidation (incl. Advanced oxidation) - Sand filtration - Chemical reduction - Microfiltrat ion - Reverse osmosis	25.2	28.8	20.0
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CZ017_w{1}	INDIR	Spinning - Fabric production - Singeing - Functional finishing - Shrink- proof finishing - Thermal treatment (e.g drying, thermofixat ion, curing) - Other	polyester- wool	0.01	0.04	0.08	0.128	Equalisatio n - Other	172.8	190.4	NI
PT115_w{1}	INDIR	Dyeing - Functional finishing	cotton	0.02	0.06	0.09	0.140	Equalisatio n - Neutralisati on - Screening	NI	106.7	NI

SE118_w{1}	INDIR	Washing synthetic fibre - Scouring - Scouring - Bleaching - Dyeing - Singeing - Printing - Functional finishing - Shrink-proof finishing - Coating (also back-coating) and laminating - Thermal treatment (e.g drying, thermofixation, curing)	blend cotton-synthetic-cotton-polyester	0.02	0.04	0.09	NI	Sedimentation - Equalisation - Neutralisation	168.0	175.0	NI
IT067_w{1}	DIR	Dyeing - Printing - Other - Shrink-proof finishing	wool	0.01	0.04	0.09	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation	43.7	48.6	NI
IT070_w{1}	INDIR	NI	other	0.03	0.07	0.09	0.021	No information	235.0	16.4	94.7

IT092_w{1}	DIR	Dyeing - Other	wool	0.01	0.03	0.10	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/ denitrification - Sedimentation - Reverse osmosis	99.4	196.9	NI
PT113_w{1}	INDIR	Dyeing - Washing synthetic fibre - Bleaching - Functional finishing	cotton	0.10	0.10	0.10	0.163	Screening - Other	81.0	86.7	1.3
FR136_w{1}	INDIR	Desizing - Scouring - Bleaching - Mercerising - Dyeing - Singeing - Fabric production - Functional finishing	blend cotton- synthetic- cotton- polyester	0.04	0.07	0.11	0.076	Grit separators - Neutralisation	60.1	99.9	10.2



IT088_w{1}	INDIR	Dyeing - Bleaching	acrylic- blend cotton-synthetic-cotton-elastane-polyamide -polyester-rayon(viscose)-silk-wool	0.03	0.08	0.12	NI	No information	156.0	NI	100.0
AT001_w{1}	INDIR	Dyeing - Bleaching	NI	0.02	0.09	0.15	0.089	No technique used	NI	NI	NI
DE041_w{1}	INDIR	Desizing - Bleaching - Dyeing	cotton	0.02	0.05	0.15	NI	No information	50.4	76.0	NI
IT078_w{1}	INDIR	Wool Fulling - Washing synthetic fibre - Dyeing	blend cotton-synthetic- blend wool-synthetic-cotton-polyester-rayon(viscose)-wool	0.00	0.03	0.15	NI	Other	88.7	94.2	NI
DE039_w{1}	INDIR	Mercerising - Dyeing - Washing synthetic fibre - Bleaching - Desizing	blend cotton-synthetic-cotton-polyamide-polyester	0.11	0.13	0.15	NI	Equalisation - Neutralisation	36.0	36.0	NI

IT063_w{1}	INDIR	Dyeing - Fabric production - Dry cleaning - Printing - Printing - Functional finishing	elastane- polyamide	0.01	0.04	0.16	0.120	Equalisatio n	NI	198.5	NI
DE022_w{1}	INDIR	Raw wool scouring - Washing synthetic fibre - Desizing - Scouring - Bleaching - Dyeing - Thermal treatment (e.g drying, thermofixat ion, curing) - Functional finishing - Coating (also back- coating) and laminating	acrylic- blend cotton- synthetic- blend wool- synthetic- cellulose acetate- cotton- polyamide- polyester- rayon (viscose)- other	0.01	0.03	0.17	NI	Neutralisati on - Oil separation - Evaporatio n	65.0	80.0	NI
IT071_w{1}	INDIR	Dyeing - Bleaching - Scouring	acrylic- cotton- polyester- rayon(visco se)-wool- other	0.02	0.06	0.18	2.787	No information	35.8	35.8	NI

DE049_w{1}	INDIR	Desizing - Bleaching - Bleaching - Dyeing - Singeing - Printing - Coating (also back- coating) and laminating - Scouring - Functional finishing	cotton- other	0.02	0.05	0.18	NI	Equalisatio n - Neutralisati on	43.4	54.0	7.0
IT077_w{1}	INDIR	Desizing - Mercerisin g - Scouring - Bleaching - Singeing - Thermal treatment (e.g drying, thermofixat ion, curing)	blend cotton- synthetic- blend wool- synthetic- cotton- polyester- rayon(visco se)-wool	NI	0.06	0.19	1.803	No information	NI	21.6	19.1
FR132_w{2}	DIR	Bleaching - Dyeing	cotton-flax	0.06	0.12	0.20	0.072	Screening - Activated sludge process	0.1	216.0	NI

PT099_w{1}	INDIR	Dyeing - Printing - Functional finishing	blend cotton- synthetic- cotton- elastane- polyamide- polyester- rayon(lyoce ll)- rayon(mod al)- rayon(visco se)-silk	0.03	0.16	0.20	NI	Screening - Oil separation - Other	127.0	140.0	NI
PT102_w{1}	INDIR	Scouring - Dyeing - Bleaching	cotton	0.03	0.17	0.20	NI	Other	101.6	89.0	NI
PT105_w{1}	INDIR	Dyeing - Bleaching	polyester- rayon(visco se)-wool- other	0.20	0.20	0.20	NI	No information	82.5	NI	NI
PT110_w{2}	INDIR	Dyeing	cotton	0.10	0.18	0.20	NI	Equalisatio n - Grit separators - Screening	21.6	102.3	NI

PT114_w{1}	INDIR	Mercerising - Dyeing - Washing synthetic fibre - Desizing - Scouring - Bleaching - - Thermal treatment (e.g drying, thermofixation, curing) - Dry cleaning	NI	0.20	0.20	0.20	0.281	Equalisation - Neutralisation - Screening - Coagulation and flocculation - Sedimentation - Sand filtration - Adsorption (e.g. powdered/g granular activated carbon, lignite coke, etc.)	154.0	186.0	53.3
SE119_w{1}	INDIR	Washing synthetic fibre - Desizing - Functional finishing - Dyeing	polyamide-polyester	0.09	NI	0.22	0.032	No technique used	115.0	120.0	NI
IT059_w{1}	INDIR	Scouring - Mercerising - Bleaching - Dyeing - Singeing - Dry cleaning	blend cotton-synthetic-cotton	0.01	0.07	0.24	0.032	Other	695.8	732.5	NI

IT097_w{1}	DIR	Dyeing - Shrink- proof finishing - Printing - Other	wool	0.01	0.04	0.25	NI	Equalisatio n - Neutralisati on - Activated sludge process - Nitrificatio n/denitrific ation - Sedimentati on	258.6	292.7	NI
PT104_w{1}	INDIR	Dyeing - Bleaching	cotton	0.11	0.20	0.25	0.099	Ultrafiltrati on - Other	53.4	109.4	NI
PT111_w{1}	DIR	Desizing - Dyeing - Fabric production - Wool Fulling - Functional finishing - Shrink- proof finishing - Dry cleaning - Thermal treatment (e.g drying, thermofixat ion, curing)	blend wool- synthetic- cotton- elastane- flax- polyester- wool	0.01	0.17	0.25	0.160	Equalisatio n - Neutralisati on - Activated sludge process - Sedimentati on - Sand filtration - Other	225.3	267.3	100.0

DE030_w{1}	INDIR	Washing synthetic fibre - Desizing - Mercerising - Bleaching - Singeing - Dyeing - Functional finishing - Thermal treatment (e.g drying, thermofixation, curing)	blend cotton-synthetic-cotton-rayon (viscose)	0.07	0.11	0.29	NI	Equalisation - Neutralisation - Screening	51.2	61.4	NI
DE026_w{1}	INDIR	Washing synthetic fibre - Desizing - Dyeing - Bleaching	cotton-flax-polyamide-polyester-other	0.03	0.10	0.30	0.030	No information	NI	NI	NI
DE031_w{1}	INDIR	Dyeing	acrylic-blend wool-synthetic-blend cotton-synthetic-cotton-flax-polyester	0.01	0.10	0.32	NI	No information	33.7	18.0	NI
FR134_w{1}	DIR	Washing synthetic fibre - Desizing - Mercerising - Bleaching - Dyeing - Singeing - Functional finishing	cotton	0.05	0.12	0.32	0.149	Equalisation - Neutralisation - Grit separators - Activated sludge process - Anaerobic treatment	67.0	72.5	NI

PT108_w{1}	INDIR	Fabric production - Fabric production	NI	0.22	0.26	0.32	0.259	Neutralisation - Sand filtration - Sand filtration	99.3	96.5	37.0
FR135_w{1}	INDIR	Washing synthetic fibre	acrylic	NI	0.04	0.35	NI	Grit separators	11.5	17.6	NI
AT002_w{1}	INDIR	Bleaching - Dyeing	NI	0.06	0.15	0.37	0.646	Screening - Neutralisation	NI	NI	NI
DE051_w{1}	INDIR	Washing synthetic fibre - Scouring - Bleaching - Dyeing - Functional finishing	blend cotton-synthetic-blend wool-synthetic-cotton-polyacrylonitrile-polyamide-polyester-wool-other	0.01	0.09	0.39	0.238	Neutralisation - Coagulation and flocculation - Equalisation	60.0	60.0	NI
<p>NB:  DIR: Direct discharge.  INDIR: Indirect discharge.  NI: No information.  Source: [ 50, TWG 2019 ]</p>											



Table 4.39: Environmental performance of individual or combinations of waste water treatment techniques for nickel (Ni) emissions to water

Emission point	Type of discharge	Associated processes	Type of fibre	Minimum concentration over 3 years (mg/l)	Average concentration over 3 years (mg/l)	Maximum concentration over 3 years (mg/l)	Maximum load over 3 years (g/day)	Combination of techniques	Maximum amount of waste water discharged (m <sup>3</sup> /t of textile)	Maximum specific water consumption at plant level (m <sup>3</sup> /t of textile)	% of recycled/reused water in total water consumed
PT098_w{1}	DIR	Wool Fulling - Functional finishing - Dyeing - Thermal treatment (e.g drying, thermofixation, curing)	elastane-polyamide-polyester-rayon(viscose)-wool-other	0.0003	0.0014	0.0032	0.0012922	Equalisation - Neutralisation - Sedimentation - Sand filtration - Activated sludge process - Other	328.2	259.0	NI
IT059_w{1}	INDIR	Scouring - Mercerising - Bleaching - Dyeing - Singeing - Dry cleaning	blend cotton-synthetic-cotton	0.0009	0.0027	0.0044	0.0049283	Other	695.8	732.5	NI
IT067_w{1}	DIR	Dyeing - Printing - Other - Shrink-proof finishing	wool	0.0050	0.0050	0.0050	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation	43.7	48.6	NI

IT076_w{1}	INDIR	Raw wool scouring	wool	0.0050	0.0050	0.0050	NI	Equalisation - Flotation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sedimentation - Membrane bioreactor	58.3	52.9	NI
IT084_w{1}	INDIR	Bleaching - Dyeing - Thermal treatment (e.g drying, thermofixation, curing)	cotton-polyester-rayon(modal)-rayon(viscose)	0.0050	0.0050	0.0050	NI	Equalisation - Neutralisation - Grit separators - Screening - Coagulation and flocculation - Sedimentation	0.1	150.0	NI
UK124_w{1}	DIR	Dyeing - Functional finishing - Washing synthetic fibre	polyamide-polyester-other	0.0017	0.0032	0.0056	NI	Neutralisation - Coagulation and flocculation - Flotation - Other	310.8	355.9	NI

DE034_w{1}	DIR	Washing synthetic fibre - Desizing - Bleaching - Dyeing	cotton-elastane-polyamide-polyester-rayon (viscose)-other	0.0050	0.0052	0.0060	0.00331	Activated sludge process - Nitrification/denitrification	38.0	41.4	NI
BE014_w{1}	DIR	Bleaching - Dyeing - Functional finishing	cotton-wool-other	0.0056	0.0060	0.0064	0.000392	Equalisation - Activated sludge process - Nitrification/denitrification	20.9	23.7	10.0
IT059_w{2}	INDIR	Thermal treatment (e.g drying, thermofixation, curing) - Functional finishing	blend cotton-synthetic-cotton	0.0032	0.0061	0.0089	NI	No technique used	36.6	732.5	NI
IT091_w{1}	INDIR	Scouring - Dyeing - Functional finishing - Thermal treatment (e.g drying, thermofixation, curing) - Other	cotton-flax-polyester-rayon(viscose)	0.0040	0.0065	0.0090	NI	No information	127.1	134.2	70.6
AT005_w{1}	INDIR	Dyeing	blend wool-synthetic-wool	0.0100	0.0100	0.0100	0.00946	Neutralisation	97.2	98.8	NI

DE025_w{1}	DIR	Washing synthetic fibre - Dyeing - Printing	polyamide-polyester	NI	0.0003	0.0100	NI	Equalisation - Neutralisation - Coagulation and flocculation - Sedimentation - Activated sludge process	25.8	139.0	NI
DE031_w{1}	INDIR	Dyeing	acrylic- blend wool- synthetic- blend cotton- synthetic- cotton-flax- polyester	0.0100	0.0100	0.0100	NI	No information	33.7	18.0	NI
DE042_w{1}	INDIR	Washing synthetic fibre - Desizing - Bleaching - Dyeing - Functional finishing	cotton- polyacrylon itrile- polyester- other	0.0050	0.0057	0.0100	0.00233	Neutralisation - Equalisation	NI	29.7	NI

IT073_w{1}	INDIR	Dyeing - Functional finishing	acrylic- blend cotton- synthetic- cellulose acetate- cotton- elastane- polyamide- polyester- rayon(mod al)- rayon(visco se)-wool	NI	0.0060	0.0100	0.01	No technique used	129.6	147.7	48.0
IT082_w{2}	INDIR	Dyeing - Singeing - Functional finishing - Thermal treatment (e.g drying, thermofixat ion, curing) - Wool Fulling	wool	0.0100	0.0100	0.0100	NI	Equalisatio n	NI	142.0	20.0
DE045_w{1}	INDIR	Washing synthetic fibre - Desizing - Desizing	cotton- polyester	NI	0.0100	NI	0.00574	No information	NI	48.7	NI
SE119_w{1}	INDIR	Washing synthetic fibre - Desizing - Functional finishing - Dyeing	polyamide- polyester	NI	0.0100	NI	0.00144	No technique used	115.0	120.0	NI

IT074_w{1}	INDIR	Washing synthetic fibre - Scouring - Functional finishing - Dry cleaning - Other	blend cotton-synthetic- blend wool-synthetic-cotton-polyester-silk	0.0040	0.0067	0.0110	NI	Other - Other	NI	46.0	NI
IT074_w{2}	INDIR	Washing synthetic fibre - Scouring	blend cotton-synthetic- blend wool-synthetic-cotton-polyester-silk	0.0050	0.0082	0.0110	NI	Other - Other	NI	46.0	NI
BE011_w{1}	DIR	Dyeing	NI	0.0100	0.0106	0.0120	0.0070095	Equalisation - Neutralisation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sand filtration - Nanofiltration - Chemical oxidation (incl. Advanced oxidation)	62.9	70.2	20.3

DE026_w{1}	INDIR	Washing synthetic fibre - Desizing - Dyeing - Bleaching	cotton-flax-polyamide-polyester-other	0.0050	0.0071	0.0120	0.0009954	No information	NI	NI	NI
IT078_w{1}	INDIR	Wool Fulling - Washing synthetic fibre - Dyeing	blend cotton-synthetic- blend wool-synthetic-cotton-polyester-rayon(viscose)-wool	0.0040	0.0073	0.0120	NI	Other	88.7	94.2	NI
IT065_w{1}	INDIR	Desizing - Mercerising - Bleaching - Dyeing - Singeing - Functional finishing	blend cotton-synthetic-cotton-polyester	0.0112	0.0121	0.0129	0.0171699	Other	0.1	147.0	NI
AT002_w{1}	INDIR	Bleaching - Dyeing	NI	NI	0.0009	0.0130	0.00858	Screening - Neutralisation	NI	NI	NI
DE039_w{1}	INDIR	Mercerising - Dyeing - Washing synthetic fibre - Bleaching - Desizing	blend cotton-synthetic-cotton-polyamide-polyester	0.0120	0.0125	0.0130	NI	Equalisation - Neutralisation	36.0	36.0	NI
BE008_w{2}	INDIR	Dyeing - Printing	blend wool-synthetic-polyamide	0.0090	0.0120	0.0149	0.0027389	Equalisation - Grit separators - Other	45.6	48.2	NI

BE008_w{1}	INDIR	Printing - Dyeing	blend wool- synthetic- polyamide	NI	0.0099	0.0150	NI	Equalisatio n - Grit separators - Other	45.6	48.2	NI
BE009_w{2}	DIR	Printing - Coating (also back- coating) and laminating	other- polyamide	NI	0.0099	0.0200	NI	Screening - Sedimentati on - Equalisatio n - Activated sludge process - Sand filtration - Coagulatio n and flocculation - Flotation - Chemical oxidation (incl. Advanced oxidation) - Sand filtration - Chemical reduction - Microfiltrat ion - Reverse osmosis	25.2	28.8	20.0



CZ017_w{1}	INDIR	Spinning - Fabric production - Singeing - Functional finishing - Shrink- proof finishing - Thermal treatment (e.g drying, thermofixat ion, curing) - Other	polyester- wool	0.02	0.02	0.02	0.0345632	Equalisatio n - Other	172.8	190.4	NI
DE051_w{1}	INDIR	Washing synthetic fibre - Scouring - Bleaching - Dyeing - Functional finishing	blend cotton- synthetic- blend wool- synthetic- cotton- polyacrylon itrile- polyamide- polyester- wool-other	0.01	0.01	0.02	0.0122	Neutralisati on - Coagulatio n and flocculation - Equalisatio n	60.0	60.0	NI
IT071_w{2}	INDIR	Dyeing - Other - Functional finishing	acrylic- cotton- polyester- rayon(visco se)-wool- other	NI	0.01	0.02	0.40136	Other	35.8	35.8	NI

IT079_w{1}	INDIR	Scouring - Wool Fulling - Functional finishing - Thermal treatment (e.g drying, thermofixat ion, curing) - Other	blend wool- synthetic- wool	0.01	0.01	0.02	0.107846	Other	41.9	41.9	100
DE049_w{1}	INDIR	Desizing - Bleaching - Bleaching - Dyeing - Singeing - Printing - Coating (also back- coating) and laminating - Scouring - Functional finishing	cotton- other	0.01	0.01	0.02	NI	Equalisatio n - Neutralisati on	43.4	54.0	7.0
DE024_w{1}	INDIR	Desizing - Dyeing - Scouring - Singeing	blend cotton- synthetic- cotton- polyamide- polyester	0.01	0.01	0.03	0.000658	Equalisatio n	3.9	4.7	NI

DE030_w{1}	INDIR	Washing synthetic fibre - Desizing - Mercerising - Bleaching - Singeing - Dyeing - Functional finishing - Thermal treatment (e.g drying, thermofixation, curing)	blend cotton-synthetic-cotton-rayon (viscose)	0.01	0.01	0.03	NI	Equalisation - Neutralisation - Screening	51.2	61.4	NI
DE032_w{1}	DIR	Washing synthetic fibre - Desizing - Bleaching - Dyeing - Printing	blend cotton-synthetic-cotton-polyester	0.01	0.02	0.03	NI	Equalisation - Neutralisation - Grit separators - Coagulation and flocculation - Sedimentation - Sand filtration - Nitrification/denitrification - Activated sludge process	NI	47.1	NI

ES058_w{1}	INDIR	Mercerising - Bleaching - Dyeing - Desizing - Fabric production - Printing - Thermal treatment (e.g drying, thermofixation, curing)	blend cotton-synthetic-cotton	NI	0.03	NI	0.0687	No information	27.8	30.5	NI
IT061_w{1}	INDIR	Scouring - Wool Carbonising	wool	0.01	0.02	0.04	NI	Other	6.3	NI	100
DE029_w{1}	INDIR	Dyeing	polyamide-polyester-other	0.02	0.02	0.04	NI	No information	18.0	21.0	NI
FR135_w{1}	INDIR	Washing synthetic fibre	acrylic	NI	0.005	0.04	NI	Grit separators	11.5	17.6	NI
IT137_w{1}	INDIR	Dyeing	polyamide	0.01	0.011	0.04	NI	No technique used	108.0	NI	NI
AT003_w{1}	INDIR	Mercerising - Dyeing - Desizing - Bleaching	cotton	NI	0.022	0.05	0.095	Neutralisation	74.1	155.8	NI

IT097_w{1}	DIR	Dyeing - Shrink- proof finishing - Printing - Other	wool	0.01	0.035	0.05	NI	Equalisatio n - Neutralisati on - Activated sludge process - Nitrificatio n/denitrific ation - Sedimentati on	258.6	292.7	NI
IT087_w{1}	INDIR	Dyeing - Shrink- proof finishing - Shrink- proof finishing - Other	acrylic- cotton- rayon(visco se)-wool- other	0.05	0.053	0.05	NI	Equalisatio n	64.0	90.2	NI
AT001_w{1}	INDIR	Dyeing - Bleaching	NI	NI	0.005	0.06	NI	No technique used	NI	NI	NI
PT109_w{1}	INDIR	Mercerisin g - Desizing - Scouring - Bleaching - Dyeing - Shrink- proof finishing - Singeing - Functional finishing - Thermal treatment (e.g drying, thermofixat ion, curing)	blend cotton- synthetic- cotton- polyester-	0.07	0.07	0.07	0.1199174	Oil separation - Neutralisati on	74.0	91.6	14.0

IT070_w{1}	INDIR	NI	other	0.01	0.04	0.07	0.0115	No information	235.0	16.4	94.7
IT088_w{1}	INDIR	Dyeing - Bleaching	acrylic-blend cotton-synthetic-cotton-elastane-polyamide-polyester-rayon(viscose)-silk-wool	0.01	0.03	0.07	NI	No information	156.0	NI	100
BE007_w{1}	DIR	Dyeing	polyamide-other	0.05	0.07	0.08	NI	Equalisation - Neutralisation - Sand filtration - Activated sludge process - Nitrification/denitrification	10.7	14.3	5.4

BE009_w{1}	DIR	Printing - Coating (also back- coating) and laminating	other- polyamide	NI	0.02	0.09	0.0190174	Screening - Sedimentati on - Equalisatio n - Activated sludge process - Sand filtration - Coagulatio n and flocculation - Flotation - Chemical oxidation (incl. Advanced oxidation) - Sand filtration - Chemical reduction - Microfiltrat ion - Reverse osmosis	25.2	28.8	20.0
IT063_w{1}	INDIR	Dyeing - Fabric production - Dry cleaning - Printing - Printing - Functional finishing	elastane- polyamide	0.02	0.04	0.10	0.048	Equalisatio n	NI	198.5	NI

PT099_w{1}	INDIR	Dyeing - Printing - Functional finishing	blend cotton- synthetic- cotton- elastane- polyamide- polyester- rayon(lyoce ll)- rayon(mod al)- rayon(visco se)-silk	0.01	0.07	0.10	NI	Screening - Oil separation - Other	127.0	140.0	NI
PT110_w{2}	INDIR	Dyeing	cotton	0.01	0.07	0.10	NI	Equalisatio n - Grit separators - Screening	21.6	102.3	NI
PT113_w{1}	INDIR	Dyeing - Washing synthetic fibre - Bleaching - Functional finishing	cotton	0.10	0.10	0.10	0.1627	Screening - Other	81.0	86.7	1.3
<p>NB: DIR: Direct discharge. INDIR: Indirect discharge. NI: No information. Source: [ 50, TWG 2019 ]</p>											



Table 4.40: Environmental performance of individual or combinations of waste water treatment techniques for zinc (Zn) emissions to water

Emission point	Type of discharge	Associated processes	Type of fibre	Minimum concentration over 3 years (mg/l)	Average concentration over 3 years (mg/l)	Maximum concentration over 3 years (mg/l)	Maximum load over 3 years (g/day)	Combination of techniques	Maximum amount of waste water discharged (m <sup>3</sup> /t of textile)	Maximum specific water consumption at plant level (m <sup>3</sup> /t of textile)	% of recycled/reused water in total water consumed
BE011_w{1}	DIR	Dyeing	NI	0.02	0.03	0.04	0.03	Equalisation - Neutralisation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sand filtration - Nanofiltration - Chemical oxidation (incl. Advanced oxidation)	62.9	70.2	20.3

ES058_w{1}	INDIR	Mercerising - Bleaching - Dyeing - Desizing - Fabric production - Printing - Thermal treatment (e.g drying, thermofixation, curing)	blend cotton-synthetic-cotton	NI	0.05	NI	0.11	No information	27.8	30.5	NI
DE045_w{1}	INDIR	Washing synthetic fibre - Desizing - Desizing	cotton-polyester	NI	0.06	NI	0.03	No information	NI	48.7	NI
PT109_w{1}	INDIR	Mercerising - Desizing - Scouring - Bleaching - Dyeing - Shrink-proof finishing - Singeing - Functional finishing - Thermal treatment (e.g drying, thermofixation, curing)	blend cotton-synthetic-cotton-polyester-	0.06	0.06	0.06	0.10	Oil separation - Neutralisation	74.0	91.6	14.0

DE022_w{1}	INDIR	Raw wool scouring - Washing synthetic fibre - Desizing - Scouring - Bleaching - Dyeing - Thermal treatment (e.g drying, thermofixation, curing) - Functional finishing - Coating (also back-coating) and laminating	acrylic-blend cotton-synthetic-blend wool-synthetic-cellulose acetate-cotton-polyamide-polyester-rayon (viscose)-other	0.01	0.03	0.06	NI	Neutralisation - Oil separation - Evaporation	65.0	80.0	NI
UK124_w{1}	DIR	Dyeing - Functional finishing - Washing synthetic fibre	polyamide-polyester-other	0.01	0.03	0.06	NI	Neutralisation - Coagulation and flocculation - Flotation - Other	310.8	355.9	NI
PT105_w{1}	INDIR	Dyeing - Bleaching	polyester-rayon(viscose)-wool-other	0.08	0.08	0.08	NI	No information	82.5	NI	NI
BE013_w{1}	INDIR	Mercerising	blend cotton-synthetic-cotton	0.03	0.06	0.09	0.01	Distillation/rectification - Equalisation - Neutralisation	9.7	12.7	NI

PT115_w{1}	INDIR	Dyeing - Functional finishing	cotton	0.01	0.05	0.09	0.15	Equalisatio n - Neutralisati on - Screening	NI	106.7	NI
DE032_w{1}	DIR	Washing synthetic fibre - Desizing - Bleaching - Dyeing - Printing	blend cotton- synthetic- cotton- polyester	0.02	0.04	0.10	NI	Equalisatio n - Neutralisati on - Grit separators - Coagulatio n and flocculation - Sedimentati on - Sand filtration - Nitrificatio n/denitrific ation - Activated sludge process	NI	47.1	NI

IT082_w{1}	DIR	Dyeing - Singeing - Functional finishing - Thermal treatment (e.g drying, thermofixat ion, curing) - Wool Fulling	wool	NI	0.03	0.10	NI	Equalisatio n - Neutralisati on - Activated sludge process - Nitrificatio n/denitrific ation - Sedimentati on - Adsorption (e.g. powdered/g ranular activated carbon, lignite coke, etc.) - Other	117.0	142.0	20.0
PT110_w{2}	INDIR	Dyeing	cotton	0.05	0.09	0.10	NI	Equalisatio n - Grit separators - Screening	21.6	102.3	NI
DE029_w{1}	INDIR	Dyeing	polyamide- polyester- other	0.02	0.06	0.11	NI	No information	18.0	21.0	NI

BE009_w{2}	DIR	Printing - Coating (also back- coating) and laminating	other- polyamide	NI	0.05	0.12	NI	Screening - Sedimentati on - Equalisatio n - Activated sludge process - Sand filtration - Coagulatio n and flocculation - Flotation - Chemical oxidation (incl. Advanced oxidation) - Sand filtration - Chemical reduction - Microfiltrat ion - Reverse osmosis	25.2	28.8	20.0
BE010_w{1}	DIR	Bleaching - Dyeing - Bleaching - Scouring - Functional finishing	blend cotton- synthetic- cotton	0.03	0.06	0.12	0.02	Equalisatio n - - Activated sludge process - Nitrificatio n/denitrific ation - Other	67.7	92.9	2.0

SE118_w{1}	INDIR	Washing synthetic fibre - Scouring - Scouring - Bleaching - Dyeing - Singeing - Printing - Functional finishing - Shrink-proof finishing - Coating (also back-coating) and laminating - Thermal treatment (e.g drying, thermofixation, curing)	blend cotton-synthetic-cotton-polyester	0.03	0.07	0.12	NI	Sedimentation - Equalisation - Neutralisation	168.0	175.0	NI
FR132_w{2}	DIR	Bleaching - Dyeing	cotton-flax	0.02	0.05	0.13	0.07	Screening - Activated sludge process	0.135	216.0	NI
IT074_w{1}	INDIR	Washing synthetic fibre - Scouring - Functional finishing - Dry cleaning - Other	blend cotton-synthetic- blend wool-synthetic-cotton-polyester-silk	0.11	0.12	0.14	NI	Other - Other	NI	46.0	NI

BE009_w{1}	DIR	Printing - Coating (also back-coating) and laminating	other-polyamide	NI	0.05	0.14	0.03	Screening - Sedimentation - Equalisation - Activated sludge process - Sand filtration - Coagulation and flocculation - Flotation - Chemical oxidation (incl. Advanced oxidation) - Sand filtration - Chemical reduction - Microfiltration - Reverse osmosis	25.2	28.8	20.0
PT102_w{1}	INDIR	Scouring - Dyeing - Bleaching	cotton	0.03	0.06	0.14	NI	Other	101.6	89.0	NI
PT108_w{1}	INDIR	Fabric production - Fabric production	NI	0.05	0.10	0.14	0.10	Neutralisation - Sand filtration - Sand filtration	99.3	96.5	37.0



DE031_w{1}	INDIR	Dyeing	acrylic- blend wool- synthetic- blend cotton- synthetic- cotton-flax- polyester	0.03	0.09	0.16	NI	No information	33.7	18.0	NI
DE046_w{1}	INDIR	Washing synthetic fibre - Dyeing	polyamide- polyester	0.03	0.10	0.16	NI	No information	32.0	32.0	NI
AT006_w{1}	INDIR	Bleaching - Dyeing	NI	0.06	0.10	0.18	0.09	Flotation	NI	NI	NI
PT098_w{1}	DIR	Wool Fulling - Functional finishing - Dyeing - Thermal treatment (e.g drying, thermofixat ion, curing)	elastane- polyamide- polyester- rayon(visco se)-wool- other	0.09	0.15	0.18	0.07	Equalisati on - Neutralisati on - Sedimentati on - Sand filtration - Activated sludge process - Other	328.2	259.0	NI
FR136_w{1}	INDIR	Desizing - Scouring - Bleaching - Mercerisin g - Dyeing - Singeing - Fabric production - Functional finishing	blend cotton- synthetic- cotton- polyester	0.04	0.12	0.19	0.16	Grit separators - Neutralisati on	60.1	99.9	10.2

DE030_w{1}	INDIR	Washing synthetic fibre - Desizing - Mercerising - Bleaching - Singeing - Dyeing - Functional finishing - Thermal treatment (e.g drying, thermofixation, curing)	blend cotton-synthetic-cotton-rayon (viscose)	0.06	0.10	0.19	NI	Equalisation - Neutralisation - Screening	51.2	61.4	NI
IT063_w{1}	INDIR	Dyeing - Fabric production - Dry cleaning - Printing - Printing - Functional finishing	elastane-polyamide	0.05	0.10	0.19	0.24	Equalisation	NI	198.5	NI

FR131_w{1}	DIR	Washing synthetic fibre - Bleaching - Dyeing - Printing - Functional finishing - Coating (also back-coating) and laminating - Thermal treatment (e.g drying, thermofixation, curing)	blend cotton-synthetic-cotton-polyester	0.07	0.13	0.20	NI	Screening - Sedimentation - Activated sludge process - Sedimentation - Other	29.4	37.6	NI
IT076_w{1}	INDIR	Raw wool scouring	wool	0.20	0.20	0.20	NI	Equalisation - Flotation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sedimentation - Membrane bioreactor	58.3	52.9	NI

PT099_w{1}	INDIR	Dyeing - Printing - Functional finishing	blend cotton- synthetic- cotton- elastane- polyamide- polyester- rayon(lyoce ll)- rayon(mod al)- rayon(visco se)-silk	0.09	0.13	0.20	NI	Screening - Oil separation - Other	127.0	140.0	NI
FR134_w{1}	DIR	Washing synthetic fibre - Desizing - Mercerisin g - Bleaching - Dyeing - Singeing - Functional finishing	cotton	0.02	0.09	0.21	0.10	Equalisatio n - Neutralisati on - Grit separators - Activated sludge process - Anaerobic treatment	67.0	72.5	NI
IT059_w{2}	INDIR	Thermal treatment (e.g drying, thermofixat ion, curing) - Functional finishing	blend cotton- synthetic- cotton	0.04	0.10	0.21	NI	No technique used	36.6	732.5	NI
CZ015_w{1}	INDIR	Dyeing - Functional finishing	polyester- other	0.05	0.09	0.22	0.12	Grit separators - Equalisatio n - Sedimentati on	0.014	0.021	NI

DE039_w{1}	INDIR	Mercerising - Dyeing - Washing synthetic fibre - Bleaching - Desizing	blend cotton-synthetic-cotton-polyamide-polyester	0.08	0.16	0.23	NI	Equalisation - Neutralisation	36.0	36.0	NI
BE008_w{1}	INDIR	Printing - Dyeing	blend wool-synthetic-polyamide	0.01	0.13	0.24	NI	Equalisation - Grit separators - Other	45.6	48.2	NI
SE119_w{1}	INDIR	Washing synthetic fibre - Desizing - Functional finishing - Dyeing	polyamide-polyester	0.06	NI	0.24	0.04	No technique used	115.0	120.0	NI
AT003_w{1}	INDIR	Mercerising - Dyeing - Desizing - Bleaching	cotton	0.11	0.15	0.25	0.44	Neutralisation	74.1	155.8	NI
DE026_w{1}	INDIR	Washing synthetic fibre - Desizing - Dyeing - Bleaching	cotton-flax-polyamide-polyester-other	0.04	0.10	0.26	0.03	No information	NI	NI	NI
IT084_w{1}	INDIR	Bleaching - Dyeing - Thermal treatment (e.g drying, thermofixation, curing)	cotton-polyester-rayon(modal)-rayon(viscose)	0.01	0.04	0.26	NI	Equalisation - Neutralisation - Grit separators - Screening - Coagulation and flocculation - Sedimentation	0.134	150.0	NI

BE007_w{1}	DIR	Dyeing	polyamide- other	0.03	0.07	0.26	NI	Equalisation - Neutralisation - Sand filtration - Activated sludge process - Nitrification/ denitrification	10.7	14.3	5.4
BE008_w{2}	INDIR	Dyeing - Printing	blend wool- synthetic- polyamide	0.08	0.15	0.28	0.05	Equalisation - Grit separators - Other	45.6	48.2	NI
CZ017_w{1}	INDIR	Spinning - Fabric production - Singeing - Functional finishing - Shrink- proof finishing - Thermal treatment (e.g drying, thermofixation, curing) - Other	polyester- wool	0.17	0.24	0.28	0.45	Equalisation - Other	172.8	190.4	NI
IT069_w{1}	INDIR	Scouring - Bleaching - Mercerising	blend cotton- synthetic- cotton-flax- rayon(viscose)	0.09	0.16	0.29	NI	Other	11.2	12.0	NI

BE014_w{1}	DIR	Bleaching - Dyeing - Functional finishing	cotton- wool-other	0.03	0.10	0.30	0.05	Equalisatio n - Activated sludge process - Nitrificatio n/denitrific ation	20.9	23.7	10.0
IT070_w{1}	INDIR	NI	other	0.02	0.11	0.30	0.02	No information	235.0	16.4	94.7
IT094_w{1}	INDIR	NI	acrylic- blend cotton- synthetic- blend wool- synthetic- cotton-flax- hemp- polyamide- polyester- rayon(visco se)-silk	0.00	0.11	0.30	NI	Other	41.9	3.0	95.9
IT092_w{1}	DIR	Dyeing - Other	wool	0.31	0.31	0.31	NI	Equalisatio n - Neutralisati on - Activated sludge process - Nitrificatio n/denitrific ation - Sedimentati on - Reverse osmosis	99.4	196.9	NI

PT113_w{1}	INDIR	Dyeing - Washing synthetic fibre - Bleaching - Functional finishing	cotton	0.07	0.18	0.32	0.35	Screening - Other	81.0	86.7	1.3
AT001_w{1}	INDIR	Dyeing - Bleaching	NI	0.10	0.18	0.33	0.21	No technique used	NI	NI	NI
IT078_w{1}	INDIR	Wool Fulling - Washing synthetic fibre - Dyeing	blend cotton- synthetic- blend wool- synthetic- cotton- polyester- rayon(visco se)-wool	0.07	0.18	0.34	NI	Other	88.7	94.2	NI
AT002_w{1}	INDIR	Bleaching - Dyeing	NI	0.06	0.12	0.39	0.36	Screening - Neutralisati on	NI	NI	NI
DE051_w{1}	INDIR	Washing synthetic fibre - Scouring - Bleaching - Dyeing - Functional finishing	blend cotton- synthetic- blend wool- synthetic- cotton- polyacrylon itrile- polyamide- polyester- wool-other	0.06	0.21	0.39	0.27	Neutralisati on - Coagulatio n and flocculation - Equalisatio n	60.0	60.0	NI



IT067_w{1}	DIR	Dyeing - Printing - Other - Shrink- proof finishing	wool	0.18	0.27	0.40	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/ denitrification - Sedimentation	43.7	48.6	NI
IT073_w{1}	INDIR	Dyeing - Functional finishing	acrylic- blend cotton- synthetic- cellulose acetate- cotton- elastane- polyamide- polyester- rayon(modal)- rayon(viscose)-wool	0.11	0.21	0.43	0.43	No technique used	129.6	147.7	48.0
IT091_w{1}	INDIR	Scouring - Dyeing - Functional finishing - Thermal treatment (e.g drying, thermofixation, curing) - Other	cotton-flax- polyester- rayon(viscose)	0.12	0.23	0.48	NI	No information	127.1	134.2	70.6

IT071_w{2}	INDIR	Dyeing - Other - Functional finishing	acrylic- cotton- polyester- rayon(visco se)-wool- other	0.27	0.38	0.50	8.46	Other	35.8	35.8	NI
IT083_w{1}	INDIR	Scouring - Dyeing - Functional finishing	blend cotton- synthetic- cellulose acetate- elastane- polyamide- polyester- rayon(cupr amonium)- rayon(visco se)	0.28	0.40	0.50	NI	Other - Other	139.2	139.2	NI
IT097_w{1}	DIR	Dyeing - Shrink- proof finishing - Printing - Other	wool	0.01	0.13	0.50	NI	Equalisatio n - Neutralisati on - Activated sludge process - Nitrificatio n/denitrific ation - Sedimentati on	258.6	292.7	NI
<p>NB: DIR: Direct discharge. INDIR: Indirect discharge. NI: No information. Source: [ 50, TWG 2019 ]</p>											

Table 4.41 Environmental performance of combinations of waste water treatment techniques for sulphides (S<sup>2-</sup>) emissions to water

Emission point	Type of discharge	Associated processes	Type of fibre	Minimum concentration over 3 years (mg/l)	Average concentration over 3 years (mg/l)	Maximum concentration over 3 years (mg/l)	Maximum load over 3 years (g/day)	Combination of techniques	Maximum amount of waste water discharged (m <sup>3</sup> /t of textile)	Maximum specific water consumption at plant level (m <sup>3</sup> /t of textile)	% of recycled/reused water in total water consumed
PT115_w{1}	INDIR	Dyeing - Functional finishing	cotton	0.02	0.02	0.02	0.037	Equalisation - Neutralisation - Screening	NI	106.7	NI
DE039_w{1}	INDIR	Mercerising - Dyeing - Washing - synthetic fibre - Bleaching - Desizing	blend cotton-synthetic-cotton-polyamide-polyester	0.03	0.035	0.04	NI	Equalisation - Neutralisation	36.0	36.0	NI
DE024_w{1}	INDIR	Desizing - Dyeing - Scouring - Singeing	blend cotton-synthetic-cotton-polyamide-polyester	0.1	0.1	0.1	0.007	Equalisation	3.9	4.7	NI
IT067_w{1}	DIR	Dyeing - Printing - Other - Shrink-proof finishing	wool	0.1	0.1	0.1	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation	43.7	48.6	NI

IT076_w{1}	INDIR	Raw wool scouring	wool	0.1	0.1	0.1	NI	Equalisation - Flotation - Coagulation and flocculation - Activated sludge process - Nitrification/denitrification - Sedimentation - Membrane bioreactor	58.3	52.9	NI
IT092_w{1}	DIR	Dyeing - Other	wool	0.1	0.1	0.1	NI	Equalisation - Neutralisation - Activated sludge process - Nitrification/denitrification - Sedimentation - Reverse osmosis	99.4	196.9	NI

ES058_w{1}	INDIR	Mergerising - Bleaching - Dyeing - Desizing - Fabric production - Printing - Thermal treatment (e.g drying, thermofixation, curing)	blend cotton-synthetic-cotton	NI	0.14	NI	0.321	No information	27.8	30.5	NI
DE022_w{1} (1)	INDIR	Raw wool scouring - Washing synthetic fibre - Desizing - Scouring - Bleaching - Dyeing - Thermal treatment (e.g drying, thermofixation, curing) - Functional finishing - Coating (also back-coating) and laminating	acrylic-blend cotton-synthetic-blend wool-synthetic-cellulose acetate-cotton-polyamide-polyester-rayon (viscose)-other	0.006	0.03	0.34	NI	Neutralisation - Oil separation - Evaporation	65.0	80.0	NI
PT105_w{1}	INDIR	Dyeing - Bleaching	polyester-rayon(viscose)-wool-other	0.4	0.4	0.4	NI	No information	82.5	NI	NI

DE030_w{1} ( <sup>1</sup> )	INDIR	Washing synthetic fibre - Desizing - Mercerising - Bleaching - Singeing - Dyeing - Functional finishing - Thermal treatment (e.g drying, thermofixation, curing)	blend cotton-synthetic-cotton-rayon (viscose)	0.04	0.179	0.58	NI	Equalisation - Neutralisation - Screening	51.2	61.4	NI
PT108_w{1} ( <sup>2</sup> )	INDIR	Fabric production - Fabric production	NI	0.05	0.36	0.97	0.669	Neutralisation - Sand filtration - Sand filtration	99.3	96.5	37.0
<p>(<sup>1</sup>) Dyeing with sulphur dyes.  (<sup>2</sup>) Dyeing with low-sulphide dyes.  NB:  DIR: Direct discharge.  INDIR: Indirect discharge.  NI: No information.  Source: [ 50, TWG 2019 ]</p>											

## 4.1.8 Prevention and reduction of emissions to air

### 4.1.8.1 Overview

This section contains techniques used in the textiles sector to prevent, reduce or control the emissions to air.

This section only covers those techniques most relevant to the textiles sector. These techniques have already been described and analysed in the CWW BREF [ 77, COM 2016 ]. For this reason, it is not intended in this section to provide a complete analysis of each of the different techniques. Instead, Sections 4.1.8.2 to 4.1.8.12 only give a short description of the techniques reported by the plants that participated in the data collection. Section 4.1.8.13 presents examples of combinations of techniques used to abate most common pollutants in the textile plants as reported in the data collection. Sections 4.1.8.14 and 4.1.8.15 refer to channelling diffuse emissions and reducing the number of emission points. Section 4.1.8.16 refers to the substitution and use of preparations and substances ('recipes') that can prevent or reduce the emissions to air of organic compounds or ammonia.

### 4.1.8.2 Wet scrubbing

#### Description

Wet scrubbing (or absorption) is a mass transfer between a soluble gas 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.

Scrubbing or absorption is widely used as a raw material and/or product recovery technique for the separation and purification of gaseous streams that contain high concentrations of VOCs, especially compounds soluble in water such as alcohols, acetone or formaldehyde. The use of absorption as the primary control technique for organic vapours is subject to the availability of a suitable solvent, with a high solubility for the gas, low vapour pressure and low viscosity.

The major waste gas treatment applications of scrubbing processes are as follows:

- The removal of gaseous pollutants, such as hydrogen halides, SO<sub>2</sub>, ammonia, hydrogen sulphide (H<sub>2</sub>S) or volatile organic solvents.
- The removal of dust with certain types of scrubbers. Wet dust scrubbing entails separating the dust by intensively mixing the incoming gas with water, usually combined with the removal of the coarse particles through the use of centrifugal force. In order to achieve this, the gas is inserted tangentially (at an angle from the side). This technique allows the abatement of dust emissions and bioaerosols as well as inorganic chemicals (such as SO<sub>2</sub>, NH<sub>3</sub>, NH<sub>4</sub>Cl), VOCs and heavy metals that may be attached to the dust.

Depending on the pollutants to be removed, several aqueous scrubbing liquids are used including the following:

- Water, to remove solvents and gases such as hydrogen halides or ammonia, with the main aim being to recover and reuse these contaminants.
- Alkaline solutions (e.g. caustic soda (i.e. sodium hydroxide) and sodium carbonate), to remove acid components such as hydrogen halides, sulphur dioxide, hydrogen sulphide (H<sub>2</sub>S), phenols, chlorine; also used for second-stage scrubbing to remove residual hydrogen halides after first-stage aqueous absorption; and for biogas desulphurisation.

- Alkaline oxidation solutions, i.e. alkaline solutions with oxidants such as sodium hypochlorite (NaClO), chlorine dioxide (ClO<sub>2</sub>), ozone (O<sub>3</sub>) or hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>).
- Oxidation solutions, to recover NO<sub>x</sub> from concentrated waste gases.
- Sodium hydrogen sulphite solutions, to remove odour (e.g. aldehydes).
- Na<sub>2</sub>S<sub>4</sub> solutions, to remove mercury from waste gas.
- Acidic solutions, to remove alkaline components, e.g. ammonia, amines and esters. The dosing of the acid is done by means of pH regulation.
- Monoethanolamine and diethanolamine solutions, suitable for the absorption and recovery of hydrogen sulphide.
- Organic solvents with low volatility, e.g. chilled nonane for the recovery of light VOCs such as butanes and pentanes.

### Environmental performance and operational data

In textile finishing, the abatement efficiency is between 40 % and 70 %. In certain processes, with appropriate fresh water throughput, higher separation rates of up to 90 % can be achieved provided that the substances are water-soluble and have appropriate (not too low) vapour pressure [ 58, EURATEX 2020 ], [ 216, Zietlow B. 2020 ].

### Example plants

Table 4.42 shows the list of plants from the data collection equipped with wet scrubbers (either water or acid scrubbers).

**Table 4.42: Plants from the data collection equipped with wet scrubbing**

Plants equipped with a wet scrubbing system as an abatement technique	Type of scrubbing
AT003, BE013, CZ016, DE022, DE023, DE030, DE032, DE041, DE049, DE050, IT059, IT061, IT063, IT064, IT065, IT067, IT070, IT071, IT072, IT074, IT077, IT078, IT079, IT082, IT087, IT094, IT097, PT109, PT111, UK127	Water scrubbing
IT060, UK127	Acid scrubbing

*Source:* [ 50, TWG 2019 ]

According to the data collection, wet scrubbing is used to abate emissions from finishing, singeing, coating, lamination, printing and thermal treatment associated with these processes.

### Reference literature

[ 58, EURATEX 2020 ], [ 77, COM 2016 ], [ 216, Zietlow B. 2020 ]

#### 4.1.8.3 Electrostatic precipitator (ESP)

##### Description

An electrostatic precipitator (ESP) is a particulate collection device that removes particles from a gas flow using the force of an induced electrostatic charge. The entrained particles are given an electrical charge when they pass through a corona where gaseous ions flow. Electrodes in the centre of the flow lane are maintained at a high voltage and generate the electrical field that forces the particles to the collector walls.

In dry ESPs, the collectors are knocked or rapped by various mechanical means to dislodge the particles, which slide downwards into a hopper.

In wet ESPs, the collectors are either intermittently or continuously washed by a spray of water, and the collection hoppers are replaced with a drainage system.



**Environmental performance and operational data**

ESP abatement efficiency for particulate solid and liquid pollutants can range from 80 % to 95 % with appropriate raw gas loading and chemical substances.

For a high overall efficiency, it is expected that as many condensable substances as possible are removed as aerosols before they enter the ESP. This can be achieved by upstream capacitors, heat exchangers or exhaust scrubbers.

ESP technology is often primarily used in all types of crude thermofixing processes (in the case of oil mist). In all other processes such as anti-crease, dyeing/printing/coating and subsequent drying and condensation, a stand-alone use is less or no longer useful. Combinations with other techniques, preferably exhaust air scrubbers, could also be used [ 58, EURATEX 2020 ], [ 216, Zietlow B. 2020 ].

**Example plants**

Table 4.43 shows the list of plants from the data collection equipped with ESPs (either dry or wet ESPs).

**Table 4.43: Plants from the data collection equipped with ESPs**

Plants equipped with an ESP as an abatement technique	Type of ESPs
DE022, IT063, IT084, UK124, UK127	Dry ESP
AT001, DE023, DE050	Wet ESP
Source: [ 50, TWG 2019 ]	

According to the data collection, ESPs are used to abate emissions from thermal treatment, coating, lamination and printing.

**Reference literature**

[ 58, EURATEX 2020 ], [ 77, COM 2016 ], [ 216, Zietlow B. 2020 ]

**4.1.8.4 Condensation****Description**

Condensation is a technique that eliminates vapours of organic and inorganic compounds from a waste gas stream by reducing its temperature below its dew point.

There are different methods of condensation, depending on the operating temperature range and including:

- 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.

**Environmental performance and operational data**

The emissions from textile finishing contain compounds such as mineral oils/paraffins, fatty acid esters, glycols, caprolactam, trialkyl phosphates, which have a high boiling point and partly condense already in the exhaust gas path or are emitted as aerosols, are usually abated by the condensation. Volatile substances, which also occur very often in the exhaust air of stenters,

usually cannot be abated by condensation. The separation rate for the above-mentioned substances evaporating at high temperatures is 30-40 %. In order to increase this, the heat exchanger can be supplied with cooling fluid; however, ice will quickly be formed in the capacitor due to the high content of water in the exhaust air. A second system should be used when processing in continuous operation, while the first one is de-iced [ 58, EURATEX 2020 ], [ 216, Zietlow B. 2020 ].

#### Example plants

Plants from the data collection: DE049, IT077, IT083, SE118, SE119, UK124 and UK127. According to the data collection, condensation is used to abate emissions from finishing, singeing, printing and thermal treatment associated with these processes.

#### Reference literature

[ 58, EURATEX 2020 ], [ 77, COM 2016 ], [ 216, Zietlow B. 2020 ]

### 4.1.8.5 Thermal oxidation

#### Description

Thermal oxidation (also often referred to as ‘incineration’, ‘thermal incineration’ or ‘oxidative combustion’) is the oxidation of combustible gases and odorants in a waste gas stream by heating a mixture of contaminants with air or oxygen above its ignition point in a combustion chamber and maintaining it at a high temperature for sufficient time to complete combustion to carbon dioxide and water.

Thermal oxidisers are used to reduce emissions from almost all VOC sources. They can handle minor fluctuations in flow, but large fluctuations require the use of other techniques such as flares and flash tanks. Their fuel consumption can be high when low-loaded waste gases are fed so thermal units are best suited for smaller process applications with moderate to high VOC loadings.

Several types of thermal oxidisers are operated:

- the straight thermal oxidiser;
- the regenerative thermal oxidiser;
- the recuperative thermal oxidiser;
- gas engines or steam boilers.

#### Environmental performance and operational data

High exhaust air flow rates with comparatively low concentrations are common in textile finishing. Exhaust air volumes also fluctuate. In principle, all organic pollutants can be removed from the raw gas, with cleaning capacities up to 99 % when using thermal oxidation [ 58, EURATEX 2020 ], [ 216, Zietlow B. 2020 ].

#### Example plants

Table 4.44 below shows the plants from the data collection equipped with thermal oxidation systems.

**Table 4.44: Plants from the data collection equipped with thermal oxidation**

Plants equipped with a thermal oxidation system as an abatement technique	Type of thermal oxidiser
DE024	Thermal oxidiser
DE032, DE042	Regenerative thermal oxidiser
Source: [ 50, TWG 2019 ]	

According to the data collection, thermal oxidation is used to abate emissions from finishing, coating, lamination and thermal treatment associated with these processes.

### Reference literature

[ 58, EURATEX 2020 ], [ 77, COM 2016 ], [ 216, Zietlow B. 2020 ]

#### 4.1.8.6 Catalytic oxidation

##### Description

Catalytic oxidisers operate in a very similar way to thermal oxidisers (see Section 4.1.8.5), with the main difference being that the gas, after passing through the flame area, passes through a catalyst bed. The catalyst has the effect of increasing the oxidation reaction rate, enabling conversion at lower reaction temperatures than in thermal oxidation units. Catalysts, therefore, also allow smaller oxidisers to be used.

##### Example plants

Plant DE047 where catalytic oxidation is used to abate emissions from singeing.

##### Reference literature

[ 77, COM 2016 ]

#### 4.1.8.7 Cyclone

##### Description

Equipment for the removal of dust from a waste gas stream based on imparting centrifugal forces, usually within a conical chamber. Cyclones are mainly used as pretreatment before further dust abatement (e.g. for coarse dust).

##### Example plants

Plants from the data collection: IT064, IT069, IT078 and PT115. According to the data collection, cyclones are used to abate emissions from thermal treatment and singeing.

##### Reference literature

[ 77, COM 2016 ]

#### 4.1.8.8 Absolute filter

##### Description

In absolute filters (e.g. HEPA (high-efficiency particle air filter), ULPA (ultra-low penetration air filter), the filter medium is paper or matted glass fibre with a high packing density. The waste gas stream is passed through the filter medium, where dust is collected. The dust cake that forms on the filter medium can increase the collection efficiency. The filter medium is pleated to provide a smaller A/C ratio (volume flow rate to surface area).

The most common designs are a box filter cell and a cylindrical filter cell. In a box filter cell, the pleated medium is placed in a rigid, square frame constructed of wood or metal. The air flows from the front to the back of the filter. In a cylindrical filter cell, a metal cap seals the medium at one end. The air flows from the outside to the inside of the filter.

##### Example plants

Plants from the data collection: IT072 and IT083. In the first case, absolute filters are used to abate dust emissions from pressing and packaging and in the second case dust emissions from weighing of hydrosulphite.

**Reference literature**

[ 77, COM 2016 ]

**4.1.8.9 Fabric filter****Description**

The creation of a barrier separates the dust from the waste gases. Solid particles are trapped by a woven fabric while the gas flow can pass through it.

**Example plants**

Plants from the data collection: IT061 and IT094. In the first case, a fabric filter is used to abate dust emissions from beating and folding of wool and in the second case dust emissions from thermal treatment.

**Reference literature**

[ 77, COM 2016 ]

**4.1.8.10 Mist filter****Description**

The most common mist filters (mist eliminators, demisters) are mesh pad filters. Mesh pad filters usually consist of woven or knitted metallic or synthetic material monofilament in either a random or specific configuration and are used for deep-bed filtration, which takes place over the entire depth of the filter. Solid dust particles remain in the filter until it is saturated and thus has to be cleaned by flushing. When the mist filter is used to collect droplets and/or aerosols, it is usually self-cleaning, drained by the liquid. It works by mechanical impingement and is velocity-dependent. Baffle angle separators are also commonly used as mist filters.

Demisters often form an integrated part of other techniques, for example gas scrubbers.

**Example plants**

Plant UK127.

**Reference literature**

[ 77, COM 2016 ]

**4.1.8.11 Adsorption****Description**

Adsorption is a heterogeneous reaction in which gas molecules are retained on a solid or liquid surface (the adsorbent is also referred to as a molecular sieve) that prefers specific compounds to others and thus removes them from effluent streams. When the surface has adsorbed as much as it can, the adsorbent is replaced or the adsorbed content is desorbed as part of the regeneration of the adsorbent. When desorbed, the contaminants are usually at a higher concentration and can either be recovered or disposed of.

Typical adsorbents include:

- granular activated carbon (GAC), the most common adsorbent with a wide efficiency range and not restricted to polar or non-polar compounds; GAC can be impregnated, e.g. with oxidants such as potassium permanganate or with sulphur compounds (improving the retention of heavy metals);
- zeolites, with properties depending on their manufacture, working either as mere molecular sieves, selective ion exchangers or hydrophobic VOC adsorbers;

- macroporous polymer particles, which are used as granules or beads, without being highly selective with respect to VOCs;
- silica gel;
- sodium-aluminium silicates.

The application of adsorption encompasses:

- the recovery of VOCs (raw material, product, solvent, etc.) for reuse or recirculation; it may be used as a stand-alone system, as a concentration step to improve the viability of further recovery operations such as membrane separation or to treat the tail gas emissions from an abatement system;
- the abatement of pollutants that cannot be recirculated or otherwise used, possibly with GAC as an adsorbent which is then not regenerated but incinerated;
- its use as a guard filter after final treatment facilities.

### Example plants

Plants from the data collection: CZ015 to abate emissions from lamination and IT074 to abate emissions from dry cleaning.

### Reference literature

[ 77, COM 2016 ]

#### 4.1.8.12 Biological waste gas treatment after flame lamination

[ 44, ÖKOPOL 2011 ]

### Description

Combination of biotrickling and a biofilter for abatement of cyanide (HCN) from the waste gas of flame lamination.

### Technical description

The abatement system consists of a washer and a filter module, both filled with plastic material for growth of organics. Additionally, the plants have a waste gas fan and a circulation pump. The circuit has an automatic conditioning system to keep the temperature and the pH constant. The plant is vaccinated with a specific bacteria culture, able to degrade HCN into non-toxic metabolites.

The plant works as a two-step trickle reactor. In the first step, HCN contained in the waste gas is dissolved in water by intensive gas-water contact (countercurrent gas wash). Afterwards, washing water loaded with HCN is conducted to the second step (filter), where the biological elimination takes place. In the second step, the remaining HCN is dissolved, at the same time as the biological elimination.

After the filter module, the cleaned waste gas is channelled to the stack and released into the atmosphere [ 44, ÖKOPOL 2011 ].

See [ 77, COM 2016 ] for more details on biotrickling and biofiltration.

### Achieved environmental benefit

Reduction of cyanide and dust emissions to air.

### Environmental performance and operational data

Two example plants achieve a HCN reduction of 30-60 %. Both plants generally achieve HCN concentrations < 3 mg/Nm<sup>3</sup> [ 44, ÖKOPOL 2011 ].

Furthermore, improved working conditions for the employees at the flame lamination machine are achieved.

**Data of example plant A:**

- Treated waste gas volume: 15 500 m<sup>3</sup>/h.
- Filling material volume of the washer: approximately 8 m<sup>3</sup>.
- Filling material volume of the filter: approximately 12 m<sup>3</sup>.
- Water reservoir: 6.6 m<sup>3</sup>.
- Circuit pump: 4 kW.
- Automatic pH and temperature control.
- Beds of the washer and the filter are filled with loose heaped-up polypropylene pall rings.
- Twice a year maintenance is carried out, including disposal of the circuit water and the biomass sludge [44, ÖKOPOL 2011].

**Cross-media effects**

Waste water is generated by operating the waste gas treatment system and is disposed of as hazardous waste. In example plant A, the waste water amount is approximately 10 m<sup>3</sup>/year [44, ÖKOPOL 2011].

The operation of the waste gas treatment system also leads to additional energy consumption: in plant A, additional energy consumption is 52 550 kWh/year. This consumption does not include the electricity consumption of the fans (54 912 kWh/year), as for workers' protection several small fans were needed before installing the waste gas abatement system, comprising similar electricity consumption [44, ÖKOPOL 2011].

**Technical considerations relevant to applicability**

The biological waste gas cleaning system is applicable to new and existing plants. In existing plants, the applicability may be restricted by space availability.

**Economics**

Investment and operating costs depend on the waste gas volume treated. In example plant A, specific treatment costs for about 5 000 operation hours per year were approximately EUR 0.94 per 1 000 m<sup>3</sup> (or EUR 0.77 per 1 000 m<sup>3</sup> when deducting the electricity costs which were also needed for ventilation before installing the waste gas abatement system).

More details about example plant A are given below: [44, ÖKOPOL 2011]

- Investment costs: approximately EUR 130 000 (complete waste gas treatment system without construction costs and connecting ducts).
- Annual costs: EUR 29 700 for a volume of waste gas treated of approximately 38 700 000 m<sup>3</sup>/year (EUR 36 400 when including the electricity costs for the fan). This includes:
  - Capital costs: EUR 13 000 (over 10 years).
  - Maintenance costs: EUR 7 000.
  - Operating material:
    - buffer and nutrition media: EUR 2 200;
    - water/waste water costs: EUR 1 200;
    - electricity costs: EUR 6 300 without fans or EUR 13 000 with fan.

**Driving force for implementation**

Environmental legislation.

**Example plants**

- C.H.Müller GmbH, DE-08486 Netzschkau (Plant A);
- Vowalon GmbH, DE-08233 Treuen.

**Reference literature**

[44, ÖKOPOL 2011]

### 4.1.8.13 Reduction of emissions to air of ammonia, dust and organic compounds

#### Description

One or a combination of techniques (see Sections 4.1.8.2 to 4.1.8.12) to abate emissions to air from thermal treatment (e.g. drying, thermofixation or heat-setting in dryers, curers and stenters), singeing, coating, lamination, pretreatment, dyeing, printing, and finishing.

#### Technical description

One or a combination of the following techniques may be used to reduce emissions to air of VOCs, including formaldehyde:

- wet scrubbing (see Section 4.1.8.20);
- condensation (see Section 4.1.8.4);
- thermal oxidation (see Section 4.1.8.5);
- catalytic oxidation (see Section 4.1.8.6);
- adsorption (see Section 4.1.8.11).

Wet scrubbing, as well as an ESP (see Section 4.1.8.3) or cyclone (see Section 4.1.8.7), may be used alone or in combination to reduce dust emissions to air.

Wet scrubbing may be used to reduce NH<sub>3</sub> emissions to air.

Biowashers and biofilters (e.g. trickle bed reactors with filling material) are not used after drying because the waste gas load may vary significantly and may contain bactericide substances (e.g. formaldehyde). Biowashers and biofilters are more appropriate for treatment of emissions from flame lamination (see Section 4.1.8.12) [44, ÖKOPOL 2011].

#### Achieved environmental benefits

Reduction of volatile organic compounds, including hazardous substances such as formaldehyde or methanol, ammonia, oil mist and dust in the off-gas as well as minimisation of odour nuisances.

#### Environmental performance and operational data

To achieve high operational reliability, adjustment of the appropriate operating conditions and proper maintenance (in some cases a weekly inspection and cleaning of the devices) of the equipment are crucial [5, UBA 2001].

#### *Oxidation techniques*

The disadvantage of thermal oxidation is the high energy consumption for heating the off-gas to at least 750 °C. After oxidation, the temperature of the cleaned off-gas is around 200 °C to 450 °C and heat could be recovered for the process with a heat exchanger.

Another problem arises from the gas-air mixture typical of exhaust air from textile finishing. In the textile industry, most of the emissions to be treated are characterised by high off-gas flows, but relatively low loads. Moreover, the characteristics of the off-gases are often subject to fluctuation, leading to inefficient thermal oxidation.

Usually, thermal oxidation of waste gas from stenters is not considered proportionate due to the low VOC content of the raw waste gas (less than 500 mg/Nm<sup>3</sup>) and the high energy consumption required for thermal oxidation.

In addition, the presence of halogenated compounds can cause the formation of dioxins and hydrogen halogen acids. The combustion of siloxanes and phosphorous compounds can lead to silicon dioxide and phosphorus pentoxide. These oxides can deposit on the burning chamber and clog the burner nozzle [324, TWG 2020].

In catalytic incineration, phosphorus compounds, halogens, silicones and heavy metals can poison the catalyst. These compounds are relatively common in the textile industry, so special care has to be taken when using catalytic oxidation.

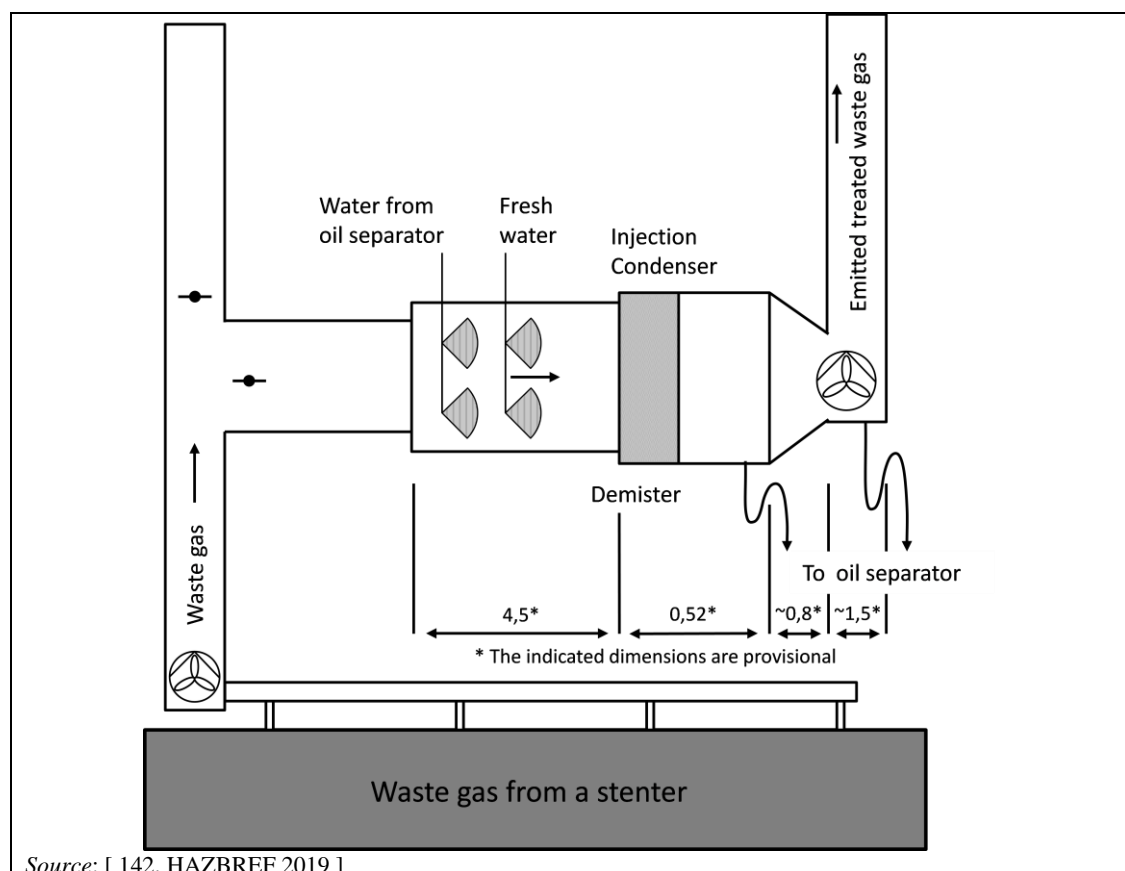
Catalytic oxidation with full heat recovery is applied in some mills for treating off-gases arising from singeing operations (see Section 2.6.1.1). The hot gas at the outlet of the catalytic oxidiser is drawn through air-to-water heat exchangers and the hot water generated by the cooling process is used in the pretreatment process or in the heating system. The gas (with its remaining thermal content) is further used in the drying step taking place after the pretreatment process [ 22, TWG 2002 ], [ 44, ÖKOPOL 2011 ].

If softeners are contained in the waste gas, this can lead to coatings in the inlet of the heat exchanger of a regenerative thermal oxidiser and subsequent blocking of the system. Such coatings can be incinerated with a burnout system. If silicon-organic compounds are contained in the waste gas, the system is equipped with sufficiently large openings for maintenance as silica oxide compounds may cover the honeycombs of the regenerative system. Such coatings may be removed with compressed air [ 44, ÖKOPOL 2011 ].

#### *Absorption techniques*

In the case of formaldehyde, the scrubber can be operated with addition of hydrogen peroxide in alkaline conditions. The scrubbing liquor is usually circulated and thus warms up quickly.

In the case of methanol, the removal efficiency depends on the concentration of methanol in the raw waste gas, the quantity of water used for scrubbing and the temperature of the circulating scrubber liquor. A possible scrubber set-up is shown in Figure 4.24 [ 142, HAZBREF 2019 ].



Source: [ 142, HAZBREF 2019 ]

**Figure 4.24: Example of a scrubbing system for the abatement of water-soluble and partly insoluble compounds**



Volatile substances (e.g. formaldehyde, methanol) may evaporate from the scrubbing liquor. [ 44, ÖKOPOL 2011 ]

*Electrostatic precipitation*

Electrostatic precipitation in combination with heat exchangers or scrubbers is successfully applied in the treatment of fumes emitted from the stenters where the fabric is submitted to thermofixation.

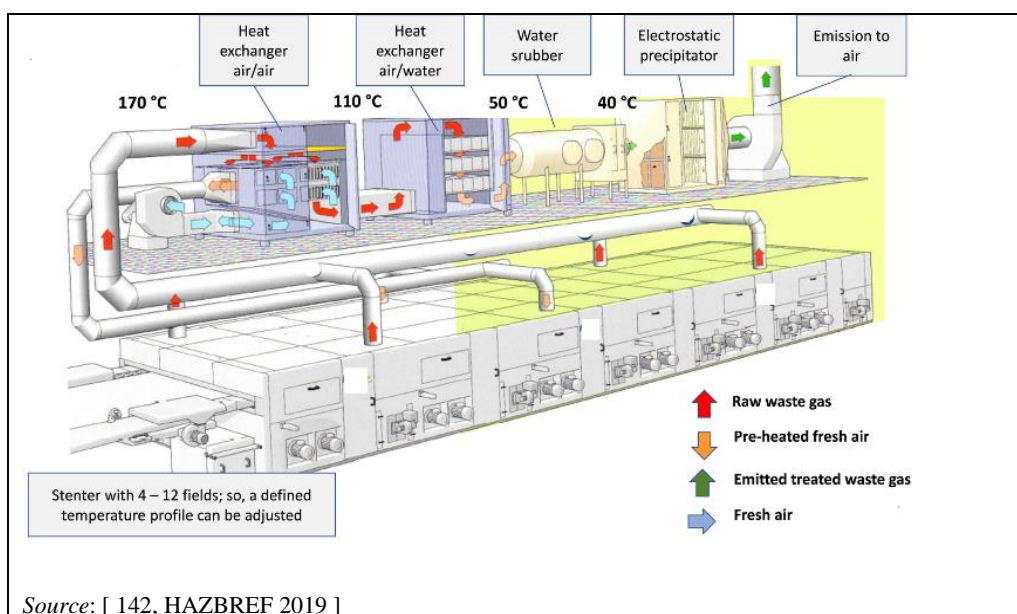
The combination of electrostatic precipitation with heat exchangers (dry electrofiltration) is particularly advantageous when this operation is carried out as a first treatment step before washing. The oils and preparation agents present on the grey fabric evaporate and give rise to a dense smoke and oil mist also associated with odour emissions. This off-gas can be treated in four steps:

1. mechanical filtration;
2. cooling and condensation (the suspended condensable compounds are separated in the form of oily droplets and thermal energy is recovered);
3. ionisation/electrofiltration;
4. collection of the condensates and separation of the oily phase from the aqueous phase in a static decanter.

One of the advantages of this dry electrofiltration system is that the oily condensates (mineral oils, silicone oils, etc.) are collected separately and thus recovered instead of being transferred to the water effluent (e.g. via a scrubber). Energy recovery is another advantage of this technique. Recovered energy (35-40 % of the supplied amount) can be used to preheat the fresh air supplied to the stenter or to heat up process water.

*Combination of techniques [ 142, HAZBREF 2019 ]*

The design of an end-of-pipe treatment system depends on the type and concentration of pollutants. In the case of oily compounds and particles as well as some easily water-soluble compounds, a combination of a two-stage heat exchanger, followed by a fine (oil) mist scrubber and an electrostatic precipitator could for instance reduce the aforementioned components by 90 %. The scrubber can often further reduce the waste gas temperature, which also improves the efficiency of the electrostatic precipitator. The combination of techniques described above is shown in Figure 4.25.



**Figure 4.25: Example of end-of-pipe treatment system for the abatement of oily and water-soluble compounds**

Provided that the waste gas temperature is not higher than 50 °C after heat exchange, the specific water consumption is in the order of 0.2-0.4 l/Nm<sup>3</sup> for a methanol removal efficiency of 50-60 % and can be as high as 2 l/Nm<sup>3</sup> for a removal efficiency of about 90 %. However, by cooling the circulating scrubbing liquor, the specific water consumption for high removal efficiencies can be significantly reduced.

It is important to regularly clean the heat exchanger and the electrostatic precipitator. The required frequency depends on the type of compounds and their concentration in the raw waste gas. For example, in the case of raw fixation of synthetic knitwear, heat exchangers and electrostatic precipitators are cleaned very often, i.e. weekly.

The environmental performance of the abatement techniques for TVOC, formaldehyde, dust and ammonia are shown in Table 4.45, Table 4.46, Table 4.47 and Table 4.48 respectively.

Table 4.45: Environmental performance of abatement techniques for TVOC emissions to air

Emission point	Associated processes	Minimum concentration over 3 years (mg/Nm <sup>3</sup> )	Average concentration over 3 years (mg/Nm <sup>3</sup> )	Maximum concentration over 3 years (mg/Nm <sup>3</sup> )	Maximum mass flow over 3 years (g/h)	Combination of techniques	Use of emission factor
IT094_{4}	Thermal treatment	0.8	0.8	0.8	5.8	Water scrubber system	No
DE042_{1}	Functional finishing - Coating (also back-coating) and laminating - Thermal treatment - Other	0.9	0.9	0.9	29.0	Regenerative thermal oxidation	Yes
IT097_{4}	Shrink-proof finishing	1.9	1.9	1.9	26.6	Water scrubber system	No
IT082_{1}	Singeing	2.1	2.1	2.1	31.7	Water scrubber system	No
IT070_{3}	No information	0.4	1.1	2.8	78.6	Water scrubber system	NI
IT082_{3}	Functional finishing - Thermal treatment	3.0	3.0	3.0	72.6	Water scrubber system	No
IT082_{4}	Functional finishing - Thermal treatment	3.0	3.0	3.0	96.0	Water scrubber system	No
DE032_{1}	Functional finishing - Coating (also back-coating) and laminating - Thermal treatment	2.7	3.0	3.2	38.1	Regenerative thermal oxidation	Yes
DE044_{1}	Functional finishing - Thermal treatment	4.0	4.0	4.0	152.4	No information	Yes
DE030_{8}	Functional finishing	0.0	4.0	0.0	26.5	No information	Yes
PT109_{22}	Functional finishing - Shrink-proof finishing - Thermal treatment	4.9	4.9	4.9	45.0	Water scrubber system	No
AT003_{2}	Functional finishing	3.2	4.2	5.4	0.0	Water scrubber system	NI
IT082_{2}	Functional finishing - Thermal treatment	5.8	5.8	5.8	154.3	Water scrubber system	No
IT094_{3}	Thermal treatment (e.g drying, thermofixation, curing)	6.0	6.0	6.0	44.4	Water scrubber system	No
IT082_{10}	Functional finishing - Thermal treatment	6.1	6.1	6.1	104.3	Water scrubber system	No
CZ015_{1}	Functional finishing	6.3	6.3	6.3	50.0	Adsorption	No
IT065_{8}	Singeing	4.1	5.2	8.2	82.9	Water scrubber system	NI

DE047_{2}	Thermal treatment - Functional finishing	2.6	5.4	8.2	42.5	No technique used	Yes
PT109_{23}	Functional finishing - Shrink-proof finishing - Thermal treatment	8.9	8.9	8.9	59.9	Water scrubber system	No
DE047_{6}	Thermal treatment - Functional finishing	1.9	5.7	9.5	92.3	No technique used	Yes
IT083_{14}	Functional finishing	8.4	9.2	9.8	277.4	Condensation - Ionisation	No
DE049_{3}	Functional finishing - Coating (also back-coating) and laminating	10.2	10.5	10.8	351.9	Water scrubber system	Yes
IT063_{3}	Printing	5.4	7.5	11.6	74.2	Water scrubber system	No
DE049_{5}	Printing	8.6	9.9	12.3	61.9	Water scrubber system	No
IT064_{3}	Thermal treatment	2.5	6.1	12.9	212.9	Water scrubber system	No
PT109_{3}	Singeing	13.9	13.9	13.9	23.7	Water scrubber system	No
IT071_{3}	Thermal treatment	1.8	6.8	14.5	130.5	Water scrubber system	No
IT094_{1}	Thermal treatment	2.8	7.9	14.6	463.6	Water scrubber system	No
DE041_{3}	Functional finishing - Thermal treatment	15.0	15.0	15.0	142.5	No information	Yes
DE030_{5}	Thermal treatment	NI	15.9	NI	122.9	No information	Yes
DE041_{2}	Functional finishing - Thermal treatment	17.0	17.0	17.0	302.6	No information	Yes
DE039_{2}	Thermal treatment	18.0	18.0	18.0	98.1	No information	Yes
DE045_{5}	Thermal treatment - Functional finishing	13.9	0.0	18.5	0.0	No information	Yes
PT111_{3}	Functional finishing - Thermal treatment	20.0	20.0	20.0	311.7	Water scrubber system - Other	No
DE030_{6}	Functional finishing	NI	20.5	NI	NI	No information	Yes
DE047_{4}	Thermal treatment - Functional finishing	16.6	20.7	22.8	547.2	No technique used	Yes
DE034_{2}	Functional finishing	24.0	24.0	24.0	136.8	No information	Yes
DE045_{4}	Functional finishing - Thermal treatment	18.3	NI	24.7	25.0	No information	Yes

DE023_{2}	Thermal treatment - Functional finishing	26.4	26.6	27.0	173.2	Water scrubber system - Wet electrostatic precipitation	Yes
DE046_{2}	Functional finishing - Thermal treatment	26.9	27.1	27.3	199.5	No information	Yes
DE045_{2}	Coating (also back-coating) and laminating	25.9	NI	27.5	NI	No information	Yes
UK124_{6}	Thermal treatment	4.7	16.7	28.9	229.1	Condensation - Dry electrostatic precipitation (ESP)	No
DE026_{5}	Functional finishing - Thermal treatment	16.3	22.2	29.0	277.1	No information	Yes
DE030_{3}	Thermal treatment	NI	30.4	NI	49.2	No information	Yes
DE030_{1}	Singeing	NI	30.6	NI	276.3	Water scrubber system	No
DE046_{1}	Functional finishing - Thermal treatment - Coating (also back-coating) and laminating	29.1	29.8	31.0	436.0	No information	Yes
DE025_{1}	Thermal treatment	32.0	32.0	32.0	247.0	No information	Yes
DE025_{2}	Thermal treatment	32.0	32.0	32.0	227.5	No information	Yes
DE045_{3}	Thermal treatment	23.5	NI	32.1	NI	No information	Yes
DE034_{1}	Thermal treatment	20.0	26.7	33.0	325.1	No technique used	Yes
DE025_{5}	Thermal treatment - Functional finishing	34.3	34.3	34.3	316.9	No information	Yes
DE026_{1}	Functional finishing - Thermal treatment - Coating (also back-coating) and laminating	17.0	25.3	35.0	594.5	No information	Yes
DE026_{4}	Functional finishing - Thermal treatment - Coating (also back-coating) and laminating	14.7	27.9	36.0	394.5	No information	Yes
DE025_{6}	Thermal treatment	38.0	38.0	38.0	310.5	No information	Yes
NB: NI: No information. Source: [50, TWG 2019]							

Table 4.46: Environmental performance of abatement techniques for formaldehyde emissions to air

Emission point	Associated processes	Minimum concentration over 3 years (mg/Nm <sup>3</sup> )	Average concentration over 3 years (mg/Nm <sup>3</sup> )	Maximum concentration over 3 years (mg/Nm <sup>3</sup> )	Maximum mass flow over 3 years (g/h)	Combination of techniques	Use of emission factor
IT094_{3}	Thermal treatment	0.02	0.02	0.02	0.15	Water scrubber system	No
IT094_{4}	Thermal treatment	0.02	0.02	0.02	0.15	Water scrubber system	No
IT094_{1}	Thermal treatment	0.02	0.02	0.02	0.80	Water scrubber system	No
IT063_{3}	Printing	0.02	0.03	0.05	0.32	Water scrubber system	No
IT083_{14}	Functional finishing	0.10	0.10	0.10	2.92	Condensation - Ionisation	No
DE042_{1}	Functional finishing - Coating (also back-coating) and laminating - Thermal treatment - Other	0.30	0.30	0.30	9.66	Regenerative thermal oxidation	Yes
DE041_{2}	Functional finishing - Thermal treatment	0.30	0.30	0.30	5.34	No information	Yes
DE041_{3}	Functional finishing - Thermal treatment	0.50	0.50	0.50	4.75	No information	Yes
UK124_{1}	Thermal treatment	0.11	0.27	0.54	8.20	Condensation - Dry electrostatic precipitation (ESP)	No
DE032_{1}	Functional finishing - Coating (also back-coating) and laminating - Thermal treatment	0.70	0.73	0.80	9.52	Regenerative thermal oxidation	Yes
UK124_{6}	Thermal treatment	0.28	0.64	0.90	8.03	Condensation - Dry electrostatic precipitation (ESP)	No
UK127_{6}	Thermal treatment	0.15	0.55	1.20	7.55	Water scrubber system	NI
DE045_{5}	Thermal treatment - Functional finishing	0.50	NI	1.20	NI	No information	Yes
DE024_{8}	Coating (also back-coating) and laminating	1.00	1.23	1.40	16.85	Thermal oxidation	No
DE030_{8}	Functional finishing	NI	1.60	NI	10.61	No information	Yes

DE046_{1}	Functional finishing - Thermal treatment - Coating (also back-coating) and laminating	1.40	1.63	1.80	25.32	No information	Yes
DE044_{2}	Functional finishing - Thermal treatment	1.90	1.90	1.90	23.81	No information	Yes
DE039_{2}	Thermal treatment	2.20	2.20	2.20	11.99	No information	Yes
DE047_{2}	Thermal treatment - Functional finishing	0.80	1.65	2.50	12.95	No technique used	Yes
DE046_{2}	Functional finishing - Thermal treatment	2.50	2.53	2.60	19.00	No information	Yes
DE047_{6}	Thermal treatment - Functional finishing	0.80	1.70	2.60	25.27	No technique used	Yes
DE049_{3}	Functional finishing - Coating (also back-coating) and laminating	2.50	2.67	2.90	94.50	Water scrubber system	Yes
UK127_{1}	Thermosol dyeing	0.23	1.32	2.90	38.76	Condensation - Dry electrostatic precipitation (ESP) - Acid scrubber system	NI
DE050_{1}	Functional finishing - Thermal treatment	2.88	3.04	3.28	101.72	Wet electrostatic precipitation - Water scrubber system	Yes
DE045_{3}	Thermal treatment	2.60	NI	3.60	NI	No information	Yes
DE030_{6}	Functional finishing	NI	3.80	NI	NI	No information	Yes
DE023_{2}	Thermal treatment - Functional finishing	3.60	3.85	4.10	26.90	Water scrubber system - Wet electrostatic precipitation	Yes
DE046_{3}	Functional finishing - Thermal treatment	3.00	3.57	4.10	22.15	No information	Yes
DE045_{4}	Functional finishing - Thermal treatment	3.00	NI	4.80	NI	No information	Yes

UK127_{2}	Thermosol dyeing	0.38	1.83	5.00	66.71	Condensation - Water scrubber system - Mist filter - Dry electrostatic precipitation (ESP)	NI
NB: NI: No information. Source: [50, TWG 2019]							

Table 4.47: Environmental performance of abatement techniques for dust emissions to air

Emission point	Associated processes	Minimum concentration over 3 years (mg/Nm <sup>3</sup> )	Average concentration over 3 years (mg/Nm <sup>3</sup> )	Maximum concentration over 3 years (mg/Nm <sup>3</sup> )	Maximum mass flow over 3 years (g/h)	Combination of techniques
IT097_{4}	Shrink-proof finishing	0.1	0.1	0.1	1.4	Water scrubber system
IT060_{9}	Singeing	0.2	0.2	0.2	3.5	Acid scrubber system
IT096_{1}	Other	0.5	0.5	0.5	0.7	Water scrubber system
IT072_{3}	Dyeing	0.3	0.4	0.5	0.8	Water scrubber system
IT082_{3}	Functional finishing - Thermal treatment	0.5	0.5	0.5	12.1	Water scrubber system
IT082_{4}	Functional finishing - Thermal treatment	0.7	0.7	0.7	22.4	Water scrubber system
IT082_{1}	Singeing	1.0	1.0	1.0	15.1	Water scrubber system
PT111_{3}	Functional finishing - Thermal treatment	1.0	1.0	1.0	15.6	Water scrubber system - Other
DE032_{2}	Singeing	1.6	1.6	1.6	11.5	Water scrubber system
DE030_{1}	Singeing	NI	1.7	NI	15.4	Water scrubber system
IT082_{2}	Functional finishing - Thermal treatment	1.8	1.8	1.8	47.9	Water scrubber system



PT109_{22}	Functional finishing - Shrink-proof finishing - Thermal treatment	1.8	1.8	1.8	16.5	Water scrubber system
DE041_{1}	Singeing	3.1	3.1	3.1	17.4	Water scrubber system
PT115_{4}	Thermal treatment - Functional finishing	2.0	2.6	3.2	16.2	Cyclonic separation
IT063_{1}	Thermal treatment - Functional finishing	0.8	2.2	3.9	NI	Dry electrostatic precipitation (ESP)
IT069_{1}	Singeing	0.1	1.2	3.9	12.6	Cyclonic separation
IT082_{10}	Functional finishing - Thermal treatment	4.0	4.0	4.0	68.4	Water scrubber system
IT059_{2}	Singeing	0.4	1.7	4.3	30.4	Water scrubber system
IT084_{3}	Thermal treatment	1.3	3.2	4.3	42.7	Dry electrostatic precipitation (ESP)
PT109_{23}	Functional finishing - Shrink-proof finishing - Thermal treatment	5.0	5.0	5.0	33.7	Water scrubber system
IT084_{4}	Thermal treatment	1.4	3.7	5.2	NI	Dry electrostatic precipitation (ESP)
PT115_{11}	Thermal treatment - Functional finishing	2.3	4.2	6.1	48.5	Cyclonic separation
IT084_{1}	Thermal treatment	1.0	2.9	6.4	58.0	Dry electrostatic precipitation (ESP)
DE049_{4}	Functional finishing - Singeing	5.0	6.5	7.4	27.4	Water scrubber system
IT084_{2}	Thermal treatment	1.0	5.1	9.1	81.8	Dry electrostatic precipitation (ESP)
NB: NI: No information. Source: [ 50, TWG 2019 ]						

Table 4.48: Environmental performance of abatement techniques for NH<sub>3</sub> emissions to air

Emission point	Associated processes	Minimum concentration over 3 years (mg/Nm <sup>3</sup> )	Average concentration over 3 years (mg/Nm <sup>3</sup> )	Maximum concentration over 3 years (mg/Nm <sup>3</sup> )	Max. load over 3 years (g/h)	Combination of techniques	Emission factor
DE049_{3}	Functional finishing - Coating (also back-coating) and laminating	2.2	2.7	3.1	100.7	Water scrubber system	Yes
DE026_{5}	Functional finishing - Thermal treatment	4.3	4.5	4.7	78.2	No information	Yes
IT094_{1}	Thermal treatment	1.2	3.4	6.9	168.0	Water scrubber system	No
DE046_{1}	Functional finishing - Thermal treatment - Coating (also back-coating) and laminating	1.0	4.0	7.9	112.7	No information	Yes
IT063_{3}	Printing	2.2	6.8	9.7	62.3	Water scrubber system	No
<i>Source: [ 50, TWG 2019 ]</i>							

In each case, for the installation of an off-gas cleaning system, a tailor-made solution using the above-mentioned techniques is developed. In general, however, the following considerations about the performance of the different abatement techniques have to be borne in mind.

#### *Condensation techniques*

Pollutants with a high volatility and, in most cases, intensely odorous substances are removed.

#### *Absorption techniques*

The efficiency of wet scrubbers in textile finishing depends strongly on process-specific parameters. Normally the efficiency is in the range of 40 % to 60 %. Applicability for water-insoluble pollutants is limited.

#### *Electrostatic precipitation*

Electrostatic precipitators can precipitate dusts and aerosols with a size of 0.01-20  $\mu\text{m}$ . Maximum efficiency will be reached at around 0.1-1.5  $\mu\text{m}$ . Manufacturers therefore recommend installing a mechanical filter before the electrostatic filter, which precipitates most of the particles with a size  $> 20 \mu\text{m}$ .

The efficiency of electrostatic precipitators for particle-sized solid and liquid pollutants is in the range of 90 % to 95 %. Gaseous pollutants and odorous substances cannot be precipitated. For best overall efficiency, it is therefore important that almost all condensable substances, emitted as aerosols, are removed before reaching the electrostatic precipitator. This can be achieved by heat exchangers or scrubbers.

Table 4.49 shows removal efficiencies reported for the following combinations

**Table 4.49 Removal efficiency for combinations of abatement techniques.**

Type of abatement	Efficiency	Problems
Condensation (heat recovery)	30-40 %	Shift of emissions, high-boiling agents
Condensation and electrostatic precipitator	-9*-84 %	Shift of emissions, high-boiling agents
Scrubber and electrostatic precipitator	-9*-84 %	Electrostatic problems, corrosion, oil in water
Electrostatic precipitator and scrubber (turbulence principle)	No data	Inlet temperature, corrosion, oil in water
Scrubber (turbulence/injection condensator/filling material)	0-75 %	Operating mode, non-soluble low-boiling agents, tensides addition
Condensation + electrostatic precipitator + scrubber	-9*-95 %	Considered as BAT, requires process controlled parametrisation
Injection condensator + mechanical filter	55-71 %	Operating mode, bad mass transfer rate, non-soluble low-boiling agents, filter cleaning
Thermal oxidation with/without heat recovery	$> 98 \%$	Siloxanes produce deposits of silicate on burner nozzles, halogenated nitrogenous compounds are converted to $\text{NO}_x$ and to HCN, corrosion from phosphoric esters, halogenated organic compounds may produce dioxins
* Negative efficiency values originate from shift of emissions: high-boiling agents can condensate inside of the waste gas system or the waste gas duct and will be emitted in a later process step (e.g. at higher temperature and lower raw gas concentration), leading to higher concentrations in clean gas than in raw gas inlet.		
Source: [ 44, ÖKOPOL 2011 ]		

**Cross-media effects**

See the CWW BREF [ 77, COM 2016 ] for the cross-media effects of the individual abatement techniques.

Concerning wet scrubbing, most compounds dissolved in the scrubbing liquor can be decomposed biologically. However, substances may be introduced into the waste water that have toxic potential for bacteria (e.g. from biocide finishing), such as formaldehyde, triclosan, isothiazolinone or mercaptobenzimidazole. In the case of PA 6, the nitrogen load introduced into the waste water is increased by caprolactam adsorption [ 44, ÖKOPOL 2011 ].

**Technical considerations relevant to applicability**

See [ 77, COM 2016 ] for the applicability of the individual abatement techniques.

**Economics**

See [ 77, COM 2016 ] for the economics of the individual abatement techniques.

The investment costs for a heat exchanger, fine mist scrubber and electrostatic precipitator for a stenter (based on a waste gas flow in the range of 7 000-10 000 Nm<sup>3</sup>/h) are in the order of EUR 200 000 [ 142, HAZBREF 2019 ].

**Driving force for implementation**

Environmental legislation.

**Example plants**

See Sections 4.1.8.2 to 4.1.8.13 for example plants.

**Reference literature**

[ 5, UBA 2001 ], [ 22, TWG 2002 ], [ 44, ÖKOPOL 2011 ], [ 50, TWG 2019 ], [ 142, HAZBREF 2019 ]

**4.1.8.14 Diffuse emissions****Description**

Diffuse emissions are reduced by collecting and channelling waste gases.

**Technical description**

Diffuse emissions are non-channelled emissions that are not released via specific emission points such as stacks. Diffuse emissions in the textile sector could be for example VOCs or sometimes even dust and can result from:

- ‘area’ sources such as baths, bag filling/emptying, storage areas or waste water treatment facilities;
- or ‘point’ sources such as pipe flanges, valves, pumps and other components.

Localised collection of diffuse emissions is possible by enclosing the equipment concerned and extracting/channelling the waste gases. Modern machinery is usually pre-enclosed (see example of spray dyeing in Section 4.5.1.9).

**Achieved environmental benefits**

Reduced emissions to air.

**Environmental performance and operational data**

Diffuse emissions are usually related to small/localised areas.

### **Cross-media effects**

A reduction in diffuse emissions can also result in improved process safety and reduced operator exposure to harmful substances.

### **Technical considerations relevant to applicability**

In the case of existing plants, the applicability may be restricted by operational constraints or by the high volume of air to be extracted.

### **Economics**

The cost will be site-specific, and lower for new plants.

### **Driving force for implementation**

- To comply with environmental legislation/protection in a cost-effective manner.
- Improved operator health and safety.

### **Example plants**

Many textile plants use enclosed machinery.

### **Reference literature**

[ 96, Pinasseau et al. 2018 ], [ 357, COM 2017 ]

## **4.1.8.15 Reduction of the number of emission points**

### **Description**

The number of emission points is optimised in order to facilitate the recovery of energy and the abatement of channelled emissions to air. Care is taken that limiting the number of emission points does not lead to the dilution of emissions.

### **Technical description**

The combined treatment of waste gases with similar characteristics ensures more effective and efficient treatment compared to the separate treatment of individual waste gas streams.

### **Achieved environmental benefits**

Energy savings and improved abatement efficiency of emissions to air.

### **Environmental performance and operational data**

In most textiles plants, several emission outlets from stenters are typically combined into a limited number of emission points (e.g. one or two) [ 217, EURATEX 2021 ], [ 218, Zietlow B. 2021 ].

### **Cross-media effects**

None expected.

### **Technical considerations relevant to applicability**

The extent to which the number of emission points can be optimised depends on technical (e.g. compatibility of the individual waste gas streams) and economic factors (e.g. distance between different emission points).

### **Economics**

The cost will be site-specific, and lower for new plants due to more efficient layout design.

### **Driving force for implementation**

Reduction of monitoring and abatement costs due to a lower number of emission points.

**Example plants**

Plants PT109 and DE050 from the data collection report common stacks from different outlets of the same stenter.

**Reference literature**

[ 50, TWG 2019 ], [ 217, EURATEX 2021 ], [ 218, Zietlow B. 2021 ]

**4.1.8.16 Selection and use of mixtures of chemicals ('recipes') leading to low emissions of organic compounds and/or ammonia****Description**

Mixtures with low emissions of organic compounds are selected and used taking into consideration product specifications. As an example, emission factors may be used for selection (see Section 4.1.6.4).

**Technical description**

The selection and use of 'recipes' (mixtures of chemicals) leading to low emissions of organic compounds and/or ammonia is related to the following techniques:

- chemicals management system (Section 4.1.6.1) includes principles of chemicals selection in terms of lowering their environmental impact;
- substitution of mineral-oil-based agents (e.g. antifoaming agents, see Section 4.1.6.9.3);
- use of printing and finishing agents and chemicals with improved environmental performance (i.e. with low contents of volatile organic compounds and ammonia); for printing pastes, see Section 4.6.3.1; for flame retardants, see Section 4.7.4.1; for oil-, water- and soil-repellence agents, see Section 4.7.5.1);
- different preparations (mixtures of chemicals) can be compared based on the emission factors of their components (see Section 4.1.6.4).

**Achieved environmental benefits**

Reduced emissions of organic compounds and/or ammonia to air.

**Environmental performance and operational data**

The performance of plants using emission factors to control the input / select recipes with reduced emissions are presented in Figures 3-60, 3-61, 3-62, for TVOC; in Figure 3-65 for formaldehyde, and in Section 3.5.7 for ammonia.

**Cross-media effects**

None expected.

**Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

**Economics**

The preparations with lower environmental impact may cost more than conventional preparations.

**Driving force for implementation**

Environmental regulation.

**Example plants**

See plants in the sections referred to in 'Environmental performance and operational data' above.

### Reference literature

See references in the sections cited above.

## 4.1.9 Waste management

### 4.1.9.1 Waste management plan

#### Description

The waste management plan is part of the EMS (see Section 4.1.1.1) and is a set of measures to minimise the generation of waste, to optimise the reuse, recycling and/or recovery of the waste and to ensure the proper disposal of waste.

#### Technical description

A variety of techniques can be used for waste optimisation and they range:

- from basic housekeeping techniques;
- through statistical measurement techniques;
- to the application of clean technologies;
- to the use of process chemicals before their expiry date;
- to the use of residues as fuel;
- to the reuse or recycling of packaging.

In particular, a waste management plan could be based on the five-stage hierarchy of Directive 2008/98/EC and the Commission notice on technical guidance on the classification of waste (2018/C 124/01), and includes the following:

- Identifying, characterising and quantifying each of the waste streams generated (see Section 4.1.1.2). Maintaining a waste tracking system can help operators to record the quantity, nature, origin and, where relevant, the destination, frequency of collection, mode of transport and treatment method of any waste which is disposed of or recovered on that site.
- Identifying the current or proposed handling arrangements, and possibilities to implement circular economy [ 219, Hemkhaus et al. 2019 ].
- Fully describing how each waste stream is proposed to be recovered or disposed of. If it is to be disposed of, the plan explains why recovery is not technically or economically possible and then describes/explains the measures planned to avoid or reduce the impact on the environment.

Practical techniques to reduce the amount of waste sent for disposal may include the following:

- applying housekeeping operations; these can be as simple as sweeping prior to washing floors and can substantially reduce waste volumes;
- established criteria associated for example with maximum storage time of process chemicals, and monitoring of relevant parameters to avoid process chemicals perishing;
- separate capture of high-loaded waste streams from low-concentrated effluent to allow more efficient treatment (see Section 4.1.7.2);
- separate collection of unavoidable solid waste (see Section 4.1.9.2);
- reduction of packaging;
- use of returnable containers;
- recycling of textile wastes (textile residues, spoiled work, raising, etc.).

Various examples of potential wastes from different processes of the textile finishing plants are given in the Table 4.50 below.

**Table 4.50: Examples of potential wastes from different processes of the textile finishing plants**

<i>Textile material wastes, leftovers, cuts</i>		
04 02 – wastes from the textile industry	04 02 09	wastes from composite materials (impregnated textile, elastomer, plastomer)
	04 02 10	organic matter from natural products (for example grease, wax)
	04 02 21	wastes from unprocessed textile fibres
	04 02 22	wastes from processed textile fibres
<i>Wastes from dyeing, printing and finishing</i>		
04 02 – wastes from the textile industry	04 02 14*	wastes from finishing containing organic solvents
	04 02 15	wastes from finishing other than those mentioned in 04 02 14
	04 02 16*	dyestuffs and pigments containing hazardous substances
	04 02 17	dyestuffs and pigments other than those mentioned in 04 02 16
08 03 – wastes from MFSU of printing inks	08 03 08	aqueous liquid waste containing ink
<i>Wastes from waste water treatment</i>		
04 02 – wastes from the textile industry	04 02 19*	sludges from on-site effluent treatment containing hazardous substances
	04 02 20	sludges from on-site effluent treatment other than those mentioned in 04 02 19
07 03 – wastes from the MFSU of organic dyes and pigments (except 06 11)	07 03 01*	aqueous washing liquids and mother liquors
19 08 – wastes from waste water treatment plants not otherwise specified	19 08 01	screenings
	19 08 09	grease and oil mixture from oil/water separation containing only edible oil and fats
	19 08 10*	grease and oil mixture from oil/water separation other than those mentioned in 19 08 09
	19 08 11*	sludges containing hazardous substances from biological treatment of industrial waste water
	19 08 12	sludges from biological treatment of industrial waste water other than those mentioned in 19 08 11
	19 08 13*	sludges containing hazardous substances from other treatment of industrial waste water
	19 08 14	sludges from other treatment of industrial waste water other than those mentioned in 19 08 13
<i>Wastes containing oils</i>		
13 05 – oil/water separator contents	13 05 06*	oil from oil/water separators
13 08 – oil wastes not otherwise specified	13 08 02*	other emulsions
	13 08 99*	wastes not otherwise specified
<i>Wastes of textile auxiliaries</i>		
08 01 – wastes from MFSU and removal of paint and varnish	08 01 11*	waste paint and varnish containing organic solvents or other hazardous substances
	08 01 12	waste paint and varnish other than those mentioned in 08 01 11
08 04 – wastes from MFSU of adhesives and sealants (including waterproofing products)	08 04 09*	waste adhesives and sealants containing organic solvents or other hazardous substances
	08 04 10	waste adhesives and sealants other than those mentioned in 08 04 09
	08 04 11*	adhesive and sealant sludges containing organic solvents or other hazardous substances
	08 04 12	adhesive and sealant sludges other than those mentioned in 08 04 11
16 03 – off-specification batches and unused products	16 03 03*	inorganic wastes containing hazardous substances
	16 03 04	inorganic wastes other than those mentioned in 16 03 03
	16 03 05*	organic wastes containing hazardous substances
	16 03 06	organic wastes other than those mentioned in 16 03 05
<i>Wastes and leftovers of chemicals</i>		
16 05 – gases in pressure containers and	16 05 07*	discarded inorganic chemicals consisting of or containing hazardous substances



discarded chemicals	16 05 08*	discarded organic chemicals consisting of or containing hazardous substances
	16 05 09	discarded chemicals other than those mentioned in 16 05 06, 16 05 07 or 16 05 08
<i>Contaminated packaging waste</i>		
15 01 – packaging (including separately collected municipal packaging waste)	15 01 10*	packaging containing residues of or contaminated by hazardous substances
Source: [ 220, LFU BW/BY 2004 ], [ 221, COM 2014 ]		

### Achieved environmental benefits

The steps above help to ensure the prudent use of natural resources and can reduce waste generation in the textile plant as well as helping to identify a good disposal route.

### Environmental performance and operational data

No information provided.

### Cross-media effects

None identified.

### Technical considerations relevant to applicability

The level of detail of the waste management plan will generally be related to the nature, scale and complexity of the plant.

### Economics

No information provided.

### Driving force for implementation

The prevention of waste generation is a principle of the IED [ 16, EU 2010 ] and the Waste Directive [ 222, EU 2008 ].

### Example plants

Plants from the data collection: BE007, BE008, BE009, BE010, BE011, BE013, BE014, CZ016, DE021, DE024, DE025, DE026, DE029, DE032, DE039, DE041, DE044, DE045, DE049, DE051, FR135, IT065, IT082, IT083, IT084, PT098, PT104, PT108, PT115, PT117, SE119, SE120, UK124, UK126 and UK129.

### Reference literature

[ 96, Pinasseau et al. 2018 ], [ 219, Hemkhaus et al. 2019 ], [ 220, LFU BW/BY 2004 ], [ 221, COM 2014 ]

## 4.1.9.2 Separate collection and storage of wastes contaminated with hazardous substances or substances of very high concern

### Description

Wastes contaminated with hazardous substances and/or substances of very high concern (e.g. finishing chemicals such as flame retardants, and oil, water and soil repellents) are collected and stored separately. These wastes may contain high loads of pollutants such as organophosphorus and brominated flame retardants, PFAS, phthalates and chromium-(VI)-containing compounds (see also concentrated waste water streams in Section 4.1.7.2) and include in particular:

- liquid waste (e.g. first rinsing water in flame-retardance finishing), coating and printing pastes;
- waste paper, cloths, absorbent material;
- laboratory waste;
- sludge from waste water treatment.

**Technical description**

Examples of waste containing residues of brominated flame retardants (e.g. DBDPE),  $\text{Sb}_2\text{O}_3$  and/or PFOA include paper, cloths or other absorbent materials that are used for the dry removal of solid residues as well as laboratory waste.

NP/NPE are primarily released during washing processes on purchased tissues and yarns and are not used in the textile industry as such. PAHs originate from mineral oils and are present in purchased tissues and yarns, for example, or are formed on thermo-fixed tissues. Consequently, NP/NPE and PAHs are not likely to be found in solid waste.

Paper, cloths or other absorbent materials are stored in an appropriate manner, while awaiting disposal by a qualified processing company. This waste can be stored, for example, in enclosed recipients in a specifically designated area.

Examples of liquid waste are spent finishing liquors (see Section 4.1.7.2).

Storage and handling of waste containing hazardous substances and substances of very high concern should follow the same rules that apply for storage and handling of these substances (see Section 4.1.6.6).

**Achieved environmental benefits**

Prevention of the uncontrolled emissions of hazardous substances to air, water and soil.

**Environmental performance and operational data**

It is possible to prevent hazardous substances entering waste water and the soil by storing waste containing brominated flame retardants (e.g. DBDPE),  $\text{Sb}_2\text{O}_3$  and/or PFOA in an appropriate manner and disposing of it via a qualified processing company.

In Flanders, the collection and disposal of process baths containing brominated flame retardants (e.g. DBDPE) and/or  $\text{Sb}_2\text{O}_3$  is required by regulation and is normal practice.

The sedimentation and leaching of the brominated flame retardants from the piping in the installations that used brominated flame retardants (e.g. deca-BDE prior to its ban) can be the cause of the pollution long after the process baths containing brominated flame retardants are collected and disposed of or even not used anymore. Of three textiles companies in Flanders that discharge into surface water, and where deca-BDE was used for finishing activities, the average concentration of deca-BDE in the effluent, in the period prior to collection and disposal of process baths, amounted to 155  $\mu\text{g}/\text{l}$  on average (17 measurements), with a range of <1  $\mu\text{g}/\text{l}$  to 1 153  $\mu\text{g}/\text{l}$ . The remaining deca-BDE pollution in the effluent of the same companies, in the period after collection and disposal of the process baths, amounted to 42  $\mu\text{g}/\text{l}$  on average (32 measurements), with a range of <1  $\mu\text{g}/\text{l}$  to 370  $\mu\text{g}/\text{l}$  [108, Derden et al. 2010], [223, Derden et al. 2013]. To stop the pollutants from leaching, the piping in the installation should be replaced (with new pipes).

**Cross-media effects**

None identified.

**Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

**Economics**

Waste disposal via a qualified processing company is accompanied by certain costs such as:

- the rental price of containers for storing industrial waste: EUR 8 per month;
- the collection cost per ASP waste container: EUR 75;
- the cost for rinsing and returning IBC containers to the market: EUR 40;

- the processing costs for waste containing residues of brominated flame retardants (e.g. DBDPE), Sb<sub>2</sub>O<sub>3</sub> and/or PFOA:
  - EUR 0.75/l;
  - EUR 0.93/kg.

Concerning liquid waste, because the collection and disposal of rinsing water from process baths containing D brominated flame retardants (e.g. BDPE), Sb<sub>2</sub>O<sub>3</sub> and/or PFOA is a standard technique in Flanders, this measure is regarded as economically feasible for all textile companies that use such process baths.

The cost for disposing of process baths and rinsing water from process baths (with for example brominated flame retardants (e.g. DBDPE) and Sb<sub>2</sub>O<sub>3</sub>) amounts to EUR 150-500 for 1 000 litres, depending on the solid matter content (the higher the solid matter content, the higher the price).

For process baths that contain hazardous substances, the price for disposal is higher, e.g. EUR 1 500 per 1 000 litres (in 2007, including handling costs for incineration using a chemical scrubber). Furthermore, in order to prevent concrete erosion, the cement industry also sets requirements for the amount of bromine in cement (< 50 ppm) [ 108, Derden et al. 2010 ].

### **Driving force for implementation**

Environmental waste and chemical legislation (e.g. environmental quality standards, EU LoW 200/532/EC and REACH).

### **Example plants**

Plants DE024, DE030, DE039, DE40 and FR133 handle spent dye baths as waste.

Plants DE025, DE032 and DE049 handle spent printing pastes as waste.

Plants DE022, DE024, DE025, DE030, DE032, DE046, DE047, DE049, FR135 and SE119 handle finishing baths as waste.

### **Reference literature**

[ 108, Derden et al. 2010 ], [ 223, Derden et al. 2013 ]

## 4.2 Raw wool scouring

### 4.2.1 Techniques to increase resource efficiency

#### 4.2.1.1 Integrated dirt removal/grease recovery loops

##### **Description**

Waste water from wool scouring is treated (e.g. by a combination of centrifugation and sedimentation) to separate grease, dirt and water. Grease is recovered, water is partially recycled to scouring and dirt is sent to further treatment.

##### **Technical description**

As already described in Section 2.3.1.1 (see Figure 2.4), a wool scouring plant operating in countercurrent mode normally produces three liquid waste streams:

- a dirt-rich flow, from the bottoms of the scouring bowls;
- a less concentrated dirty flow, from the bottoms of the rinse bowls;
- a grease-rich flow, from the top of the first scouring bowl, or from the side tank of the first scouring bowl, which receives the liquor removed from the wool as it exits the bowl through the squeeze press.

All of these flows can be partially decontaminated and recycled to the scouring plant, by means of grease recovery and dirt removal loops.

There is no consensus on the best way to operate the loop(s). Some mills prefer to treat the dirt-rich flow and the grease-rich flow separately, whilst others combine the two streams and carry out sequential treatment, first for dirt removal, then for grease recovery.

For grease recovery, plate-type centrifuges are employed. They are usually protected from the abrasive effects of dirt by hydrocyclones in cases where separate rather than sequential grease recovery and dirt removal is practised. The centrifuge produces a top phase, known as 'cream', which is grease containing a small amount of water. This 'cream' is usually passed to a secondary centrifuge, which produces an upper, a lower and a middle phase. The upper phase consists of anhydrous grease, which can be sold as a by-product. The bottom phase is high in dirt and may be passed to the input side of the dirt recovery loop, or to the effluent treatment plant. The middle phase is impoverished in both grease and dirt and may be completely or partially recycled to the scouring plant, by addition to the first scouring bowl. A portion of the middle phase may flow to effluent treatment.

Dirt removal may employ gravity settling tanks, hydrocyclones or decanter centrifuges – or combinations of these methods.

In the case of Plant CZ016, the volume of waste water discharged is further reduced by evaporation. The remaining condensates are treated by stripping, then by oxidation with ozone for deodorisation before being reused in the process.

In mills with more than one scouring line, the lines normally share dirt removal/grease recovery facilities.

For fine and extra-fine wool, when carried out using machinery that has a separate continuous sludge flow output, the wool grease recovery loop also allows the elimination of the very fine dirt fraction without the need for a separate loop for dirt removal.

##### **Achieved environmental benefits**

- Reduction of water and energy consumption.
- Reduced waste water generation.

- Reduction of emissions to water.
- Resource efficiency.

**Environmental performance and operational data**

The implementation of dirt removal/grease recovery loops allows the following:

- A reduction in water consumption ranging from a minimum of 25 % to a maximum of more than 50 %, taking as a reference point the consumption of water of a conventional plant operating countercurrently (between 5 l/kg and 10 l/kg of greasy wool).
- A reduction in energy consumption equivalent to the amount of thermal energy carried by the recycled liquor (the liquor temperature is generally about 60 °C).
- The production of a valuable by-product: wool grease.
- A reduction in detergent and detergent builder consumption proportional to the water savings achieved.
- The conversion of suspended dirt into spadeable sludge.
- A reduction of the load (oxygen-demanding substances and suspended solids) sent to the effluent treatment plant, which means a reduction in the consumption of energy and chemicals for the treatment of the waste water. This reduction is proportional to the dirt removal and grease recovery rate achieved.

Of the six wool scourers which took part in the data collection, four reported a grease recovery rate between 11 g/kg and 15 g/kg of raw wool for coarse wool and between 50 g/kg and 60 g/kg of raw wool for extra- and super-fine wool (see Section 3.7.1) [ 50, TWG 2019 ].

There is probably a maximum amount of grease that can be recovered centrifugally, which is governed by the ratio between hydrophobic and less hydrophobic grease (top grease and oxidised grease) present on the scoured wool [ 15, INTERLAINE 1999 ].

**Cross-media effects**

Consumption of energy by the centrifuges is one cross-media effect.

The COD concentration of the effluent resulting from the dirt removal and grease recovery loop may be too high for on-site aerobic treatment plants. The installation of coagulation/flocculation or anaerobic biological treatment before the aerobic biological plant would overcome this problem.

**Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

This measure is applicable in all new and most existing wool scouring plants.

**Economics**

A calculation of the net economic benefit per tonne of greasy wool can be done, based on the assumptions reported in Table 4.51. The unit costs refer to the situation in the UK at the time of the research (1999); therefore they can only be indicative of the European situation at that time.

**Table 4.51: Estimate of the economic benefits achievable with the installation of integrated dirt removal/grease recovery loops**

Benefits per tonne of greasy wool processed	Unit cost
Water saved: 4 m <sup>3</sup>	EUR 0.68/m <sup>3</sup> mains water
Energy saved: 836.8 MJ (a)	EUR 0.00245/MJ
Detergent saved: 1 kg	EUR 1.40/kg
Builder saved: 1 kg	EUR 0.27/kg (Na <sub>2</sub> CO <sub>3</sub> )
Avoided treatment of waste water: 4 m <sup>3</sup>	EUR 0.53/m <sup>3</sup> water discharged (b)

Avoided disposal of sludge: about 150 kg (wet weight)	EUR 0.041/kg of sludge (wet weight)
Grease produced for sale: - 50-60 kg (fine wool scourers) - 11-15 kg (coarse wool scourers)	EUR 2/kg of wool grease (but very variable)
(a) The energy saved to heat water to the operating temperature of 60 °C can be estimated at 209.2 MJ per m <sup>3</sup> of saved water (using direct gas at 90 % efficiency). (b) UK cost (1999) considering only the volume charge. In a real case, energy, chemicals, manpower, etc. should be taken into account. <i>Source:</i> [ 15, INTERLAINE 1999 ] except (c), I.M. Russell personal communication	

It is estimated that the installation of dirt removal/grease recovery loops at a mill processing 15 000 tonnes to 25 000 tonnes per year of greasy wool would cost between EUR 400 000 and EUR 800 000, depending on the nature, quality and capacity of the particular system chosen. The payback time for the installation, ignoring the benefits of reduced effluent disposal costs, would be between 2.04 and 4.08 years [ 15, INTERLAINE 1999 ].

### Driving force for implementation

The driving forces are economic benefit for medium and large mills, especially those processing fine (high grease content) wools. Economic benefit derives from savings in water, energy, sewage treatment and chemical costs and the proceeds from sales of wool grease. Disincentives are the high capital cost, high maintenance costs and complexity.

### Example plants

Plants from the data collection: CZ016, IT075, IT076, UK128 and UK129. In particular, Plant CZ016 uses evaporation to reduce even further the amount of waste water discharged.

### Reference literature

[ 15, INTERLAINE 1999 ], [ 50, TWG 2019 ]

## 4.2.1.2 Biological treatment of wool scouring sludge

### Description

The wool scouring sludge is treated, for example by composting.

### Technical description

Material for composting ideally has a C/N ratio between 20:1 and 35:1 ([ 96, Pinasseau et al. 2018 ]), which means that wool scouring sludges need an addition of carbon-rich material. Green waste, sawdust, woodchip and straw have reportedly been used successfully. Some 'structural material' (size up to 50 mm) is needed in the co-composted material in order to allow the ready ingress of air.

The residual grease content of the sludge sent for composting is a key control parameter. For coarse wool, this content is about of 10-12 % by weight and may be higher for fine wool. With a higher content of residual grease, the composting time may be longer and the C/N ratio would need to be adjusted accordingly. Moreover, the sludge gets stickier and is therefore more difficult to handle mechanically [ 224, Seaman S. 2019 ].

The composting process is described extensively in [ 96, Pinasseau et al. 2018 ].

### Achieved environmental benefits

Benefits include resource efficiency and reduction of the volume of waste sent for disposal.

The carbon which is decomposed by the composting process is converted aerobically into carbon dioxide, rather than methane (as in landfill). Carbon dioxide is a much less potent greenhouse gas than methane [ 15, INTERLAINE 1999 ].

### Environmental performance and operational data

For wool scouring sludges, the purpose of composting is to destroy, as far as possible, the components of the sludges which would be undesirable if spread on agricultural land. In the main, these are wool grease and ectoparasiticide residues. Composts produced from mixtures containing wool grease should therefore be periodically monitored for grease and ectoparasiticide content.

In composting trials carried out in the UK, similar results were achieved by composting for 6-7 weeks in a 10-tonne open windrow and for 14 days in an enclosed tunnel composter. The grease, organochlorine and synthetic pyrethroid ectoparasiticide content of the compost were reduced by 60 % and organophosphate ectoparasiticides were reduced by 80 %. Further reductions were expected during the maturation phase, but were not monitored. Interestingly, the woodchips and sawdust used as co-compostable material in this trial were found to be contaminated with lindane (OC) [15, INTERLAINE 1999].

### Cross-media effects

Composting can cause air pollution by odours and dust and water pollution via leachate (see [96, Pinasseau et al. 2018]). The use of compost as a soil conditioner may also cause water pollution if ectoparasiticide residues are present [15, INTERLAINE 1999].

### Technical restrictions related to applicability

Generally, there are no technical restrictions to the applicability of this technique.

This measure is applicable on site by scourers who have sufficient space. Off site, it is widely available, though transport costs (because of distance from merchant composters) might be a problem for some scourers.

### Economics

Composting is not an inexpensive technique. Capital costs are reported in Figure 4.26 for composting plant start-ups, while Table 4.52 gives information for in-vessel systems.

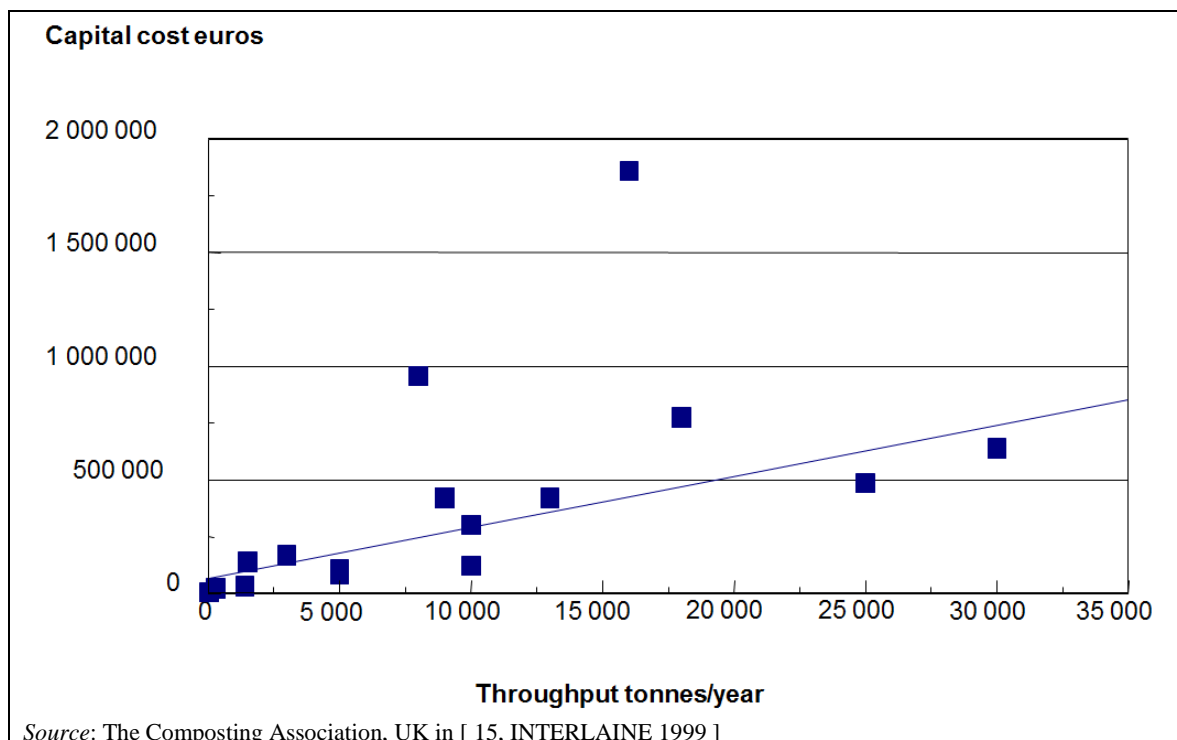


Figure 4.26: Capital costs of composting plant start-ups in the UK

**Table 4.52: Composting and maturation times, capital and treatment costs, for three types of in-vessel composting plant**

System	Composting time (days)	Maturation time (days)	Capital cost (EUR/10 000 t/yr)	Treatment cost (EUR/t)
Bay	7-36	0-120	450-2 250K	9-75
Container	10-20	30-100	450-1 500K	15-45
Tunnel	6-30	0-56	75-3 000K	9-45

*Source:* [ 15, INTERLAINE 1999 ]

**Driving force for implementation**

Costs of landfilling.

**Example plants**

Plants from the data collection: CZ016, IT075, IT076, UK128 and UK129.

**Reference literature**

[ 15, INTERLAINE 1999 ], [ 224, Seaman S. 2019 ]

**4.2.2 Techniques to increase energy efficiency in wool scouring installations****Description**

Set of measures to reduce energy consumption, including:

- heat recovery;
- covered scouring bowls;
- optimised temperature of the last scouring bowl;
- direct gas heating.

**Technical description**

In addition to fitting a heat exchanger to recover heat from the dirt/grease loop outlet, further savings arise from each of the following measures [ 15, INTERLAINE 1999 ]:

- Fitting of covers on scouring bowls to prevent heat loss by convection or evaporation. Optimising the performance of the final squeeze press in order to improve mechanical removal of water from the wool before it enters the evaporative dryer. The presses used for squeezing wool usually have steel bottom rollers and a porous top roller. Traditionally, the top roller was a steel roller wound with a crossbred (coarse) wool top (a sliver of parallel fibres). This has been replaced with a blended top of wool and nylon (polyamide), a nylon top, or a square section rope, usually of a wool and nylon blend. The last option combines durability with good performance. Porous composition rollers are offered commercially, but no information is available on their performance in this application.
- Running the last bowl at relatively high temperature in order to improve squeezing efficiency. Many scouring plants are set to run with bowl temperatures decreasing from the first or second to last bowl. Since heat losses from the last bowl will increase as its temperature increases and heat consumption in the dryer will correspondingly decrease as the squeezing efficiency improves, it follows that there is an optimum temperature for the last bowl. It has been shown that this temperature is 60-65 °C for wool throughput rates above about 500 kg/h.
- Direct gas firing of scouring bowls and dryers in order to avoid the losses which occur in the generation and distribution of steam for use in direct or indirect steam heating.



**Achieved environmental benefits**

Reduction in energy consumption, which will have the effect of reducing emissions of CO<sub>2</sub>, SO<sub>x</sub> and NO<sub>x</sub>, either from the scouring plant itself or off site.

**Environmental performance and operational data**

Energy savings from a dirt/grease recovery loop can be estimated as about 2 MJ/kg of greasy wool if a scouring plant with a loop and heat exchangers is used. It is assumed that a conventional scourer discharging 10 litres of water per kg of greasy wool needs 2.09 MJ to heat 10 litres of fresh water from 10 °C to 60 °C (209 kJ/l). A scouring installation with a loop and heat exchangers discharges only 2 l/kg (see Section 4.2.1.1) and recovers 80 % of the heat contained in the effluent (the energy input needed becomes 0.084 MJ/kg of greasy wool).

Table 4.53 shows the energy savings achievable in the dryer by operating the last bowl at optimum temperature (65 °C) as discussed earlier.

**Table 4.53: Energy savings from operating the last bowl at optimum temperature**

Last bowl temperature (°C)	20	30	40	50
Savings if the last bowl was operated at 65 °C instead, expressed in MJ/kg wool <sup>(1)</sup>	0.42	0.25	0.12	0.04
<sup>(1)</sup> Calculations were made considering an indirect steam dryer. Source: [ 15, INTERLAINE 1999 ]				

Energy savings from direct gas firing of scouring bowls and dryers are 0.3 MJ/kg.

In conclusion, medium-to-large wool scouring plants can be operated with an energy consumption of 4-4.5 MJ/kg of greasy wool processed, comprising approximately 3.5 MJ/kg thermal energy and less than 1 MJ/kg electrical energy. Smaller plants may have higher limits for specific energy consumption, but no information is available to confirm this [ 15, INTERLAINE 1999 ].

**Cross-media effects**

No negative effects are expected.

**Technical considerations relevant to applicability**

Fitting of covers on scouring bowls or direct gas firing of scouring bowls and dryers may be only applicable to major plant upgrades or to new plants.

**Economics**

Economic considerations are the major driving force from the industry's point of view. No further information has been provided.

**Driving force for implementing these techniques**

Savings in energy consumption.

**Example plants**

Plants from the data collection: CZ016, IT061, IT075, IT076, UK128 and UK129.

**Reference literature**

[ 15, INTERLAINE 1999 ]

## 4.3 Spinning of fibres (other than man-made fibres) and production of fabric

### 4.3.1 Techniques to avoid or reduce the use of hazardous substances

#### 4.3.1.1 Mineral-oil containing preparations

##### 4.3.1.1.1 Mineral oils substitution in wool spinning lubricants

#### **Description**

Mineral oils used as wool spinning lubricants are replaced by synthetic and ester oils.

#### **Technical description**

Spinning lubricants are usually removed during pretreatment to ensure uniform penetration of the dye and finishing agents and to avoid reaction and precipitation with them. Since in the case of wool the processes that take place first in the finishing mill are wet treatments (washing/scouring), the presence of lubricants primarily affects emissions to water rather than air.

In carded wool and wool blend yarns, where a higher load of lubricants is applied (compared to worsted wool), spinning oils (together with detergents used in the scouring process) may contribute up to 80 % of the oxygen-demanding load in dyehouse waste water [9, TWG 2001].

Mineral-oil-based lubricants were once used universally in the wool sector. These substances may not be fully degraded in biological sewage treatment works (i.e. poorly biodegradable).

Moreover, the formulations of conventional spinning lubricants can contain variable amounts of even more hazardous substances such as polyaromatic hydrocarbons or other 'hard surfactants' such as emulsifiers (see Section 4.1.6.9.1 for the substitution of APEO and also Section 8.1.2).

More than 20 years ago mineral oils were largely replaced with formulations based on glycols and this trend continues. Biodegradable substitutes are readily available [9, TWG 2001]. APEO compounds have long been successfully substituted by less problematic surfactants.

#### **Achieved environmental benefits**

Reduction of emissions to water.

#### **Environmental performance and operational data**

In the carpet sector, the use of mineral-oil-based lubricants is reported to have been in decline for some years, indicating that carpet yarn of commercial quality can be produced without the use of these substances [9, TWG 2001]. It is believed that the same is valid for the rest of the textiles sector.

#### **Cross-media effects**

Compared to mineral-oil-based lubricants, increased foaming in the waste water treatment may be observed.

There is some evidence that mineral-oil-based lubricants are more amenable to on-site treatment than the more water-soluble glycol-based products. Where there is on-site pretreatment, the choice of lubricant may be critical and mineral-oil-based products may be the more viable option. Further research may be required [9, TWG 2001].

#### **Technical considerations relevant to applicability**

Plants which include the manufacturing processes leading up to wet processing, such as sales yarn spinning, and vertically integrated companies have the means to control the use of these materials in house.

On the other hand, commission dyers receive yarn on which the lubricant is already present. In these cases, it is necessary to work with clients to eliminate these materials from the supply chain [ 9, TWG 2001 ].

### **Economics**

The consequences of substituting one spinning lubricant for another are difficult to predict as the yarn yield (the quantity of yarn obtained from a given mass of raw fibre) is notoriously difficult to measure accurately and very small changes in yield markedly affect the economics of yarn production. The lubricant type and level of application can have a significant impact on yield [ 9, TWG 2001 ].

### **Driving force for implementation**

Environmental legislation.

### **Example plants**

Plants from the data collection: BE011, CZ016, CZ017, CZ020, IT075, IT076, IT082, IT097, PT108, PT111, SE120 and UK129.

### **Reference literature**

[ 9, TWG 2001 ]

#### **4.3.1.1.2 Substitution of mineral oils in fabric knitting**

##### **Description**

Mineral oils used as fabric knitting lubricants are replaced by synthetic and ester oils.

##### **Technical description**

The production of knitted fabric requires efficient lubrication of the needles and mechanical elements of the knitting machine. The quantity of lubricants used depends on the technology of the machine and its speed.

The yarn driven by the needles during the manufacturing of the fabric carries part of the lubricant. As a result, the final knitted fabric can contain about 4-8 % w/w of lubricant oil that then needs to be removed during pretreatment.

Conventional knitting oils (mineral-oil-based formulations) can only be removed through emulsification using detergents, emulsifiers and anti-redeposition agents. The process is carried out under alkaline conditions and at temperatures between 80 °C and 100 °C. Water consumption is approximately 10 l/kg of fabric, and the time required for the process is about 30-60 minutes.

The technique consists of using hydrosoluble oils instead of conventional lubricants.

##### **Achieved environmental benefits**

- Reduction of emissions to water and to air.
- Reduction of water and energy consumption.

##### **Environmental performance and operational data**

Unlike conventional mineral-oil-based lubricants, hydrosoluble oils can be easily washed out of the fabric. This helps reduce water, energy and chemical consumption along with processing time. Moreover, these oils are reported to be biodegradable [ 225, Spain 2002 ], which makes the resulting effluent suitable for treatment in a biological waste water treatment plant.

The alternative hydrosoluble knitting oils described in this section produce emulsions which remain stable for 3 days [ 225, Spain 2002 ].

As for the types of fibres, hydrosoluble oils are suitable for knitted fabrics made of cellulose fibres and blends, as well as fabrics made of synthetic fibres, mainly polyester and polyamide, and their blends with natural and synthetic fibres, including elastane.

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

The technique is applicable to new and existing plants. However, corrosion problems have been observed in some existing plants.

Since the technique implies that the company has direct control of the type of lubricants used during the knitting process, implementation can be problematic for non-integrated mills and particularly for commission finishers. In particular, purchased tissues and yarns (imported from outside the EU for example) can still contain mineral oils [ 108, Derden et al. 2010 ]. In these cases, it is necessary to work with clients to eliminate these materials from the supply chain.

#### **Economics**

The overall cost of this technique is comparable with the conventional one. The water-soluble knitting oils are more expensive than the mineral-oil-based ones, but this extra cost is compensated by the higher productivity and by the higher treatability of the effluent resulting from pretreatment.

#### **Driving force for implementation**

Environmental legislation for emissions to air and water .

#### **Example plants**

Plants from the data collection: BE010, CZ015, CZ017, DE034, IT082 and SE120.

#### **Reference literature**

[ 108, Derden et al. 2010 ], [ 225, Spain 2002 ]

### **4.3.1.2 Sizing agents**

#### **4.3.1.2.1 Selection of sizing agents**

##### **Description**

Sizing agents with improved environmental performance in terms of quantity needed, washability from the textile fibres, recoverability and/or bioeliminability/biodegradability (e.g. modified starches, certain galactomannans and carboxymethyl cellulose) are selected (see Section 4.1.6.1) and used.

##### **Technical description**

Sizing agents are applied to warp yarn in order to prevent thread breakage during weaving. For subsequent processing, the sizing agents need to be removed almost completely from the fabric. This is done in the desizing step, often with a large amount of water and the addition of auxiliaries. The resulting effluent is responsible not only for a high COD/BOD load (about 30-70 % of the overall COD load), but also for the presence of substances that are difficult to degrade that may not be abated by the waste water treatment. In some cases, sizing agents may be recovered from the desizing liquor but in the current (non-circular) models recovered sizes cannot be used locally as the sizing chemical is not purchased and used as such, but on yarn or fabric to which the size was applied in another installation. More often, however, the effluent is treated in the waste water treatment plant.

Insufficient chemicals management may also lead to site operators not knowing what sizes were used by their suppliers.

Along with low add-on techniques such as pre-wetting (see Section 4.3.1.2.2), targeted selection of sizing agents may also contribute significantly to the reduction of the environmental impact of this operation.

Environmentally optimised sizing agents are:

- highly efficient with low add-on;
- completely and easily removed from the fabric;
- biodegradable or bioeliminable (ultimate aerobic biodegradability > 80 % after 7 days according to the Zahn-Wellens Test as per EN ISO 9888:1999).

It is now accepted that readily biodegradable and bioeliminable sizing agent formulations are available, covering all needs. Modified starches, certain galactomannans, polyvinyl alcohol and certain polyacrylates satisfy this requirement.

Latest-generation polyacrylates are able to fulfil all the requirements listed above. The use of these high-efficiency synthetic sizes instead of conventional modified starches allows a reduction in size add-on without any decline in weaving efficiency (in some cases, increased weaving efficiency is observed). In addition, new-generation polyacrylates are easy to wash out and can be removed with little water and without additional auxiliaries.

The new polyacrylates can be applied as almost universal sizing agents for all kinds of fibres.

For cotton, polyacrylates are applied in combination with other sizes, usually PVA, in order to increase the viscosity of the system.

### **Achieved environmental benefits**

Reduction of emissions to water.

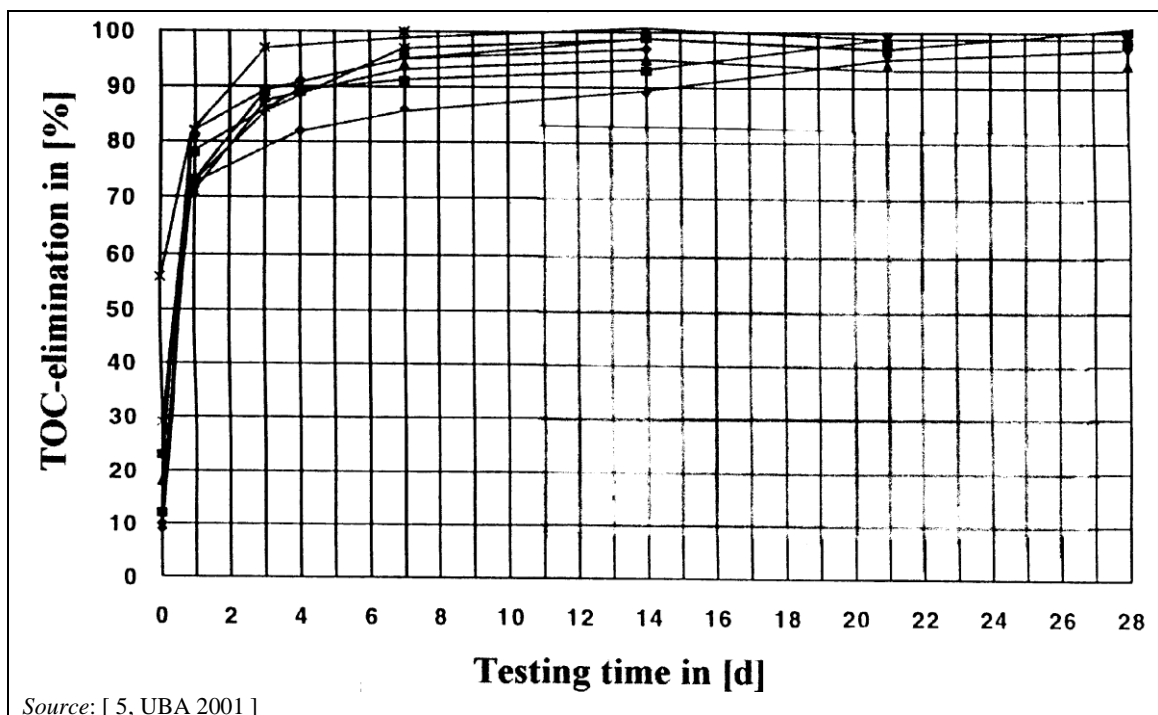
### **Environmental performance and operational data**

The application of biodegradable and bioeliminable sizing agents leads to a significant reduction of the COD load that may pass undegraded through the waste water treatment plant and be discharged to natural waters.

Additional advantages are achieved when using the highly efficient, easy-to-wash sizing agents as significant savings can be obtained in chemicals, water and energy consumption. With advanced efficient washing machines only low quantities of water are needed to remove the size, without additional auxiliaries (e.g. emulsifiers) or long cycle times (lower energy consumption).

Polyacrylates, polyvinyl alcohol and modified starch are not only biodegradable and bioeliminable, but are also suitable for size recovery techniques. New polyacrylates have the additional advantage of being applicable as almost universal sizing agents. This means that they are potentially easy to reuse as sizes in weaving firms.

The bioelimination curves of seven combinations of sizing agents based on modified starches, new-generation polyacrylates, polyvinyl alcohol and certain galactomannans are shown in Figure 4.27.



**Figure 4.27: Biodegradation/Bioelimination curves in the modified Zahn-Wellens Test (EN ISO 9888) of seven combinations of different sizing agents which are biodegraded/bioeliminated by more than 80 % after 14 days**

Modified starches are water-removable (less easily than modified polyacrylates), without the need for enzymatic or oxidative desizing. They are biodegradable/bioeliminable, but they give rise to bulky, viscous and filamentous sludge that is difficult to settle.

Polyvinyl alcohol (PVA) is easy to wash out at mid-range pH and it is recoverable. In alkaline conditions, it swells and becomes highly viscous and difficult to remove. Polyvinyl alcohol is biodegradable only under specific system conditions such as adaptation of the activated sludge, temperatures not below 15 °C and particularly low food to microorganism ratios (F/M ratios) (see Section 4.1.7.3.5.1.1). In alkaline conditions, PVA results in settlement problems.

As mentioned above, the new polyacrylates are highly efficient with lower add-on (see Table 4.54 below), they are removable with water (no need for either enzymatic or oxidative desizing) and they also have high stability when in contact with alkalis (it is possible to bleach the fabric directly, without a preliminary scouring step). Unlike classic polyacrylates, the new ones are more than 90 % eliminated under the conditions of the Zahn-Wellens Test, even in high concentrations, by adsorption on the activated sludge. Furthermore, they become insoluble by forming complexes with iron. In this way, they can be precipitated almost totally with only a small amount of precipitant.

**Table 4.54: COD reduction after replacement of conventional sizing agent by alternative recipe based on polyacrylates**

	Common recipe (modified starch, wax)	Alternative recipe (modified polyacrylate, PVA, wax) <sup>(1)</sup>
Size add-on	13	10 %
Specific COD (g O <sub>2</sub> /100 kg warp yarn)	17 800	11 550
Total COD (t/yr) <sup>(2)</sup>	712	462
Reduction of COD load	Not applicable	35 %
<sup>(1)</sup> Typical operating conditions for sizing staple fibre yarn in air jet loom at 650 rpm are as follows: PVA: 7 kg; modified acrylate (liquid 25 %): 7 kg; wax: 0.4 kg; volume sizing liquor: 100 l; nip pressure: 20 kN; sizing speed: 100 m/min. <sup>(2)</sup> Calculated on an annual production of 4 000 t warp yarn. Source: [ 5, UBA 2001 ]		

### Cross-media effects

The application of sizing agents with higher bioeliminability and biodegradability leads to an increased amount of sludge to be disposed of [ 5, UBA 2001 ]. This sludge can be bulky, filamentous and difficult to settle.

### Technical considerations relevant to applicability

Although the application of optimised sizing recipes is technically feasible for all sizing departments, the worldwide organisation of the textile chain makes it difficult for non-integrated mills and particularly for commission finishers to influence the upstream weaving mills [ 5, UBA 2001 ]. In these cases, it is necessary to work with clients to eliminate these materials from the supply chain.

Raw material input control (beyond simple visual testing) is recommended but the client only rarely consents to being charged for the related additional expenses [ 44, ÖKOPOL 2011 ].

The use of polyacrylates for filament polyester may give rise to quality problems. For example, technical problems in the finishing stage were experienced when using polyacrylates on cotton fibre that had to be submitted to pre-shrink finishing [ 22, TWG 2002 ].

### Economics

In most cases, biodegradable and bioeliminable combinations of sizing agents are no more expensive than others that do not meet the high elimination rate requirement (> 80 % after 7 days according to the Zahn-Wellens Test ) [ 5, UBA 2001 ].

Details are given in Table 4.55 below regarding, in particular, the application of alternative synthetic, high-efficiency sizes based on polyacrylates.

**Table 4.55: Comparison between conventional and high-efficiency sizing agents**

	Common recipe (modified starch, wax)	Alternative recipe (modified polyacrylate, PVA, wax) <sup>(1)</sup>
Costs for sizing agents (EUR/yr)	260 850	325 850
Warp thread breakage (thread break/10 <sup>5</sup> picks)	5.8	3.0
Savings due to minimised thread breakage (EUR/yr)	Not applicable	225 000
Total savings (EUR/yr) <sup>(1)</sup>	Not applicable	160 000
<sup>(1)</sup> Cost savings are calculated for a typical weaving mill working 8 000 h/yr (100 weaving machines, 310 rpm). Source: [ 5, UBA 2001 ]		

**Driving force for implementation**

Environmental legislation is one of the driving forces for implementation.

The selection of biodegradable/bioeliminable sizing agents is also encouraged by initiatives at the European level such as EU Ecolabel, OSPAR, etc.

In addition, the substitution of conventional size recipes with highly efficient ones is economically motivated in weaving mills, especially in combination with pre-wetting techniques (see Section 4.3.1.2.2), which can reduce size consumption by a third or even more.

**Example plants**

Environmentally optimised sizing agents are largely applied worldwide in weaving mills.

UBA reported on a voluntary initiative in Switzerland of 20 weaving mills. Seven different bioeliminable formulations of sizing agents have been developed (see also Figure 4.27) and are currently applied, which can cover all different kinds of substrates and weaving techniques. They are based on [ 5, UBA 2001 ]:

- starches and starch derivatives;
- certain polyacrylates;
- polyvinyl alcohol;
- certain galactomannans.

Plants from the data collection: CZ018, DE039, IT059, PT108, PT110, SE119 and SE120.

**Reference literature**

[ 4, EURATEX 2000 ], [ 5, UBA 2001 ], [ 19, Jacobs et al. 1998 ], [ 44, ÖKOPOL 2011 ], [ 112, COM 2014 ], [ 243, OSPAR 1994 ]

**4.3.1.2.2 Pre-wetting of the cotton warp yarns****Description**

The cotton warp yarns are dipped into hot water prior to sizing, which allows the reduction of the amounts of sizing chemicals used.

**Technical description**

In cotton finishing mills, the desizing process accounts for 50-70 % of the total COD in the waste water. Minimising the amount of size applied on the warp yarn during fabric processing is one of the most effective pollution prevention techniques for reducing the organic load caused by sizing agents.

On-line monitoring of size add-on and pre-wetting technology are now available options.

The pre-wetting technology consists of running the warp yarn through hot water before the sizing process. The warp yarn is dipped into the hot water (an additional spraying of hot water may be possible), then a squeeze roller removes the surplus water before the sizing stage. Systems with two dipping and squeezing steps are also in use.

Pre-wetting allows a more homogeneous sizing effect, increased adhesion of the size and reduced hairiness of the yarn. From experimental analysis, it seems that a lower 'core-sizing' effect is produced. As a result, a reduced amount of size can be applied to the fibre without affecting the weaving efficiency. In some cases, an increase in weaving efficiency can even be observed.



### **Achieved environmental benefits**

A reduced size load on the yarn means that a lower amount of sizing agent is discharged in the water during the textile pretreatment, with immediate positive effects on the organic load of the final effluent.

### **Environmental performance and operational data**

Depending on the setting of the warp beam and the type of yarn processed (e.g. density of the yarn, type of fibres in the blend), a reduction of the size add-on of about 20-50 % is possible.

Pre-wetting has now been tested in practice with all types of cotton yarns and blends of cotton/PES and viscose. The best results are achieved with medium to coarse yarns. Application is possible for batches of 5 000 m to 10 000 m, both for ring-spun and open-end yarns.

Technical problems may be observed in relation to the efficient measurement and control of high humidity percentages and the calibration of the wetting device [ 22, TWG 2002 ].

Existing sizing machines with two sizing boxes can be upgraded by using the first sizing box for pre-wetting and the second one for sizing.

### **Cross-media effects**

None identified.

### **Technical considerations relevant to applicability**

The applicability may be restricted by product specifications related to yarn density or the tension required on the fibre during weaving.

A high percentage of cotton fabric finished in Europe is actually imported from non EU-countries (e.g. India) where these control techniques are not yet widely used. As a result, from a practical point of view, this pollution prevention measure is more easily and immediately applicable in integrated mills than in commission finishers. In these cases, it is necessary to work with clients to eliminate these materials from the supply chain.

### **Economics**

Sizing equipment with pre-wetting boxes is approximately EUR 25 000-75 000 more expensive than sizing equipment without a pre-wetting section. Operating costs are only marginally higher, because the additional expenditure for the pre-wetting water is compensated by the reduction in sizing liquor consumption.

A direct comparison between sizing with and without pre-wetting (operational data of an Italian weaving mill) shows cost savings of about 27 %, an increase in sizing machine speed of about 22 %, and an increase in weaving efficiency of about 0.2 % [ 5, UBA 2001 ].

### **Driving force for implementation**

- Sizing agent savings.
- Increase of weaving efficiency.
- Reduction of waste water load.

### **Example plants**

About 160 pre-wetting boxes are in use worldwide [ 5, UBA 2001 ].

Plants from the data collection: DE042, DE049 and SE120.

### **Reference literature**

[ 5, UBA 2001 ], [ 22, TWG 2002 ]

### 4.3.1.2.3 Compact spinning

#### Description

The fibre strands are compressed by suction or by using mechanical or magnetic compacting. This allows a reduction of the amounts of sizing chemicals used.

#### Technical description

Normally, in ring spinning, after the draft system a spinning triangle is generated. At the moment, when they pass the spinning triangle, the fibres are not strengthened by twisting. Yarn breakage and yarn hairiness occur.

In compact spinning, the fibre strands are compressed after the draft system by means of pneumatic devices (application of suction on the fibre strands), mechanical compacting or magnetic compacting [ 5, UBA 2001 ], [ 226, Alagirusamy R. 2013 ]. A higher yarn quality results (increased fibre strength and elongation, reduced hairiness, increased abrasion resistance).

Figure 4.36 compares the operating principles of ring spinning and compact spinning.

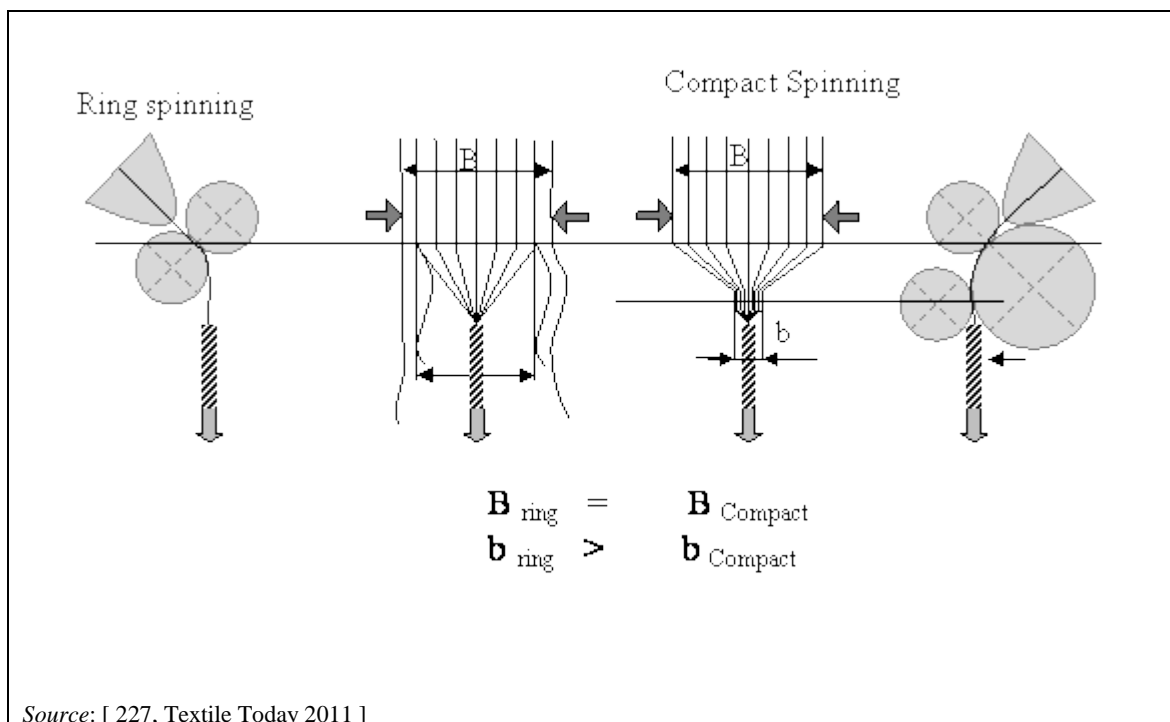


Figure 4.28: Operating principles of ring spinning and compact spinning

#### Achieved environmental benefits

Reduction of emissions to water and of chemical consumption.

#### Environmental performance and operational data

Compared to conventional ring-spun yarns, compact yarns have better running properties and less thread breakage during weaving, even when the size add-on is reduced by up to 50 %. This leads to a considerable reduction in waste water load in desizing. Due to the reduced hairiness, application of paraffins to yarns is no longer necessary [ 5, UBA 2001 ].

#### Cross-media effects

None identified.

### **Technical considerations relevant to applicability**

The applicability may be restricted by product specifications (e.g. level of hairiness or technical properties of the yarn).

The appearance and technological properties of compact spinning yarns (and fabrics made of them) are different to those of conventional manufactured yarns. The lower hairiness of the yarns is an undesired effect in the case of yarns produced for knitted goods.

Adaptation of existing spinning machines may be possible [ 5, UBA 2001 ].

### **Economics**

Additional costs in yarn manufacturing are partially or totally offset by cost savings in the weaving mill, due to higher weaving efficiency and reduced size add-on. Reduced costs in finishing are expected (e.g. lower waste water treatment cost due to the lower amount of sizing agents).

### **Driving force for implementation**

A better yarn quality and the possibility to create new effects and designs are the main reasons for installing compact spinning machines.

### **Example plants**

Plants from the data collection: PT108 and UK127.

### **Reference literature**

[ 4, EURATEX 2000 ], [ 5, UBA 2001 ], [ 226, Alagirusamy R. 2013 ], [ 227, Textile Today 2011 ]

## **4.3.2 Techniques to increase energy efficiency**

### **4.3.2.1 General energy-saving measures for spinning and weaving**

#### **Description**

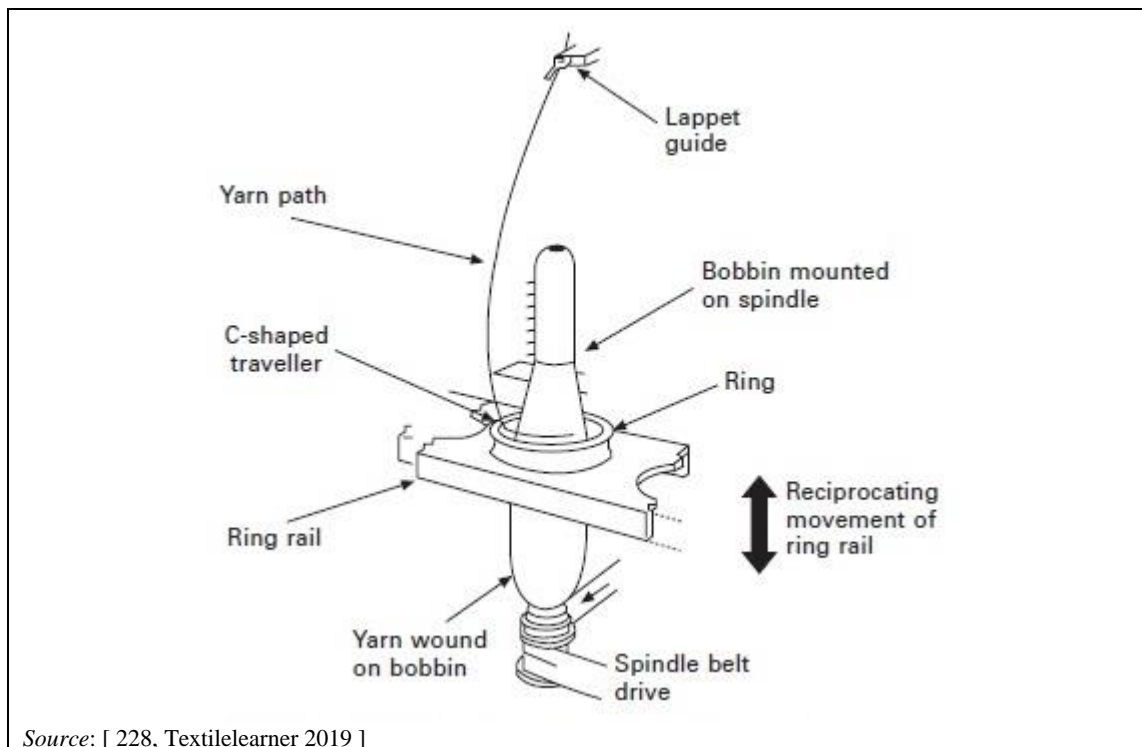
A set of technical measures identified in the energy efficiency plan (see Section 4.1.4.1) and which allow the reduction of the energy consumed by spinning and weaving. This includes:

- reducing as much as possible the volume of the production area (e.g. by installing a suspended ceiling) to reduce the amount of energy needed for humidifying the ambient air;
- using advanced sensors that detect thread breaks to stop the machines.

#### **Technical description**

Electricity is the main type of energy used in spinning (see a schematic of ring spinning in Figure 4.29 below).

The factors which most affect the energy consumption in yarn production are the speed of machines, the yarn count (i.e. the yarn fineness) and the temperature for steps involving heat treatment (for example steaming) [ 83, CITEVE 2014 ].



**Figure 4.29: Schematic of ring spinning**

Techniques to reduce energy consumption include the following:

- Carding
  - Use of a high-speed carding machine with a lower specific energy consumption.
- Roving
  - Installation of a photoelectric end-break stop-motion detector instead of a pneumatic suction tube detector.
- Ring and compact spinning
  - Use of lighter spindles and bobbins in the ring frame, which require less energy to be moved.
  - Use of energy-efficient spindle oil, incorporating a dispersant agent.
  - Ensuring an optimal oil level in the spindle bolsters as an excessive level may cause resistance in the rotation of the spindle.
  - Use of a synthetic spindle belt.
  - Optimisation of the ring diameter with respect to the yarn count in ring frames. A larger ring induces a larger and heavier bobbin, thus higher energy consumption.
  - Reduction of the energy for humidifying the ambient air of the spinning area by reducing the volume of the area (e.g. with a lower ceiling).
  - Installation of energy-efficient motors.
  - Installation of energy-efficient suction fans for the collection of loose fibres.
  - High-speed ring spinning machine with lower specific energy consumption.
  - Installation of a soft starter on motor drives, which ensures a gradual acceleration of motors of the ring spinning machines.
- Winding
  - Installation of variable frequency drive in cone winding machines.
  - Intermittent mode of movement of the empty bobbin conveyor in the cone winding machines.

- Heat treatment
  - Replacement of the electrical heating system with a steam heating system for yarn drying, which reduces the overall energy use.

**Achieved environmental benefits**

Reduction of energy consumption.

**Environmental performance and operational data**

Examples of reduction of energy consumption are given in Table 4.50.

**Table 4.56: Electricity savings made when applying energy-saving measures**

Measure	Electricity savings
Energy-efficient spindle oil	3-7 % of ring frame energy use
Installation of a false ceiling in ring spinning area	788 MWh/year
High-speed ring spinning frame	10-20 % of ring frame energy use
Installation of electronic roving end-break stop-motion detector instead of pneumatic system	3.2 MWh/year/machine
Installation of energy-efficient suction fans	5.8-40 MWh/year/ring frame
Installation of energy-efficient motor in ring frame	6.3-18.83 MWh/year/motor
Installation of variable frequency drive in cone winding machines	331.2 MWh/year <sup>(1)</sup>
Intermittent mode of movement of empty bobbin conveyer in the cone winding machines	49.4 MWh/year <sup>(1)</sup>
Optimisation of ring diameter with respect to yarn count in ring frames	10 % of ring frame energy use
Replacement of lighter spindle in place of conventional spindle in ring frame	23 MWh/year/ring frame
Replacement of the electrical heating system with steam heating system for yarn drying	19.5 MWh/year/machine
Synthetic belts for ring frames	4.4-8 MWh/year/ring frame
Use of lightweight bobbins in ring frame	10.8 MWh/year/ring frame
<sup>(1)</sup> The number of cone winding machines has not been reported. Source: [ 84, Hasanbeigi A, 2010 ] [ 83, CITEVE 2014 ]	

**Cross-media effects**

None identified.

**Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

**Economics**

Examples of investment costs are given in Table 4.57.

**Table 4.57: Investment costs of energy-saving measures**

Measure	Investment costs	Payback period (years)
High-speed carding machine	USD 100 000/carding machine <sup>(1)</sup>	< 2
Installation of electronic roving end-break stop-motion detector instead of pneumatic system	USD 180/roving machine <sup>(1)</sup>	< 1
Installation of energy-efficient suction fans in in the ring frame	USD 195-310/fan <sup>(1)</sup>	<1
Installation of energy-efficient motor in ring frame	USD 1 950-2 200/motor <sup>(1)</sup>	2-4
Installation of variable frequency drive in cone winding machines	USD 19 500 <sup>(1)</sup> <sup>(2)</sup>	< 1
Intermittent mode of movement of empty bobbin conveyor in the cone winding machines	USD 1 100 <sup>(1)</sup> <sup>(2)</sup>	< 1
Optimisation of ring diameter with respect to yarn count in ring frames	USD 1 600 / ring frame <sup>(3)</sup>	2
Replacement of lighter spindle in place of conventional spindle in ring frame	USD 13 500 / ring frame <sup>(1)</sup>	8
Replacement of the electrical heating system with steam heating system for the yarn drying	USD 980/machine <sup>(1)</sup>	< 1
Synthetic belts for ring frames	USD 540-683/ring frame <sup>(4)</sup>	1-2
Use of lightweight bobbins in ring frame	USD 660 / ring frame <sup>(1)</sup>	< 1
<sup>(1)</sup> 2008 value. <sup>(2)</sup> The number of cone winding machines has not been reported. <sup>(3)</sup> 2010 value. <sup>(4)</sup> 2005 and 2008 values respectively. <i>Source:</i> [ 84, Hasanbeigi A. 2010 ] [ 83, CITEVE 2014 ]		

**Driving force for implementation**

Savings in energy consumption.

**Example plants**

No information provided

**Reference literature**

[ 83, CITEVE 2014 ], [ 84, Hasanbeigi A. 2010 ]

**4.3.2.2 Vortex spinning****Description**

An air vortex is used to spin out the yarn.

**Technical description**

The vortex spinning technique utilises a high-speed airflow to twist the yarn. This greatly increases the rotational speed of the fibre strand, which can be as high as 200 000 turns/minute.

In the vortex spinning system, the spinning part is composed of an air-jet nozzle and a hollow spindle with a yarn passage through it. The core yarn fibres come from the front rollers, are held together (anchored and pulled through the hollow spindle) and represent the central yarn around which the outer fibres are twisted with the action of the high-speed airflow inside the nozzle. Fibres that whirl around the hollow spindle tip attach to the core fibres by wrapping onto them and yarn with a twisted structure is formed. The formed yarn is then delivered out of the nozzle through the yarn passage of the hollow spindle with the drag of the delivery rollers and fed to the winding part.

Fibres that are 100 % cotton can be spun at high speeds (500 metres/minute) and the yarn structure resembles the ring yarn structure rather than rotor yarns. The vortex system can have up to 96 spinning units; it includes a Spinning Tension Stabilising (STS) system, a spinning sensor and a spin clearer.

### **Achieved environmental benefits**

Lower energy consumption for the yarn production.

### **Environmental performance and operational data**

There are many parameters influencing this twisting system, and consequently the vortex yarn. The number of jet orifices and the diameters of the orifices directly affect the vortex magnitude. The airflow characteristics depending on the nozzle pressure have an influence on the ratio of the wrapping fibres to the core fibres, which is a determining factor for the yarn fineness: a reduction of core fibres in the yarn structure may lead to deterioration in the yarn properties as the yarn gets finer.

Airflow-fibre-nozzle interactions in the yarn formation area need to be analysed carefully for the quality improvement of vortex yarn spinning.

It is to be noted that the drapability of the resulting fabric is poor due to the stiffer yarn structure.

### **Cross-media effects**

None identified.

### **Technical considerations relevant to applicability**

Generally applicable to cotton fibres, synthetic fibres and blends thereof [ [230, MURATA 2019](#) ].

### **Economics**

This technique can be carried out with a lower operational cost than conventional spinning due to the lower energy usage. The investment costs are nevertheless higher.

### **Driving force for implementation**

This technology yields faster production processes and a significant reduction in opex costs.

### **Example plants**

No information provided.

### **Reference literature**

[ [35, RICARDO 2019](#) ], [ [229, Textilelearner 2019](#) ], [ [230, MURATA 2019](#) ]

## **4.3.2.3 Energy-saving measures for weaving**

### **Description**

A set of technical measures identified in the energy efficiency plan (see Section 4.1.4.1) and which allow the reduction of the energy consumed by weaving. This includes:

- avoiding excessive air pressure for air-jet weaving;
- using a double-width loom for large-volume batches.

### **Technical description**

The weaving process is run almost entirely on electricity only. This process is a major consumer of compressed air, particularly when the looms are air-jet. The amount of energy consumed by each loom during its weaving operation can be estimated from the motor capacity and weaving speed. Across the different weaving technologies, weft insertion systems consume a large share

of the total electricity use of the equipment. Usually, lighting is significant in terms of electricity consumption, because the weaving sections have many lighting fixtures installed. On the other hand, some thermal energy is consumed in sizing, as one of the possible preparatory operations for weaving [ 83, CITEVE 2014 ].

Techniques to reduce energy consumption include the following:

- Optimisation of the air distribution for air-jet weaving. This is done by avoiding the use of excess air, using automatic pressure control valves and software to optimise the pressure distribution during weft insertion.
- Use of a double-width loom for large-volume articles, with a lower specific energy consumption.
- Reduction of the energy for humidifying the ambient air of the weaving area by reducing the volume of the area (e.g. with a lower ceiling).

#### **Achieved environmental benefits**

Reduction of energy consumption.

#### **Environmental performance and operational data**

No information provided.

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

A double-width loom may only be applicable to new plants or major plant upgrades.

#### **Economics**

No information provided.

#### **Driving force for implementation**

Savings in energy consumption.

#### **Example plants**

No information provided.

#### **Reference literature**

[ 83, CITEVE 2014 ], [ 84, Hasanbeigi A. 2010 ]

### **4.3.3 Techniques to increase resource efficiency**

#### **4.3.3.1 Seamless knitting**

##### **Description**

Clothing is produced with whole-garment technologies like seamless (3D) knitting, which produces the garment in one step, without intermediary fabric manufacturing, fabric cutting and sewing steps.

##### **Technical description**

Whole-garment technologies use specific knitting machines with specialised circular looms to develop garments that adapt to the body shape. In these knitting machines, a computer controls and directs the movement of hundreds of needles to construct and connect several tubular knitted forms and create a whole garment in a single production step. Whole-garment techniques are used to manufacture clothing (e.g. sportswear, sweaters) or technical textile products (e.g. car seats).



### **Achieved environmental benefits**

- Reduction of textile waste.
- Reduction of energy consumption.

### **Environmental performance and operational data**

The energy consumption is not necessarily high for the knitting process. However, knitting machines have also been undergoing a shift towards high-speed and large-capacity and fine-gauge features, as the current industry trend is for high added-value goods and multi-line, small-volume production based on advanced systems such as computer-controlled pattern-making mechanisms. Therefore, there is a potential tendency for increased energy consumption [ 83, CITEVE 2014 ].

High speeds and a fine gauge produce knitted sweaters three times faster than conventional flat-bed machines. Energy consumption is reduced from 21 kWh/dozen knitted garments to 8.5 kWh simply by reducing idle machine time. Knitting speed improvements by reducing the time taken for the carriage to change direction (known as rapid response) improve efficiency by up to 8 %. Reducing friction during the knitting process reduces energy consumption in a circular knitting machine by up to 20 % and CO<sub>2</sub> emissions by 1 500 kg per machine (needles' lifetime based on 5 000 hours or 208 days) [ 35, RICARDO 2019 ].

### **Cross-media effects**

None identified.

### **Technical considerations relevant to applicability**

Generally applicable to garments that would otherwise require sewing and stitches (T-shirts, jumpers, etc.).

### **Economics**

The machinery requires a significant amount of initial capital investment. However, these costs can be offset by long-term savings in labour and resource (e.g. energy, fibre) costs.

### **Driving force for implementation**

- Reduction of production time to between 30-40 % (compared to cut and sew manufacture).
- Increased production yield.

### **Example plants**

Industrial operators that have selected this technology: UK company Quantum knitwear (whose machinery plant consists only of whole-garment machines), and Patagonia (USA).

### **Reference literature**

[ 11, Beton et al. 2014 ], [ 35, RICARDO 2019 ], [ 83, CITEVE 2014 ]

## 4.4 Pretreatment

### 4.4.1 Single or limited number of desizing liquors

#### Description

The number of desizing liquors for removing different types of sizing chemicals is limited. In some cases, e.g. for various cellulosic materials, a single oxidative desizing liquor may be used (e.g. cold-pad batch, see Section 2.6.1.1.2).

#### Technical description

Many woven fabrics contain a variety of different sizing agents (see Section 4.3.1.2.1), depending on the origin and quality of the substrate. Most textile finishers deal with many different types of fabrics, and therefore sizing agents, so they are interested in fast, consistent and reliable removal of non-fibrous material (be it the impurities and fibre-adjacent material or any preparation agent) independent of the origin of the fabric.

Under specific conditions (above pH 13),  $\text{H}_2\text{O}_2$  generates free radicals which efficiently and uniformly degrade all sizes and remove them from the fabric. This process provides a clean, absorbent and uniform base for subsequent dyeing and printing, no matter which size or fabric type is involved [ 659, D. Levy, 1998].

Studies ([ 231, VITO 2001 ]) show that above pH 13 the oxide radical anion  $\text{O}^{*-}$  is the predominant form. This species is highly reactive, but it will attack non-fibrous material (sizing agents, etc.) rather than cellulose, for various reasons. First because it is negatively charged like the cellulose polymer in a strongly alkaline medium (coulombic repulsion effect) and secondly because, unlike the  $\text{OH}^*$ , it does not react by opening the aromatic rings. The regulation of the pH is therefore important to avoid fibre deterioration by  $\text{OH}^*$  radicals.

[ 44, ÖKOPOL 2011 ]

Catalyst that is not evenly distributed over the fabric (e.g. iron particles, copper) is removed first as it may cause ‘pitting corrosion’ [ 44, ÖKOPOL 2011 ]. One possible process sequence would therefore be removal of metals (modern pretreatment lines are equipped with metal detectors), oxidative desizing (peroxide and alkali), scouring (alkali), demineralisation (acid reductive or, better still, alkaline reductive/extractive), bleaching (peroxide and alkali), rinsing and drying.

#### Achieved environmental benefits

The technique allows the reduction of water and energy consumption along with improved treatability of the effluent.

#### Environmental performance and operational data

Taking advantage of hydrogen peroxide also being used as an active substance for bleaching, it is advantageous to combine alkaline bleaching with scouring and regulate the countercurrent flow of alkali and peroxide through the different pretreatment steps, so as to save water, energy and chemicals.

Because of the action of free radicals generated by activation of hydrogen peroxide, the size polymers are already highly degraded. The process produces shorter and less branched molecules, glucose, and more carboxylated molecules such as oxalate, acetate and formate, which are easier to wash out with a reduced amount of water in efficient washing machines.

The pre-oxidation of size polymer is also advantageous at the waste water treatment level (improved treatability).

In an oxidative alkaline medium (with hydrogen peroxide), there is a potential risk of fibre damage during bleaching if  $\text{OH}^*$  formation is not controlled. The size and the cellulose have a similar molecular structure and therefore the attack of the cellulose polymer by non-selective  $\text{OH}^*$  is possible. To achieve good results and avoid damage to the fibre when removing starch-

like size, it is essential to add hydrogen peroxide at  $\text{pH} > 13$ . These operating conditions minimise  $\text{OH}^*$  radicals, which are responsible for cellulose damage.

An example of a desizing-bleaching padding recipe for PVA/starch blends is:

- detergent (0.3 %);
- sequestrant (0.1 %);
- sodium hydroxide (0.7-2.0 %);
- hydrogen peroxide (0.2-0.4 %);
- salt (0.04 %);
- emulsifiers as needed.

There is no need for sophisticated control devices as these are already available for control of oxidative bleaching. Equipment is no different from modern preparation lines.

The technique is particularly suitable for commission finishers (independent of their size), who need to be highly flexible because their goods do not all come from the same source (and consequently they do not have goods treated with the same type of sizing agents). In the interests of high productivity, these companies need to operate with a universally applicable technique to enable a right-first-time approach.

### **Cross-media effects**

None identified.

### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

### **Economics**

The steps and liquors are combined (e.g. cold pad batch) so that the resource consumption is optimised at an overall minimal cost.

### **Driving force for implementation**

Reduction of overall costs, including raw material, energy and waste water treatment costs.

### **Example plants**

Plants from the data collection: DE042, FR131, IT064, IT068, IT069, IT077 and PT109.

### **Reference literature**

[ 44, ÖKOPOL 2011 ], [ 231, VITO 2001 ], [ 232, Levy D. 1998 ]

## **4.4.2 Enzymatic desizing, washing and scouring and pretreatment to improve bleaching**

### **Description**

Enzymes (e.g. amylases, pectinases and others) are used for desizing, bleaching, washing and scouring the textile fabric.

### **Technical description**

#### Enzymatic desizing

Enzymatic desizing (by hydrolysis) using amylases is an established process that has been in use for many years. More recently, pectinases have shown promise in replacing the traditional alkaline scouring treatment. Some auxiliaries suppliers have introduced an enzymatic process to remove hydrophobic and other non-cellulosic components from cotton. The new process operates at mild pH conditions over a broad temperature range and can be applied using equipment such as jet machines. Enzyme desizing removes starches but has little effect in removing other sizes.

Enzymatic treatment to improve bleaching

It is claimed that, due to a better bleachability of enzyme-scoured textiles, bleaching can be carried out with reduced amounts of bleaching chemicals and auxiliaries. Enzymes actually make the substrate more hydrophilic (which could explain the better bleachability), but they are not able to destroy wax and seeds, which are therefore removed in the subsequent bleaching process.

Bleaching sensitive fibres with enzymes at temperatures of 65 °C and at neutral pH consumes less energy and water (compared to conventional bleaching) and results in high degrees of whiteness and minimal fibre degradation [ 44, ÖKOPOL 2011 ].

Enzymatic washing

Enzymes are used to catalyse the H<sub>2</sub>O<sub>2</sub> bleaching process and to decompose residual peroxide (washing after bleaching, so-called bleach clean-up). For example, catalases/peroxidases are used to remove residual peroxide from fabric and liquor in an isothermal neutralisation step after bleaching (e.g. with phosphonic acid derivatives) [ 44, ÖKOPOL 2011 ].

Enzymatic scouring

Enzymatic scouring (discontinuous) with pectinases (alkali-free, especially qualified before dyeing of dark colours) and the subsequent bleaching process at lower temperatures (80 °C) and with shorter reaction times are used with some textiles. Enzymes decompose residual peroxide [ 44, ÖKOPOL 2011 ].

**Achieved environmental benefits**

Sodium hydroxide used in conventional scouring treatment is no longer necessary. Furthermore, the following advantages are reported over the traditional procedure (see Table 4.58).

**Table 4.58: Environmental benefits achieved with an enzymatic scouring process**

	Enzymatic scouring	Enzymatic scouring + bleaching with reduced concentration of hydrogen peroxide and alkali
Reduction in rinsing water consumption	20 %	50 %
Reduction in BOD load	20 %	40 %
Reduction in COD load	20 %	40 %
<i>Source: [ 5, UBA 2001 ]</i>		

**Environmental performance and operational data**

A typical process for a pad-batch process combining scouring and desizing in one single step is as follows [ 5, UBA 2001 ]:

- impregnation at 60 °C (pH 8-9.5) with:
  - 2-3 ml/l wetting agent;
  - 2-5 ml/l emulsifier;
  - 5-10 ml/l enzymatic compound;
  - 4-6 ml/l amylase;
  - 2-3 g/l salt;
- storage for 3-12 hours, depending on the amount and type of starch;
- extraction and rinsing.

It is possible to combine all of the enzymatic pretreatment processes in one process step. The enzymatic treatment can be applied using jet, overflow, winch, (cold) pad-batch, pad-steam and pad-roll equipment.

### **Cross-media effects**

With enzymatic desizing, starches are not completely degraded (the long molecules are not completely broken down after desizing). This means a higher organic load to be degraded in the biological plant and it is often the cause of problems such as the production of bulky difficult-to-settle sludge.

The organic load not removed with enzymatic scouring may appear in the later wet processing steps. A more global balance would probably reveal no significant improvement.

### **Technical considerations relevant to applicability**

Generally applicable to all fibres (cellulosic, keratine and synthetic).

### **Economics**

The benefits of enzymatic treatment versus conventional chemicals need to be weighed against their typically higher cost and their compatibility with other processing steps.

### **Driving force for implementation**

- Reduced water, energy and chemical consumption.
- Quality aspects (good reproducibility, reduced fibre damage, good dimensional stability, soft handle, increased colour yield, etc.).
- Technical aspects (e.g. no corrosion of metal parts).
- Economic aspects are reported as reasons for the implementation of the enzymatic scouring technique [ 5, UBA 2001 ].

### **Example plants**

A total of 19 plants (CZ019, DE022, DE026, DE047, DE049, FR136, IT064, IT065, IT068, IT069, IT077, IT078, IT094, PT108, PT109, PT111, PT114, SE120 and UK127) reported using enzymes for desizing (12 amylases).

Meanwhile, 8 plants (FR136, IT059, IT068, IT069, IT074, IT077, IT091, PT114 and SE120) reported using enzymes for scouring of cotton (amylases and cellulase).

Finally, 6 plants (DE034, DE049, FR131, IT070, IT097 and PT108) reported using enzymes for bleaching (2 amylases, 2 catalase, 1 cellulase, 1 other).

### **Reference literature**

[ 5, UBA 2001 ], [ 31, Cotton Incorporated 2009 ], [ 44, ÖKOPOL 2011 ], [ 170, Saxena et al. 2017 ], [ 171, Cotton Incorporated 2018 ], [ 172, Novozymes 2019 ]

## **4.4.3 Combined pretreatment of cotton fabric**

### **Description**

Various pretreatment operations of cotton textiles (e.g. washing, desizing, scouring and bleaching) are carried out simultaneously.

### **Technical description**

For cotton woven fabric and its blends with synthetic fibres, a three-stage pretreatment process has been the standard procedure for many years, comprising:

- desizing;
- scouring;
- bleaching.

Some techniques which combine all three steps are the following:

- **‘Flash Steam’**  
New auxiliaries’ formulations and automatic dosing and steamers allow the so-called Flash Steam procedure which combines desizing, alkaline cracking (scouring) and pad-steam peroxide bleaching in a single step [ 183, Spain 2001 ].
- ***Semi-continuous enzymatic desizing, demineralisation and bleaching***  
Products such as dispersing agents, sequestering agents for calcium (water-hardening substance) and for iron ions as well as peroxide stabilisers used together enable demineralisation combined with enzymatic desizing and bleaching with H<sub>2</sub>O<sub>2</sub> in one bath [ 44, ÖKOPOLO 2011 ]
- ***One-step bleaching with high add-on impregnation***  
Using a one-step bleaching process reduces chemical consumption by approximately 30 % but the steaming time increases by 50 %. In order to avoid crease marks from longer steaming, a high liquor pick-up impregnation is used. The liquor film around the fibres acts as a shield against undesired partial drying.  
One-step bleaching involves the uniform application of a defined quantity of chemicals dissolved in water over the length and width of a wet or dry canvas cloth. During the reaction process in the steamer, the treatment chemicals are spread evenly across the fibre structure to achieve a homogeneous pretreatment effect over the fibre cross-section [ 175, Benninger et al. 2016 ].

#### **Achieved environmental benefits**

Reduction of water and energy consumption.

#### **Environmental performance and operational data**

Within the time of 2-4 minutes (with tight strand guidance throughout), loom-state goods are brought to a white suitable for dyeing. This is a big advantage, especially when processing fabrics that are prone to creasing [ 183, Spain 2001 ].

The chemistry is simple and completely automated with full potential for optimum use.

One of the possible recipes consists of:

- 15-30 ml/kg phosphorus-free mixture of bleaching agents, dispersant, wetting agent and detergent;
- 30-50 g/kg 100 % NaOH;
- 45-90 ml/kg 35 % H<sub>2</sub>O<sub>2</sub>.

The sequence of the ‘Flash Steam peroxide bleach’ is:

1. application of the bleaching solution;
2. steam for 2-4 minutes (saturated steam);
3. hot wash-off.

The specific water consumption for the combined pretreatment of cotton textiles by bleaching, scouring and desizing is 9-20 m<sup>3</sup>/t. The lower end of the range is typically achieved with a continuous treatment [ 50, TWG 2019 ].

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

### **Economics**

No information available.

### **Driving force for implementation**

Increase in productivity.

### **Example plants**

Plants from the data collection: DE032, DE039, DE045, DE047, DE049, FR131, FR134, FR136, IT064, IT065, IT068, IT069, IT077, IT078, IT091, PT108, PT109, PT114, SE118 and SE120.

### **Reference literature**

[ 50, TWG 2019 ], [ 183, Spain 2001 ]

## **4.4.4 Optimisation of cotton warp yarn pretreatment**

### **Description**

Wetting, scouring and bleaching of warp yarn are combined in one step. Heat from the scouring/bleaching bath is recovered.

### **Technical description**

In the production of white, undyed cotton sheets (e.g. sheets to be used under bed sheets and tablecloths), cotton warp yarn is bleached before weaving (for the production of this type of article the fabric does not need to be desized after the weaving process).

The conventional process consists of five steps, including wetting/scouring, alkaline peroxide bleaching and three subsequent rinsing steps. The last rinsing water is reused for making the first bath.

This process can be further improved by combining wetting, scouring and bleaching in one step and performing rinsing in two steps, reusing the second rinsing bath for making the bleaching/scouring bath (as above).

In addition, the energy consumption of the process is reduced by heat recovery. The heat from the scouring/bleaching bath (110 °C) is recovered (by means of a heat exchanger) and used for heating the fresh water for the first rinsing. The bath is therefore cooled to about 80 °C, while the fresh water reaches a temperature of 60-70 °C.

This cooled scouring/bleaching bath is collected in a tank together with the warm rinsing water from the first rinsing step. This waste water still has a valuable energy content. Therefore, before being drained, this stream is used to heat the water from the second rinsing step (which is then used for making the bleaching/scouring bath as explained above).

### **Achieved environmental benefits**

- Reduction of water consumption.
- Reduction of the volume of waste water generated.
- Reduction of energy consumption.

### **Environmental performance and operational data**

Water consumption and waste water discharge before and after optimisation can be seen in Table 4.59 below: a 50 % reduction of the water consumption is achieved.

**Table 4.59: Optimisation of warp yarn scouring/bleaching: absolute and specific water consumption and waste water discharge before and after process optimisation**

Process		Water consumption in the conventional process (litres) <sup>(1)</sup>	Water consumption in the optimised process (litres) <sup>(1)</sup>
Step 1	Wetting/scouring	6 400	6 400
Step 2	Bleaching	5 000	
Step 3	Cold rinsing	5 000	5 000
Step 4	Warm rinsing	5 000	
Step 5	Rinsing and pH adjustment with acetic acid	5 000	5 000
<b>Total</b>		<b>26 400</b>	<b>16 400</b>
Recycling of last rinsing bath		-5 000	-5 000
Total water consumption		21 400	11 400
Specific water consumption (800 kg yarn/batch)		26.8 l/kg	14.3 l/kg
Residual water content in the yarn		1 400	1 400
Waste water volume		20 000	10 000
Specific waste water volume		25 l/kg	12.5 l/kg
<sup>(1)</sup> Data refer to an 800 kg batch.			
Source: [ 5, UBA 2001 ]			

The consumption of chemicals and energy has also been reduced drastically. The following savings are achieved [ 5, UBA 2001 ]:

- process time: about 50 %;
- water consumption/waste water discharge: about 50 %;
- NaOH: about 80 %;
- H<sub>2</sub>O<sub>2</sub>: no reduction;
- complexing agents/stabilisers: about 65 %;
- surfactants: about 70 %;
- optical brightener: no reduction;
- COD load of waste water: about 20 %;
- energy: 1.2 kg steam/kg warp yarn.

The operating conditions of the optimised process are illustrated in Table 4.60, which also contains the calculation of COD input and output.



Table 4.60: Optimisation of warp yarn scouring/bleaching: recipe and operating conditions for the optimised process

Process input and operating conditions	Quantity		Specific COD (mg O <sub>2</sub> /g)	COD load per kg of yarn (g O <sub>2</sub> /kg)	
<u>Wetting/scouring/bleaching</u>					
• Conditions: pH approx. 12, 110 °C, 10 min					
• Recipe:					
- NaOH 38°Bé (33 %)	3.5	g/l	NA		NA
- H <sub>2</sub> O <sub>2</sub> 35 %	3.0	g/l	NA		NA
- Sequestrant and stabiliser	1.0	g/l	85		0.6
- Surfactant	1.9	g/l	1 610		24.2
- Optical brighteners	0.15	wt-%	2 600		3.9
				<b>Total from auxiliaries</b>	<b>28.7</b>
				<b>Extracted from cotton</b>	<b>70.0</b>
<u>First rinsing</u>					
Conditions: 70 °C, 15 min			3 000		18.7
<u>Second rinsing</u>					
Conditions: 70°C, 15 min			1 000		6.2
				<b>Total</b>	<b>124</b>
NB: NA: Not applicable. Source: [ 5, UBA 2001 ]					

### Cross-media effects

None identified.

### Technical considerations relevant to applicability

The optimisation of the process is possible for both existing and new installations. For the recovery of heat, space for additional tanks is required, which may be a limiting factor in some cases. The impurities contained in the cotton yarn have to be considered (as regards content of iron, seeds, etc.) in order to make sure that the process can be applied.

### Economics

The considerable savings in terms of time, water, chemicals and energy make the process highly economical. The optimised process does not require new equipment for pretreatment, but tanks, heat exchangers, pipes and control devices for energy recovery from waste water are required.

### Driving force for implementation

Environmental legislation and savings in water and energy consumption.

### Example plants

Two textile finishing plants in Germany are using the described optimised process successfully.

Plant PT108.

### Reference literature

[ 5, UBA 2001 ]

#### 4.4.5 Use of fully closed-loop systems for scouring with organic solvent and dry cleaning

##### **Description**

Textile fibres are washed in a closed-loop solvent washing system (e.g. scouring or dry cleaning with organic solvents). The extracted air is recirculated in the washing unit after treatment with activated carbon adsorption.

##### **Technical description**

Continuously operating solvent scouring installations for open-width fabrics have been used since the late 1960s. They have been used by the textile finishing industry in different production sectors for over 30 years mainly because of the advantages of organic solvents over water in solving technical and qualitative problems related to fabric cleaning.

The specific heat of PER (the solvent most commonly used) is about a fifth of that of water and the latent heat of evaporation is over 10 times lower, resulting in about a 90 % reduction of the total heat requirement for evaporation in favour of PER. This means much faster and cheaper evaporation with significant savings in time and energy during drying.

The lower surface tension of PER results in a quicker and deeper fibre impregnation, thereby making any cleaning or finishing treatment more complete and uniform.

Nevertheless, the application of PER and other solvents requires extreme care and sophisticated techniques for reducing and minimising their potential harmfulness for the environment and humans.

The following gives an insight into the features of advanced solvent treatment installations compared to the traditional ones.

In general terms, the components of a conventional installation are schematically represented in Figure 4.30 below.

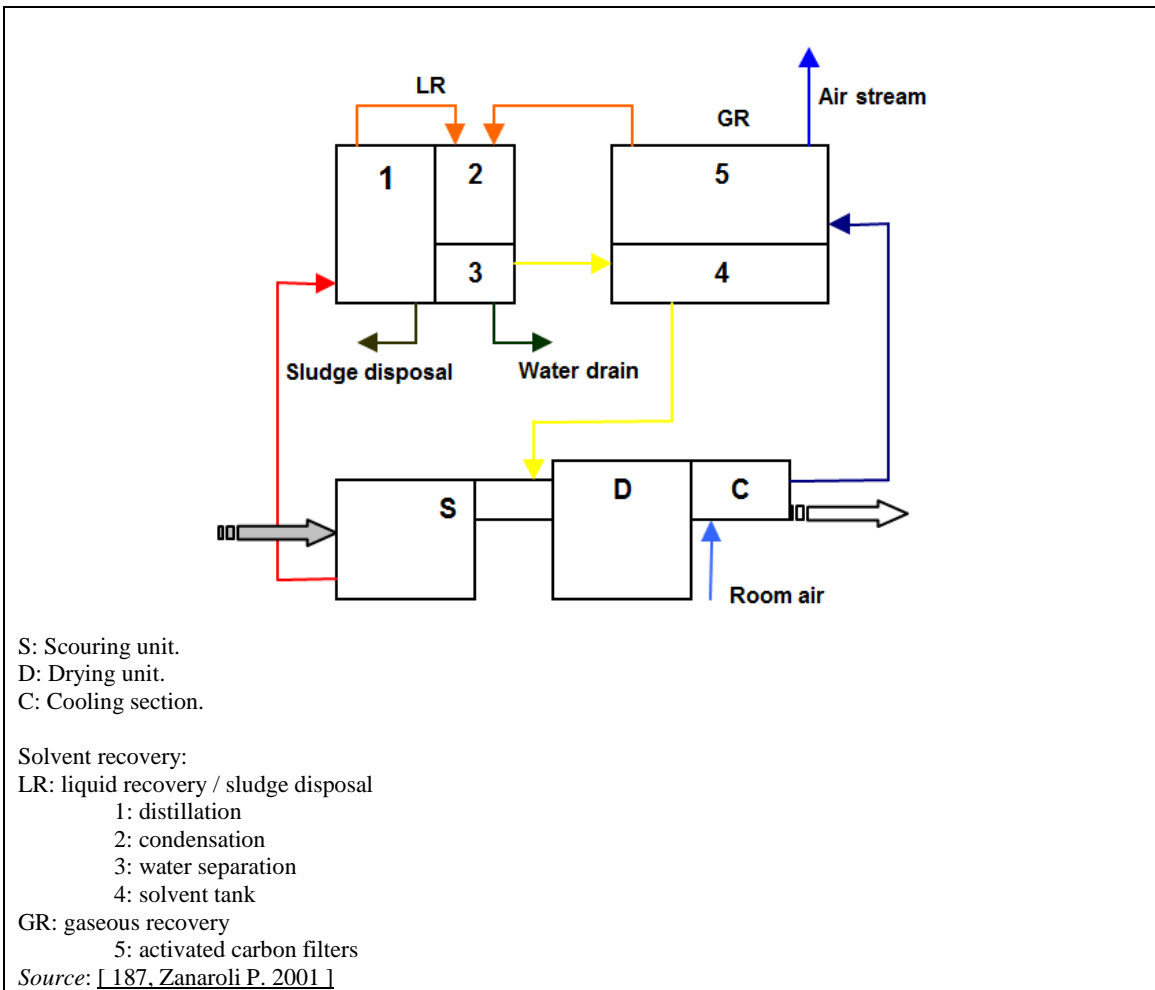
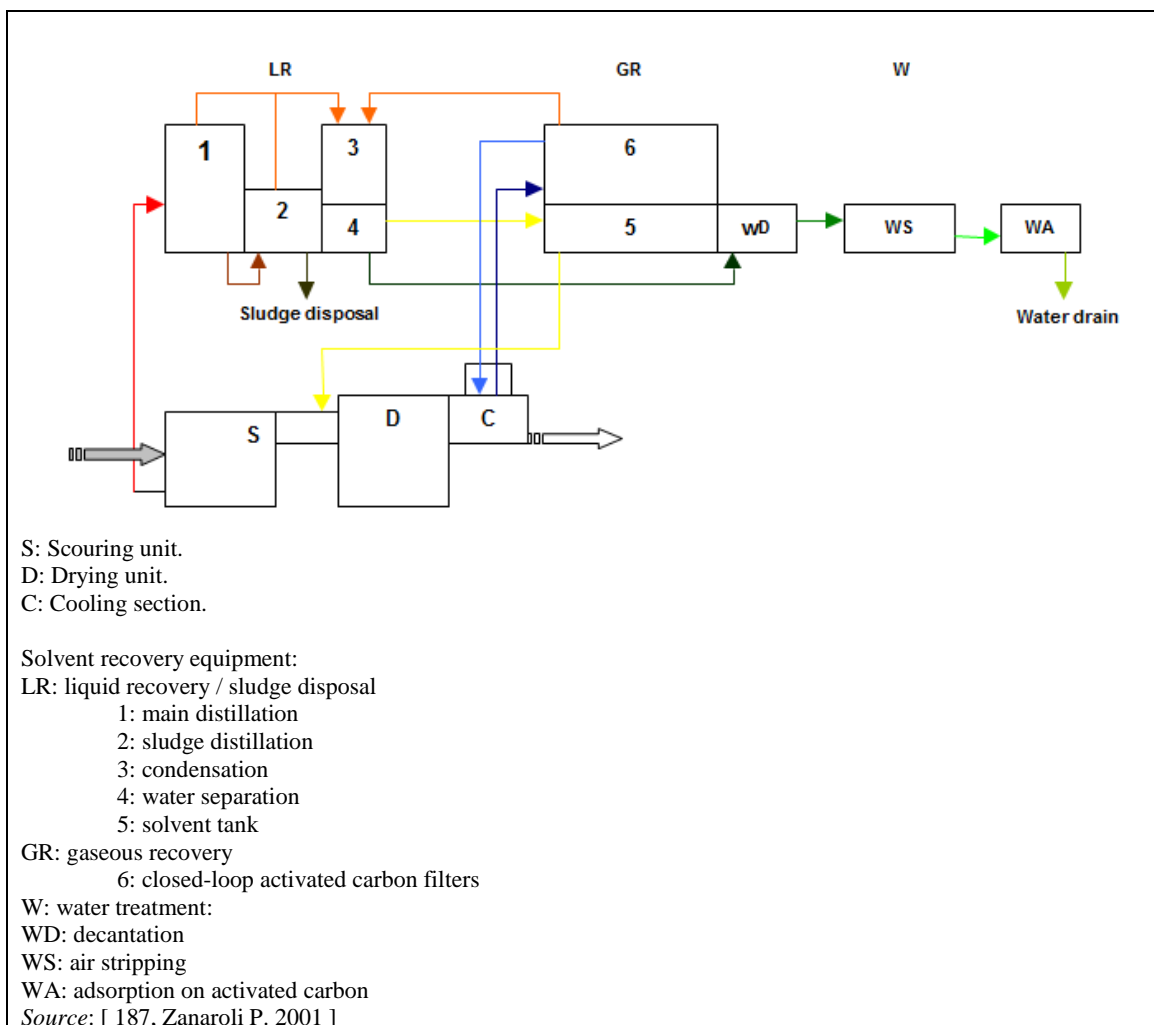


Figure 4.30: General layout of a conventional solvent scouring installation

A typical modern installation is represented in Figure 4.31 below,



**Figure 4.31: General layout of a modern solvent scouring installation**

The following solutions to the main emission and pollution sources have been developed in the new-generation equipment.

#### *Emissions to air (outside atmosphere)*

##### Problem

Open-loop activated carbon filters used for the purification of the air stream release to the outside atmosphere between 500 g/h and 1 000 g/h of PER, depending on the equipment size (at a solvent concentration in the region of 500-600 mg/m<sup>3</sup>).

##### Solution

The new installations are fitted with closed-loop activated carbon filters (see Section 2.11.2). The exhaust duct has been eliminated and the purified air is now recirculated to the fabric deodorising / cooling section of the machine: this avoids any air stream exhaust to the outside environment.

Moreover, with the closed-loop filters it has been possible to redesign more efficient sealing of the whole machine and at the inlet and outlet sides, with consequent benefits for the workplace as well.

### *Emissions to water*

#### Problem

The so-called separation water produced by the solvent recovery system with an average flow of about 0.5 m<sup>3</sup>/h and a PER content of between about 150 g/m<sup>3</sup> and 250 g/m<sup>3</sup> gives rise to an emission of 75-125 g/h of PER. This effluent used to be drained to the sewer (in the worst case) or to the central waste water treatment plant. Since the solvent is not biodegradable, once it reaches the aquifer it accumulates, and lasts indefinitely.

#### Solution

A built-in, dedicated piece of equipment is now available to pretreat, extract and recover most of the water-dissolved PER, through a two-stage process involving:

1. stripping by means of an air stream;
2. absorption through activated carbon cartridges, which are periodically changed and recharged.

Again, the closed-loop activated carbon filters are used to purify the polluted air stream from the first stage and to recover the extracted solvent.

### *Waste*

#### Problem

The high water content and the over 5 % by weight residual PER concentration in the sludge makes this waste difficult to manage at mill level and undesirable to most collectors.

#### Solution

The complete redesign of the main distilling group (of the 'forced circulation' type) and, particularly, the redesign of the sludge distiller (of the 'thin layer evaporator' type) reduces the solvent residue in the sludge well below 10 000 mg/kg (1 %), producing a dry, thick waste. This reduces collection and disposal problems and cost. The PER supplier collects the sludge and the solvent is recycled.

### *Working environment*

#### Problem

Solvent remains absorbed on fibres and this had been evaluated to be in the range of 0.1-1.0 %. New systems allow residual concentrations of 150-250 ppm [ 44, ÖKOPOL 2011 ].

Emission of this solvent to the surrounding environment is difficult to control. This also influences the air stream quality from the drying / heat-setting machines' exhaust ducts.

#### Solution

The residual concentration in the fabric depends on the stenter capacity. Besides temperature, especially long curing times lead to a reduction of residual concentrations. It has to be noted that the amount of residual PER can be significantly higher in extremely dense and heavy fabrics.

New systems with continuous measuring devices activate the alarm automatically if specified limits are reached.

The sealing systems at the machine inlet and outlet sides have been redesigned to further improve the solvent vapour pick-up efficiency. This results in a much safer environment and better preservation of human health. A typical PER concentration in ambient air around the installation is no higher than 50 mg/m<sup>3</sup>.

Concerning workers' safety, dry cleaning and textile finishing machines are equipped with an electronic interlock device in combination with measurement of the mass concentration in the

drum; the loading door is locked until the PER concentration after completion of the drying process is below  $2 \text{ g/Nm}^3$  for PER (and  $5 \text{ g/m}^3$  for other non-halogenated organic VOC solvents). The concentration is continuously measured within the drum [ 233, UBA 2019 ].

#### **Achieved environmental benefits**

The environmental benefits of scouring with organic solvent lie essentially in the following points:

- Reduction of both water and energy consumption, due to the dry-to-dry processing and to the heat requirement for solvent evaporation compared to water.
- Reduction in auxiliary usage (e.g. surfactants used as detergents, emulsifiers). A high amount of auxiliaries is needed for difficult-to-remove preparation agents such as silicone oils present on elastane fibres and their complete removal with water washing is not possible. As a result, the remaining preparation agents are released to the exhaust air from stenters in the subsequent thermal treatments.
- Reduction of the organic load sent to the waste water treatment plant (the impurities are disposed of in a concentrated form as sludge).

#### **Environmental performance and operational data**

The system is able to ensure a residual PER content into the drainage water no higher than  $0.005 \text{ mg/l}$  (emission in the water  $\leq 0.5 \text{ g/h}$  of PER) [ 44, ÖKOPOL 2011 ].

Nevertheless, since the water flow is fairly low ( $\leq 0.5 \text{ m}^3/\text{h}$ ) advanced oxidation processes (e.g. the Fenton process) are suitable for treating such low water flows on site [ 22, TWG 2002 ].

Apart from the above-mentioned contact-water drain, a solvent installation, either old or new, does not generate any other water effluent.

New systems are completely closed. Therefore, only the fabric or the sludge (recycling) are responsible for emissions. Consequently, the solvent consumption is reduced to approximately  $0.002 \%$  (referring to the textile weight) [ 44, ÖKOPOL 2011 ].

As a matter of comparison, in the case of the open circuit, PER emissions to air are reported to be between  $2.5 \text{ mg/Nm}^3$  and  $11.9 \text{ mg/Nm}^3$  (Plant IT074) [ 50, TWG 2019 ].

Solvent treatment of textiles includes all those applications where the solvent (PER) is able to perform better than water, particularly in terms of the solvency power of hydrophobic substances. The cleaning treatment of loom-state fabrics as a preparation for dyeing or printing is the most typical application of this technique, provided that some hydrophilic (water-soluble) substances, such as warp sizing agent, are not present as well.

The main application of solvent is for knitted fabrics, particularly in man-made fibres. Dry cleaning is further used for removal of unfixed dyestuffs/oligomers or pigments after dyeing/printing processes [ 234, bluesign 2016 ].

In the particular case of elastic knits (elastane blended fibres), the solvent pretreatment (e.g. by using tetrachloroethene) is particularly indicated because it is able to remove the silicone oils contained in the elastomeric fibres efficiently while conferring optimal shrinkage properties. Thanks to those features, solvent scouring is often extended to the cotton/elastane blends as well, and wool or wool blends when using tetrachloroethene [ 234, bluesign 2016 ].

In woven fabric processing, scouring of loom-state wool cloth, both grey and dyed tops/yarn, either worsted or woollen, is widely used provided that sizing agents are not present.

More recent production of wool elastic fabrics (elastane/wool and wool-polyester blends) requires an after-dyeing solvent treatment to increase the fabric colour fastness.

Particularly in the case of woollen fabrics, solvent scouring can be combined with aqueous carbonising in a single processing line (see Section 2.6.2.1).

### **Cross-media effects**

Organic halogenated solvents are non-biodegradable and persistent substances. Unaccounted losses from spills, scouring unit filters, fabric, etc. may give rise to diffuse emissions (e.g. tetrachloroethene can permeate concrete), resulting in groundwater and soil pollution. Consequently, regular measurement of solvents can be carried out at relevant locations in order to detect any emission [ 234, bluesign 2016 ].

Moreover, textiles treated with perchloroethylene have the potential to release it in the later thermal treatments. In directly heated stenter frames, dioxins and furans may be formed. In Germany, as a rule it is not permitted to treat textile substrates, which have been pre-cleaned with PER in directly heated stenters or comparable equipment. High emissions of PER, in the exhaust gas (0.1-0.8 g of PER/kg of textile substrate and emission mass flows of up to 0.3 kg/h of PER) have been observed in some installations, thereby creating difficulties in meeting the emission limit values [ 185, Germany 2001 ].

### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability.

### **Economics**

Table 4.61 and Table 4.62 attempt to evaluate the economic aspects of the solvent system by comparing it with the aqueous system in a parallel operation with the same fabric quality and at the same production rate.

Two fabrics with the same fibre composition and different construction (one knitted and one woven) have been selected, both in the range of medium-light weight (240 g/m), thus allowing the two systems to produce about 0.8 tonnes/hour each at the same speed of 55 metres/minute.

Since all the machines in the two systems have a nominal production capacity up to 1 tonne/hour, the comparison has been made at 80 % efficiency.

Both systems comprise a washing installation and a heat-setting installation, but:

- the aqueous process uses heat-setting for drying as well;
- the solvent process, including a built-in drying unit, uses heat-setting for this purpose only.

The consumption figures have been taken from the technical characteristics supplied by the relevant machinery manufacturers (Sperotto Rimar Spa for the solvent installation and Santex AG for the washing range and the stenter frame).

**Table 4.61: Consumption data: aqueous system and solvent system**

Consumption		Aqueous system			Solvent system		
Utilities	Unit	Washer	Stenter	Total	Solvent washer	Stenter	Total
Labour	h	1	1	2	1	1	2
Electricity	kW/h	94	158	252	81	158	239
Thermal energy	MJ/h	2 160	6 669	8 860	2 282	4 867	7 149
Steam	kg/h	950	2 940	3 890	1 000	2 130	3 130
Water supply	m <sup>3</sup> /h	8	NA	8	23 <sup>(1)</sup>	NA	23 <sup>(1)</sup>
Waste water	m <sup>3</sup> /h	8	NA	8	NA	NA	NA
Detergent	kg/h	16	NA	16	NA	NA	NA
PER	kg/h	NA	NA	NA	8 <sup>(2)</sup>	NA	8
Sludge	kg/h	NA	NA	NA	16	NA	16

<sup>(1)</sup> Cooling water, fully recoverable 40-45 °C.  
<sup>(2)</sup> PER is not used up, the value refers to the intrasystem flow.  
NB:  
NA: Not applicable.  
Source: [ 44, ÖKOPOL 2011 ], [ 187, Zanaroli P. 2001 ]

**Table 4.62: Hourly cost figures: aqueous system and solvent system**

Running costs		Aqueous system			Solvent system		
Utilities	EUR/unit	Washer	Stenter	Total	Solvent washer	Stenter	Total
Labour	16/h	16.00	16.00	32.00	16.00	16.00	32.00
Electricity	0.10/kWh	9.40	15.80	25.20	8.10	15.80	23.90
Steam	0.03/kg	28.50	88.20	116.70	30.00	63.90	93.90
Water supply	0.30/m <sup>3</sup>	2.40	NA	2.40	6.90	NA	6.90
Waste water	0.78/m <sup>3</sup>	6.24	NA	6.24	NA	NA	NA
Detergent	1.55/kg	24.80	NA	24.80	NA	NA	NA
PER	0.40/kg	NA	NA	NA	3.20	NA	3.20
Sludge	0.78/kg	NA	NA	NA	12.48	NA	12.48
Total	EUR/h	87.34	120.00	207.34	76.68	95.70	172.38

NB:  
NA: Not applicable.  
Source: [ 187, Zanaroli P. 2001 ]

The thermal energy consumption figures have been calculated from the heating capacity performance and expressed as steam consumption for an easier cost determination.

The detergent usage for the aqueous system and the PER consumption for the solvent system are classified as ‘chemicals’ consumption.

The water purification for the aqueous system corresponds broadly with the sludge disposal for the solvent system.

As stated earlier, the water supply in the solvent system is used for cooling purposes only and can be fully recovered, unpolluted, to be reused in the dyehouse or even recycled in the solvent installation after suitable cooling.

The disposal cost for the sludge is compensated by the savings achievable in:

- heating energy (steam);
- total water (supply and purification);
- chemicals (detergent and PER).



On the whole, the solvent system can ensure a total saving of about 17 %, i.e. EUR 35 per working hour.

The high investment cost is sometimes a disincentive, but the payback period is short (usually no longer than 2-3 years), particularly for medium-large installations and big companies with an annual production of at least 3 000 tonnes of fabric [ 187, Zanaroli P. 2001 ].

### **Driving force for implementation**

Reducing emissions to air of pollutants seems to be, at the moment, the priority for an investment decision. Second are market requirements, as new textile products are developed, creating the need for solvent systems development. Running cost reductions are also a factor (e.g. reduction of process time and reduction of returns and second choice quality).

### **Example plants**

It is estimated that at least 200 plants, either old or new, are presently operating worldwide 197. An Italian company produces machinery [ 235, Santex Rimar Group 2020 ].

Plants from the data collection: IT063, IT074, IT078, PT111 and PT114.

### **Reference literature**

[ 22, TWG 2002 ], [ 44, ÖKOPOL 2011 ], [ 185, Germany 2001 ], [ 187, Zanaroli P. 2001 ], [ 233, UBA 2019 ], [ 234, bluesign 2016 ]

## **4.4.6 Efficient washing of synthetic textiles with water**

### **Description**

Synthetic textile materials are washed prior to thermofixation or heat-setting. If needed, the washing water is sent to treatment.

### **Technical description**

With knitted fabrics *made of cotton or cotton blends with synthetic fibres*, these hydrosoluble oils can be easily washed out with water at 40 °C. This makes it possible to scour and bleach the fabric in one single step, thus saving time, water and energy.

Knitted fabrics made of *synthetic fibres* (e.g. polyester or polyamide) are often thermofixed before being washed. If conventional oils are present on the fabric, an intense emission of fumes is generated and the remaining oil becomes more difficult to remove from the fabric in the subsequent washes.

Also in this case it is often possible to use water-soluble oils instead of conventional lubricants and to carry out the washing step before thermofixation. Washing takes place in a continuous high-efficiency washing unit (e.g. TVE-Escalé type). After this step, the fabric is sent to the stenter and then dyed, washed and finished. In this way, emissions of fumes from the stenter are minimised.

### **Achieved environmental benefits**

Reduction of emissions to air.

### **Environmental performance and operational data**

With synthetic knitted fabric, one of the advantages of carrying out the washing step before thermofixation is that emissions to air from the stenter can be significantly reduced without the need for air emission abatement equipment.

Some synthetic knitted fabrics need to be thermofixed before washing. In this case, another option is the 'dry route': the fabric is submitted to thermofixation before washing and the resulting fumes are treated in an electrostatic precipitator with subsequent recovery of the oil.

The advantage is that the recovered oil can be disposed of separately, thereby reducing the contamination of the water effluent. Energy recovery is another feature of this technique.

**Cross-media effects**

- Water-soluble oils are contained in the waste water.
- Release of antimony from washing of polyester fibres produced using antimony trioxide as catalyst, or associated with flame-retardance finishing (see Section 3.4.9.1). (comment DE#196, [ 324, TWG 2020 ] and [ 122, bluesign 2020 ]).

**Technical considerations relevant to applicability**

Applicability may be limited by fabric construction.

**Economics**

No information provided.

**Driving force for implementation**

Environmental legislation for emissions to air.

**Example plants**

Plants from the data collection: BE010, CZ015, CZ017, DE034, IT082 and SE120.

**Reference literature**

[ 108, Derden et al. 2010 ], [ 122, bluesign 2020 ], [ 225, Spain 2002 ], [ 324, TWG 2020 ]

## 4.4.7 Techniques to avoid or reduce the use of harmful substances

### 4.4.7.1 Chlorine-free bleaching

#### Description

Bleaching is carried out with chlorine-free bleaching chemicals (e.g. hydrogen peroxide, peracetic acid), possibly catalysed with enzymes often combined with pretreatment with enzymes (see Section 4.4.2).

#### Technical description

The application of hypochlorite gives rise to subsidiary reactions, leading to the formation of a number of chlorinated hydrocarbons such as trichloromethane (which is also the most frequently formed as it is the end of the reaction chain). Most of these by-products can be detected as adsorbable organic halogens by means of the sum parameter AOX. Similar contributions to the formation of hazardous AOX come from chlorine or chlorine-releasing compounds and strong chlorinated acids (e.g. trichloroacetic acid). (See also Section 2.6.1.2.)

In certain conditions, sodium chlorite may also give rise to the formation of AOX, although to a lesser extent than hypochlorite. However, investigations have shown that the cause is not sodium chlorite itself, but the chlorine or hypochlorite present as impurities (from non-stoichiometric production) or used as an activating agent [ 19, Jacobs et al. 1998 ], [ 271, Bettens L. 2000 ].

Hydrogen peroxide is the preferred bleaching agent for cotton and cotton blends as a substitute for sodium hypochlorite. Bleaching with peracetic acid is also possible (Section 2.6.1.1.5).

When a single-stage process using only hydrogen peroxide cannot achieve the high degree of whiteness required, a two-stage process with hydrogen peroxide (first step) and sodium hypochlorite (second step) can be applied, in order to reduce AOX emissions. In this way, the impurities on the fibre – which act as precursors in the haloform reaction – are removed, thus producing a reduction of AOX in the effluent.

Waste water from sodium hypochlorite bleaching is separated from other streams and from the combined waste water to reduce the generation of hazardous AOX compounds [ 44, ÖKOPOL 2011 ].

A two-stage bleaching process using only hydrogen peroxide is also possible, thus completely eliminating the use of hypochlorite (cold bleaching at room temperature followed by a hot bleaching step).

Hydrogen peroxide bleach under strong alkaline conditions also achieves a high degree of whiteness after careful removal of catalysts by a reduction/extraction technique. The additional advantage claimed is the possible combination of scouring and bleaching. The reduction/extraction followed by a strong oxidative combined bleaching/scouring step (high alkali and high active oxygen concentration) is applicable for bleaching highly contaminated textiles in all make-ups and on all types of machines (discontinuous and continuous). This method takes the oxidative route and uses the active oxygen (see Section 4.4.1).

#### Achieved environmental benefits

The presence of hazardous AOX such as trichloromethane and chloroacetic acid in the effluent is avoided.

#### Environmental performance and operational data

Particular attention needs to be paid to the combination or sequence of pretreatment operations and to the mixing of streams containing hypochlorite or chlorine. For example, the application of the two-step bleaching method where hypochlorite as well as peroxide is used is potentially hazardous if the hypochlorite bleaching is performed when large quantities of organohalogen

precursors are still present on the substrate. The risk would thus be reduced if hypochlorite bleaching came as the last step after an alkaline peroxide bleach that removes the precursors from the fibre. However, no data were made available that show the importance of reversing the sequence of the two steps from hypochlorite to peroxide to peroxide to hypochlorite. It is actually more important to avoid mixing hypochlorite bleach waste water with certain other streams and mixed effluents, in particular from desizing and washing, even when the right sequence of pretreatment and bleaching is adopted. The formation of organohalogens is highly likely in combined process streams.

#### **Cross-media effects**

Complexing agents (e.g. EDTA, DTPA, phosphonates) are normally applied as hydrogen peroxide stabilisers.

In Germany, a regulation prohibits EDTA and DTPA from being discharged to the waste water [44, ÖKOPOL 2011].

The main concerns associated with the use of complexing agents arise from their ability to form stable complexes with metals (remobilisation of heavy metals), their N and P content and their often low biodegradability and bioeliminability. The addition of strong sequestering agents, however, can be avoided by fine control of the pH conditions during the bleaching process (see Section 4.4.7.2) and with the assistance of silicates, magnesium, acrylates or biologically degradable carboxylates, slowing down the uncontrolled decomposition of hydrogen peroxide (see Section 4.1.6.9.2).

Optical brighteners are often applied when peroxide bleaching is not sufficient to achieve the required level of whiteness, which results in a COD load in the waste water and emissions to air during fixation in the stenter. Moreover, optical whiteners are potentially irritating and thus not always acceptable for white goods coming into close contact with the skin (e.g. underwear, bedsheets).

#### **Technical considerations relevant to applicability**

Substitution of hypochlorite by hydrogen peroxide as the bleaching agent is applicable to both new and existing installations.

Hydrogen peroxide is a valid substitute for bleaching yarn and woven fabric made mostly of cellulosic and wool fibres and most of their blends. Today a full hydrogen peroxide bleaching process is also applicable to cotton and cotton-blend knitted fabric and a high degree of whiteness (> 75 Berger Whiteness Index) can be obtained (with a strong alkaline scour/bleach after removal of the catalyst).

Exceptions are flax and other bast fibres that cannot be bleached using hydrogen peroxide alone. Unlike chlorine dioxide, the anionic bleaching agent is not strong enough to remove all coloured material and does not preferentially access the hydrophobic region of the fibre. Two-step hydrogen peroxide-chlorine dioxide bleaching is an option for flax.

Furthermore, using hydrogen peroxide for bleaching polyacrylonitrile (PAN) and mixtures of PAN with cellulosic fibres results in a very poor bleaching effect (whiteness of 50-65 Berger), yellowing and fibre damage (e.g. up to 70 % lower tensile strength). Especially for the bleaching of PAN/cellulose mixtures, good tensile strength / elongation can only be achieved with chlorite bleach, if elemental iron is present as an impurity from the spinning mill [236, EURATEX 2021].

It is claimed that a sequence where precursors of halogenation are removed with a peroxide bleach followed by a hypochlorite bleach (or a peroxide pre-bleach followed by a combined hydrogen peroxide-/hypochlorite bleach) is still necessary for high whiteness and for fabrics that are fragile and would suffer from depolymerisation.

Sodium (hypo)chlorite is an excellent bleaching agent for flax, linen and some synthetic fibres (e.g. PAN).

### Economics

In general, bleaching with hydrogen peroxide is no more expensive than bleaching with hypochlorite.

The two-stage bleaching process with hydrogen peroxide proposed for knitted fabric is reported to be from two to six times more expensive than the conventional process using hydrogen peroxide and hypochlorite [ 5, UBA 2001 ].

### Driving force for implementation

Market demands for chlorine-free bleached textiles and the requirements set by legislation (regarding waste water discharge) are the main driving forces for the implementation of this technique.

### Example plants

Plants from the data collection: CZ019, FR131, IT059, IT068, IT069, IT070, IT071, IT072, IT088, IT094, PT102, PT108 and SE118.

Of the 57 plants from the data collection which carry out bleaching, 4 reported using sodium chlorite and 1 reported using sodium hypochlorite.

### Reference literature

[ 5, UBA 2001 ], [ 19, Jacobs et al. 1998 ], [ 231, VITO 2001 ], [ 236, EURATEX 2021 ], [ 237, Bettens L. 2000 ], [ 243, OSPAR 1994 ]

## 4.4.7.2 Optimised hydrogen peroxide bleaching

### Description

The use of complexing agents can be completely avoided or minimised by reducing the concentration of hydroxyl radicals during bleaching. This is achieved by:

- use of soft/softened water;
- prior removal of metal impurities from textile materials (e.g. by magnetic separation, chemical treatment or pre-washing);
- controlling the pH and the hydrogen peroxide concentration during bleaching.

### Technical description

When bleaching with hydrogen peroxide, oxygen species of differing reactivity may be present in water ( $O_2^{*}$ ,  $H_2O_2/HOO^-$ ,  $H_2O/OH^-$ ,  $HOO^*/O_2^{*-}$ ,  $OH^*/O^{*-}$ ,  $O_3/O_3^{*-}$ ). The kinetics of formation and disappearance depend on the concentration of oxygen, energy for activation, reduction potential, pH, catalyst and other reagents. These processes are very complex and can only be explained with dynamic simulation models. The  $OH^*$  radical is responsible for attacking the cellulose fibre and leading to its damage (depolymerisation). As the formation of the  $OH^*$  radical is mainly due to the reaction of  $H_2O_2/HOO^-$  with transition metals such as iron, manganese and copper, the prevention of 'catalytic' damage of the fibre as a consequence of the uncontrolled formation of the  $OH^*$  radical is usually achieved by using complex formers that inactivate the catalyst (stabilisers). See also Section 8.1.5.

Complexing agents (see Figure 4.15) that are typically applied in finishing mills are based on polyphosphates (e.g. tripolyphosphate), phosphonates (e.g. 1-hydroxyethane 1,1-diphosphonic acid) and amino carboxylic acids (e.g. EDTA, DTPA and NTA). The main concerns associated with the use of these substances arise from their N and P content, their often low biodegradability/bioeliminability and their ability to form stable complexes with metals, which may lead to the remobilisation of heavy metals (see also Section 8.1.5).

In Germany, a regulation prohibits EDTA and DTPA from being discharged to the waste water [ 44, ÖKOPOL 2011 ].

The use of high quantities of sequestering agents can be avoided by removing the responsible catalysts from the water used in the process and from the textile substrate and by scavenging the  $\text{OH}^*$ .

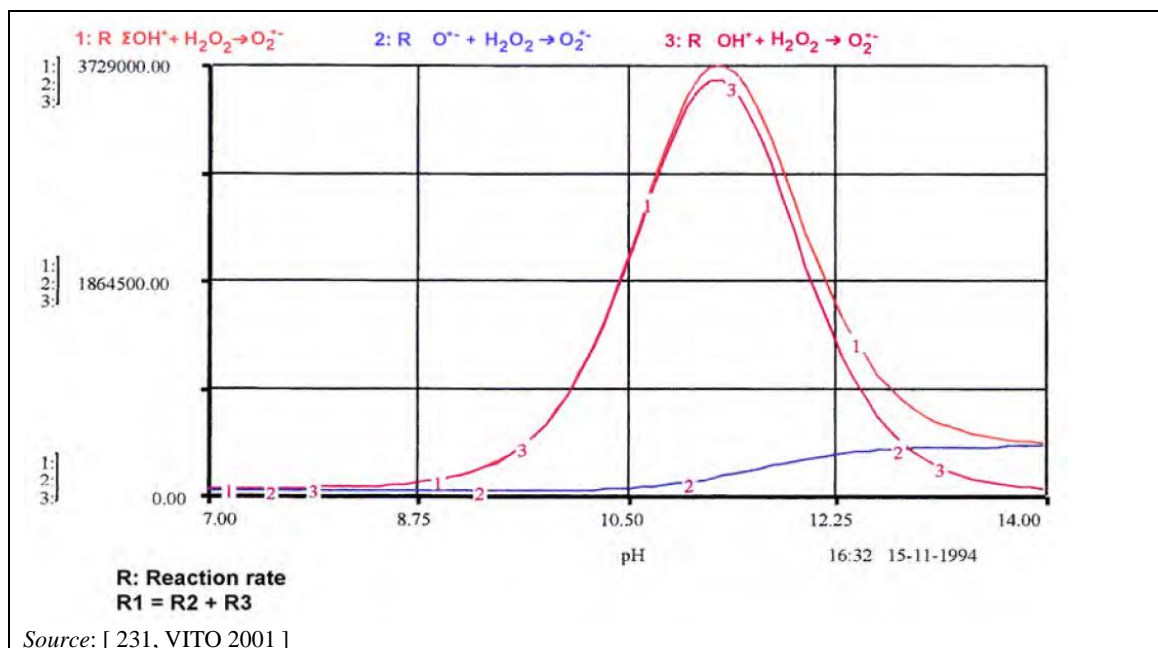
Softening of fresh water is largely applied by textile mills to remove the iron and the hardening alkaline-earth cations from the process water (magnesium hydrate has a stabilising effect and techniques that remove transition metals and calcium are therefore preferred).

Iron carried with the raw fibre can be present as fibre impurity, rust or coarse iron particles on the surface of the fabric. Iron can be detected and removed by a dry process using magnetic detectors / magnets (modern continuous lines are equipped with magnetic detectors). This treatment is convenient when the process starts with an oxidative scouring/desizing step, because otherwise a huge amount of chemicals would be required to dissolve these coarse iron particles in a wet process. On the other hand, the prior removal of coarse iron particles is not necessary when an alkaline scouring treatment is carried out as a first step before bleaching.

Magnetic sensors cannot detect non-ferromagnetic particles and magnets cannot remove the iron that is inside the fibre (fibre impurities and rust in heavily contaminated goods). This iron fraction has to be solubilised and removed from the substrate by acid demineralisation or reductive/extractive treatment before bleaching. In the case of *acid demineralisation*, Fe(III) oxide, iron metal and many other forms of iron (some organic complexes) are solubilised in strongly acidic conditions (by hydrochloric acid at pH 3). This means that the metal parts of the equipment must withstand these conditions. The advantage of the *reductive treatment* is that there is no need to use strong corrosive acids. Moreover, with the new non-hazardous reductive agents (see Section 4.5.4.2), it is possible to avoid a drastic change of pH.

As mentioned above,  $\text{OH}^*$  radicals can be scavenged in order to minimise fibre damage without the need for complexing agents.

Figure 4.32 shows that under optimal conditions (pH approximately 11.2, homogeneously distributed catalyst and controlled peroxide concentration) the hydroxyl radical  $\text{OH}^*$  is scavenged by hydrogen peroxide, forming the true bleaching agent, the dioxide radical ion (maximum formation of dioxide radical anion  $\text{O}_2^{*-}$  in accordance with the peak). Under these conditions, hydrogen peroxide itself acts as a scavenger and the reaction product is the active bleaching agent itself (which allows optimal use of hydrogen peroxide). The addition of formic acid (formate ion) as a scavenging agent is also useful to further control the formation of the  $\text{OH}^*$  radical, generating more  $\text{O}_2^{*-}$  and even repairing damage to the fibre [ 231, VITO 2001 ].



**Figure 4.32: Production of the peroxide radical ion by scavenging hydroxyl radicals (OH<sup>•</sup>) using hydrogen peroxide**

#### Achieved environmental benefits

No or reduced emissions to water of complexing agents.

#### Environmental performance and operational data

With the proposed technique, it is possible to bleach cellulose in full and even to a high whiteness, without damage to the fibre with:

- no use of hazardous sequestering agents;
- minimal consumption of peroxide (< 50 % compared with uncontrolled conditions);
- (pre-)oxidation of the removed substances.

As mentioned above, as an alternative to acid demineralisation, pre-cleaning of heavily soiled fabric (rust) is possible in more alkaline conditions using non-hazardous reducing agents, without any need for a drastic change in pH. The reduction/extraction is effective for all types of substrates and qualities of fabrics (highly contaminated, uneven distribution of iron rust). This step is easy to integrate with discontinuous and continuous processes following the oxidative route under mildly or strongly alkaline bleach conditions [ 231, VITO 2001 ].

#### Cross-media effects

None identified.

#### Technical considerations relevant to applicability

The measures described in this section are generally applicable to new and existing plants. However, fully automated equipment is necessary for the application of hydrogen peroxide under controlled process conditions [ 231, VITO 2001 ].

#### Economics

Reduction of peroxide consumption by more than 50 % is possible. The chemistry needed is not expensive and is reliable, provided that there is a good knowledge of the complex control parameters [ 231, VITO 2001 ].

**Example plants**

Plants from the data collection: DE032, DE039, DE047, IT064, IT065, IT068, IT069, IT071, IT072, IT077, IT078, IT088, IT089, IT090, IT097, PT102, PT105, PT108, SE120 and UK127. Of these plants, six reported not using complexing agents at all.

**Reference literature**

[ 44, ÖKOPOL 2011 ], [ 231, VITO 2001 ]

**4.4.7.3 Ozone bleaching****Description**

Ozone is used to bleach fabrics or garments and improve their absorption properties.

**Technical description**

In the case of bleaching or whitening the cotton fabric (e.g. for denim), ozone is used either as gas or dissolved in water (forming hydroxyl radicals). Ozone is generated on site by corona discharge and injected in a closed chamber as gas or dissolved in water for use in a washing machine. Ozone reacts with (oxidises) the surface of fibres and thereby removes natural impurities (e.g. oils, waxes, pectins) or dyes (e.g. indigo) present on the fibre and improves its whiteness and hydrophilicity (absorption or pick-up of liquids).

**Achieved environmental benefits**

- Reduced consumption of water.
- No use of chlorinated chemicals.

**Environmental performance and operational data:**

Ozone processes can be performed at room temperature. Conventional bleaching methods require much higher temperatures, longer reaction times (1-2 hours), large amounts of water and chemicals. Whiteness grades obtained after bleaching with ozone are close to the degree of whiteness after conventional bleaching, while the absorbency is lower but still acceptable.

The bleaching performance might be limited for certain man-made fibres depending on their degree of polymerisation.

**Cross-media effects**

Health and safety issues related to the use of ozone (e.g. measurements of ozone concentration and extraction of ozone from the application area) [ 238, bluesign 2019 ].

**Technical considerations relevant to applicability**

Generally applicable to cellulose, keratin and synthetic fibre.

**Economics**

- Reduced expenses for water consumption and waste water treatment.
- No energy is needed for heating the baths.
- The cost of ozone is comparable to the cost of bleaching chemicals (e.g. chlorine dioxide).

**Driving force for implementation**

- Environmental legislation.
- Reduced expenses for water and energy.

**Example plants**

No industrial site located in the EU was identified. One plant in Ksar Hellal, Tunisia, uses this technique.



### Reference literature

[ 35, RICARDO 2019 ], [ 238, bluesign 2019 ], [ 239, Inditex 2019 ], [ 240, Clothing industry 2019 ], [ 241, Körlü A. 2018 ], [ 242, Puchol et al. 2017 ]

## 4.4.8 Techniques to increase resource efficiency

### 4.4.8.1 Recovery and reuse of water-soluble sizing chemicals

#### Description

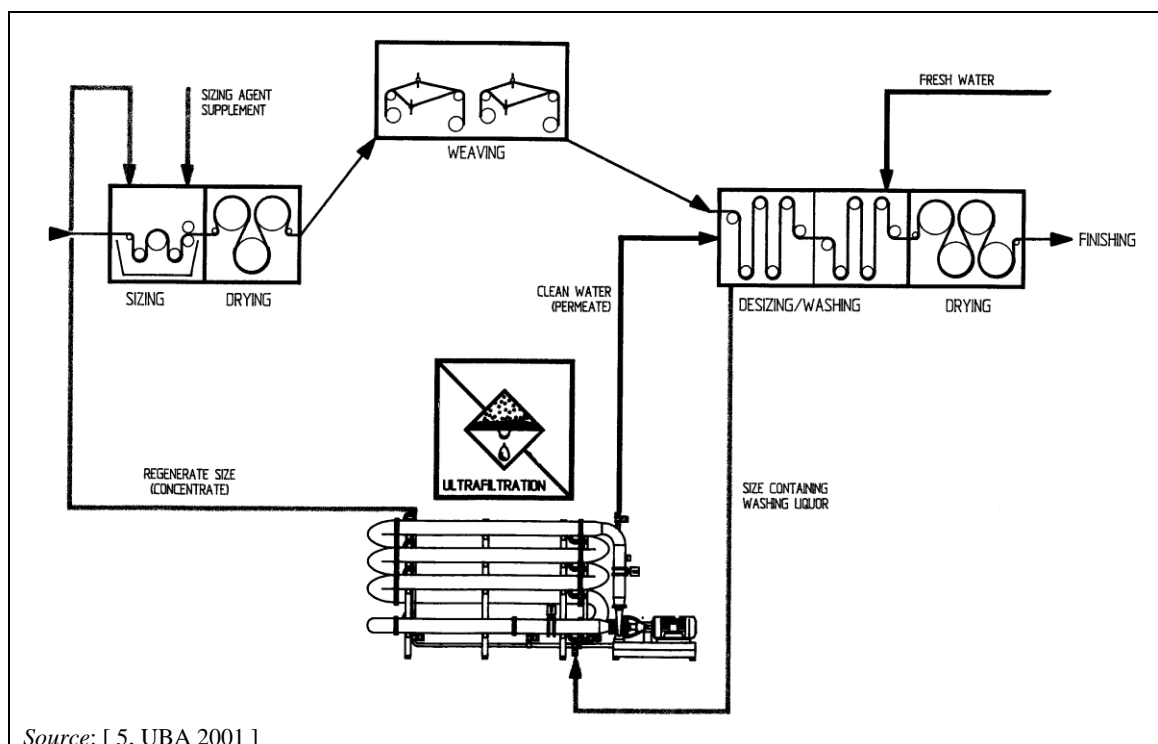
When desizing is carried out by washing with hot water, water-soluble sizing chemicals (e.g. polyvinyl alcohol and carboxymethyl cellulose) are recovered from the washing water by ultrafiltration. The concentrate is reused for sizing, whereas the permeate is reused for washing.

#### Technical description

Sizing agents are applied to warp yarn in order to protect it during the weaving process and have to be removed during textile pretreatment, thus giving rise to 40-70 % of the total COD load of woven fabric finishing mills.

Water-soluble synthetic sizing agents such as polyvinyl alcohol and carboxymethyl cellulose can be recovered from washing liquor by ultrafiltration. More recently, it has been confirmed that modified starches such as carboxymethyl starch can also be recycled.

The principle of recovery by ultrafiltration is shown in Figure 4.33. After sizing and weaving, sizing agents are removed during textile pretreatment by hot washing with water in a continuous washing machine (in order to minimise water consumption, the washing process may need to be optimised). The sizing agents' concentration in the washing liquor is about 20-30 g/l. In the ultrafiltration plant, they are concentrated to 150-350 g/l. The concentrate is recovered and can be reused for sizing, whereas the permeate can be recycled as water in the washing machine. Note that the concentrate is kept at a high temperature (80-85 °C) and does not need to be reheated, which results in less energy consumption [ 5, UBA 2001 ], [ 44, ÖKOPOL 2011 ].



Source: [ 5, UBA 2001 ]

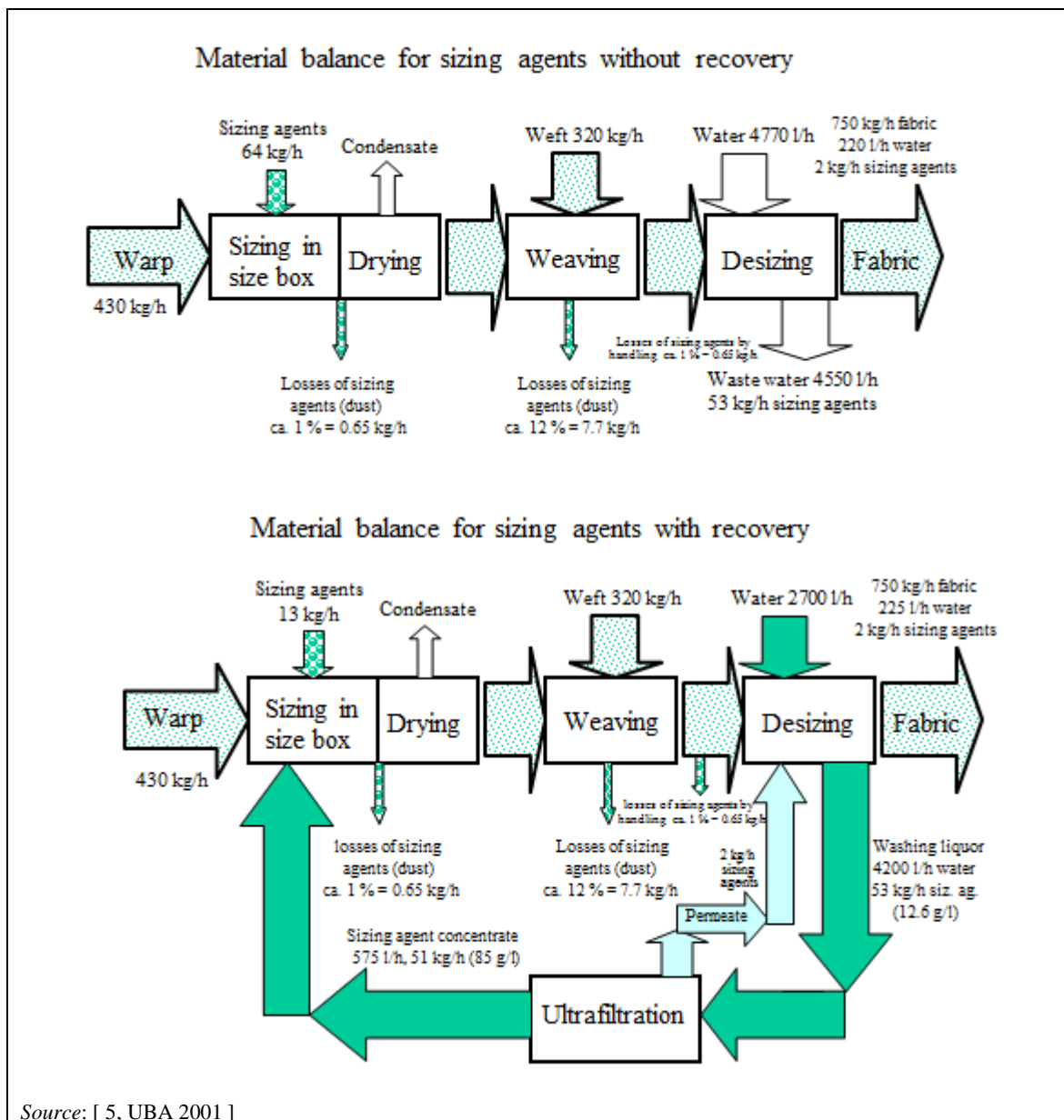
Figure 4.33: Recovery of sizing agents by ultrafiltration

### Achieved environmental benefits

- Resource efficiency as sizing agents are recovered.
- Reduction of the pollutant loads in the waste water.
- Reduction of energy consumption.

### Environmental performance and operational data

Figure 4.34 shows the mass balance of sizing agents and water for the process with and without recovery in a representative case study. It can be seen that, even with recovery, some losses of sizing agent still occur at various stages of the process, especially during weaving. Furthermore, a certain amount of sizing agent still remains on the desized fabric and a fraction ends up in the permeate. In conclusion, the percentage of sizing agents which can be recovered is 80-85 %.



**Figure 4.34: Representative example of a mass balance for sizing agents and water with and without recovery**

Rapid and complete removal of the size may be achieved by using new washing systems with, for example, a steamer or vacuum suction. The steamer facilitates the delamination of the size, improving the removal before the fabric runs into the washing process. This results in an

increase in washing efficiency, water and energy savings of the following washing process. This process is particularly gentle to fabrics and therefore suited for fine fabrics [ 44, ÖKOPOL 2011 ].

In order to minimise scaling and fouling, fibres have to be removed before ultrafiltration. The same applies to fine particles, such as singeing dust. A pre-filtration step is carried out for this purpose.

When desizing coloured woven fabric (dyed warp yarn), the desizing liquor becomes slightly coloured. Dyestuff particles are more difficult to remove and the liquor is submitted to microfiltration (which is more complex, but still feasible) [ 5, UBA 2001 ].

The operation of ultrafiltration units for recovery of sizing agents requires qualified staff and accurate maintenance. Cleaning of ultrafiltration units is carried out once a week automatically with addition of surfactants and citric acid [ 44, ÖKOPOL 2011 ].

Ultrafiltration is very efficient in reducing the high organic load from textile mills. The COD load of waste water from finishers of woven fabric is reduced by 40-70 % due to size recovery. However, it has to be remembered that the polymers used for recoverable sizing agents are also widely applied in products such as household detergents, which are found in great quantities in other effluents [ 32, Bettens L. 1999 ].

The permeate of the ultrafiltration can be reused immediately as washing water, resulting in less fresh water consumption. Furthermore, the resource input for sizing agents drops significantly [ 44, ÖKOPOL 2011 ].

Ultrafiltration needs energy, but the amount consumed is much less than the energy required to produce new sizing agents (if they are not recovered) and to treat them in a waste water treatment plant [ 5, UBA 2001 ].

Reuse in the weaving plant is not always without problems. The recovered size needs to be kept under sterile conditions when stored and mixed with fresh size. In the past, failure of protection against bacterial growth (biological degradation of concentrates and contamination of the ultrafiltration equipment) resulted in the shutdown of a recycling plant in Belgium [ 32, Bettens L. 1999 ]. Nowadays, recovered sizing agents are kept at temperatures above 75 °C. It is reported that under these conditions there are no problems of microbial attack and therefore no addition of biocides is needed to maintain sterile conditions [ 185, Germany 2001 ].

### **Cross-media effects**

None identified.

### **Technical considerations relevant to applicability**

As explained earlier, this technique is suitable only for specific types of sizing agents. These are water-soluble synthetic sizing agents such as PVA and carboxymethyl cellulose as well as some kind of modified starches such as carboxymethyl starch. It may not be applicable for synthetic sizing chemicals (e.g. containing polyester polyols, polyacrylates or polyvinyl acetate).

Limitations in the applicability of this technique may arise from cases where the auxiliaries applied to the yarn are not only sizing agents, but also waxes, antistatic agents, etc. These compounds remain in the concentrate after UF. The concentrate can be reused for sizing, but limitations can be found when reusing the same concentrate for different kinds of yarns (with different applications and end uses) which may need specific additives [ 22, TWG 2002 ]. To date, the weavers' acceptance of recovered size is still limited. Weavers are concerned about the quality of the recovered size. Furthermore, certain effects such as minting can only be carried out with non-desized fabric. For these reasons, recovery and reuse of sizing are only technically and economically feasible for integrated finishers with weaving and finishing processes nearby (e.g. sizing and desizing are carried out at the same plant). Furthermore, the sizing recipe must remain unchanged.

When weaving and finishing (desizing) take place in completely different places, a more practicable option would probably be to remove and recover the sizing agents directly in the weaving mill, which would therefore produce desized fabric. However, textile finishers' acceptance of already desized fabric is still limited.

### Economics

Table 4.63 presents a typical example of the annual savings achievable when introducing recovery of sizing agents [5, UBA 2001].

**Table 4.63: Typical example of annual savings achievable with recovery of sizing agents**

Input for sizing	Without recovery (annual basis)		With recovery (annual basis)	
	Quantity	Cost (EUR)	Quantity	Cost (EUR)
Produced woven fabric	8 750 t		8 750 t	
Quantity of warp yarn	5 338 t		5 338 t	
Load of sizing agents	13.8 %		10 %	
Recovered sizing agent	NA	NA	427 t	76 095
Starch derivative	470 t	261 435	NA	NA
PVA	264 t	722 500	75 t	205 100
Polyacrylates (100 %)	NA	NA	32 t	158 400
Wax	59 t	133 040	26.7 t	30 485
Fresh water	5 075 m <sup>3</sup>	5 840	755 m <sup>3</sup>	830
Steam	890 t	10 780	350 t	4 235
Electricity	155 680 kWh	8 560	32 000 kWh	1 760
Manpower	4 450 h	58 700	1 680 h	22 180
<b>Total cost</b>		<b>1 200 855</b>		<b>499 085</b>
NB: NA: Not applicable. Source: [5, UBA 2001]				

The cost-benefit analysis above takes into account not only the costs of ultrafiltration, but also the recipe and overall process and treatment costs. Synthetic sizing agents are more expensive than starch-based sizing agents, but they are applied in lower amounts and the weaving efficiency may be higher.

In the example given in the table, there will be additional savings because of the higher weaving efficiency and the reduced cost of pretreatment (time savings and significantly reduced consumption of chemicals for degradation and removal of size compared to starch-based products) and waste water treatment. The payback time of an ultrafiltration plant may then be less than 1 year [5, UBA 2001].

The investment costs for the ultrafiltration plant referred to above are the following [5, UBA 2001]:

	EUR
ultrafiltration plant:	1 000 000
equalisation tank:	105 000
installation:	77 000
start-up:	27 500
miscellaneous:	27 500
<b>total investment cost:</b>	<b>1 237 000</b>

Purchasing such equipment is only technically and economically feasible for integrated plants processing correspondingly large batch sizes [44, ÖKOPOL 2011].

### **Driving force for implementation**

Environmental legislation and savings in raw material.

### **Example plants**

The first plant for recovery of polyvinyl alcohol went into operation in 1975 in the USA. Meanwhile, there are two plants that have been in operation in Germany for many years and various plants are now in operation in Brazil, Taiwan and the USA. There are not many suppliers of ultrafiltration plants [ 5, UBA 2001 ].

### **Reference literature**

[ 5, UBA 2001 ], [ 32, Bettens L. 1999 ], [ 44, ÖKOPOL 2011 ], [ 185, Germany 2001 ]

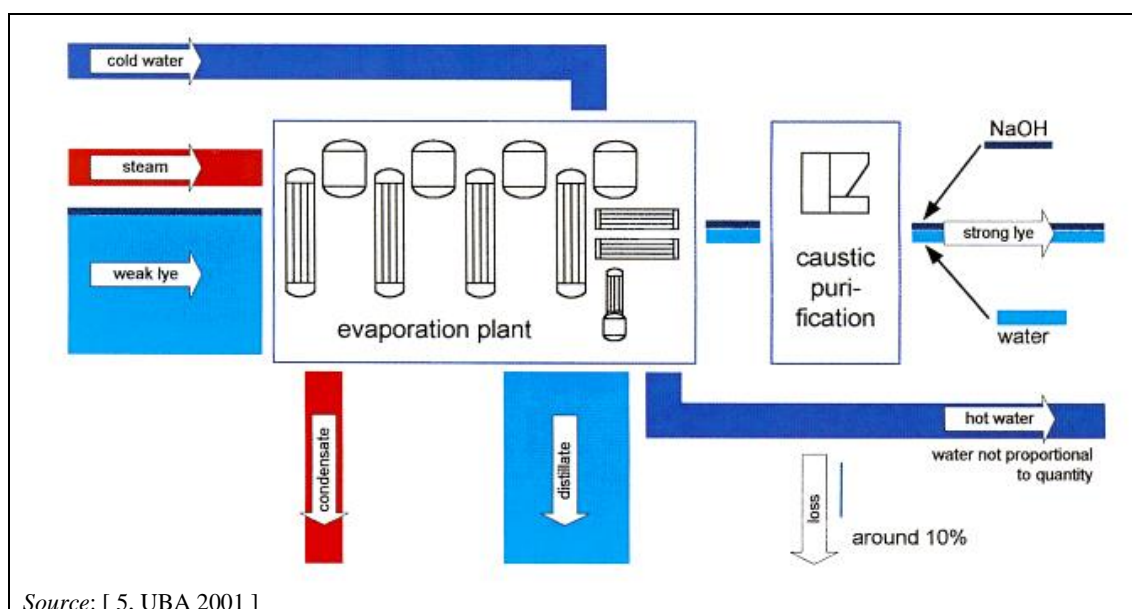
#### **4.4.8.2 Recovery of caustic soda used for mercerising**

##### **Description**

Caustic soda is recovered from the rinsing water by evaporation and further purified, if needed. Before evaporation, the impurities in the rinsing water are removed by using, for example, screens and/or microfiltration.

##### **Technical description**

During the mercerisation process, cotton yarn or fabric (mainly woven fabric but also knitted fabric) is treated under tension in a solution of concentrated caustic soda (270-300 g NaOH/l, or also 170-350 g NaOH/kg of textile substrate) for about 40-50 seconds. The textile substrate is then rinsed in order to remove caustic soda. This rinsing water is called weak lye (40-50 g NaOH/l) and can be concentrated by evaporation for recycling. The principle is shown in Figure 4.35 below.



**Figure 4.35: Caustic soda recovery process by evaporation followed by lye purification**

Before evaporation, fluff, fibres and other solid particles are removed by self-cleaning curved screens and microfiltration. In the pre-cleaning stage with curved screens, crystallisation of caustic soda occurs via contact of the lye with the carbon dioxide contained in air, resulting in a higher cleaning efficiency compared to rotary filters. More pollution is reduced by the installation of a sedimentation tank.

Weak lye is concentrated in two, three or four steps in the downstream evaporation plant. In the final purification stage, oxidation with hydrogen peroxide destroys the unwanted yellow colour of the strong lye. If the lye is reused after oxidative desizing (see Section 4.1.1), decolouring can be achieved without any addition of auxiliaries because the bath contains an excess of hydrogen peroxide.

Subsequent cleaning is done by flotation. The recovered lye is cooled before reuse. Subsequently, the cooling water can be used for hot processes [ 44, ÖKOPOL 2011 ].

#### **Achieved environmental benefits**

The alkaline load of the waste water is reduced drastically and the acid required for waste water neutralisation is minimised.

Concentration of the weak lye results in savings of resources (no add-on of new products) and energy (less energy consumption compared to white liquor production) [ 44, ÖKOPOL 2011 ].

#### **Environmental performance and operational data**

The concentration of weak lye is usually 5-8 °Bé (30-55 g NaOH/l) (Bé is unit, Baumé concentration of lye) and may be up to 25-40 °Bé (225-485 g NaOH/l), depending on the mercerising process applied. When mercerisation is carried out on the greige dry textile substrate (raw mercerisation), the achievable concentration of caustic soda is no higher than 25-28 °Bé, whereas a concentration of 40 °Bé can be obtained in non-raw mercerisation. In raw mercerisation, the concentration of impurities is significantly higher, as is the viscosity, which makes it difficult to reach higher concentrations (because the circulation in evaporators is less efficient) [ 5, UBA 2001 ].

For example, a four-step evaporation plant with a capacity of approximately 5 t/h is run using an excess pressure of 2 bar, is charged with lye concentrated at 8 °Bé (approximately 5 % lye) and returns lye at a concentration of 40 °Bé (approximately 35 % lye), for the concentration in the mercerising bath to be 28 °Bé.

For the evaporation, approximately 0.3 kg steam per kg of vaporised water is needed, corresponding to 1 kg steam/kg of recovered NaOH at 28 °Bé or 1.85 kg steam/kg of NaOH at 40 °Bé [ 44, ÖKOPOL 2011 ].

The higher the number of stages for evaporation, the more often the heat is reused, the lower the steam consumption and, therefore, the running cost. Investment, however, obviously increases with the number of stages [ 5, UBA 2001 ].

Table 4.64 shows the percentage of alkali recovered at six plants from the data collection in 2016, 2017 and 2018.

**Table 4.64: Alkali recovered from mercerising**

Plant	% of alkali recovered		
	2016	2017	2018
DE030	75	75	75
ES058	95	76	99
PT108	75	80	85
UK127	95	95	95

*Source:* [ 50, TWG 2019 ]

### Cross-media effects

In the case of lye purification with hydrogen peroxide, additional auxiliaries are needed [ 44, ÖKOPOL 2011 ].

Energy is needed for the evaporation of the weak lye.

### Technical considerations relevant to applicability

The technique is applicable to both new and existing installations. However, the applicability may be restricted by a lack of suitable recovered heat and/or by a low amount of caustic soda.

### Economics

Investment costs mainly depend on the plant size and purification technique and typically vary from EUR 200 000 to EUR 800 000. The payback time depends on the plant size and operating time per day. Usually, if mercerisation is carried out around 400 hours per year, the payback period is less than 1 year. In companies where unrecovered caustic soda lye has to be neutralised with acid, the payback time is less than 6 months. Thus, from the economic point of view, caustic soda recovery may be very attractive [ 5, UBA 2001 ].

In one plant, maintenance costs for curved screens and microfiltration are around EUR 80/week. Investment costs for recovery of 4 000 kg/h of lye are around EUR 330 000 and for 5 700 kg/h around EUR 350 000 [ 44, ÖKOPOL 2011 ].

### Driving force for implementation

High alkali content of waste water and economic aspects of caustic soda losses [ 5, UBA 2001 ].

### Example plants

Plants from the data collection: AT003, BE013, DE030, DE039, DE044, DE047, FR134, IT064, PT108, PT109 and UK127.

Some other example plants are:

- Gebrüder Otto, DE-89165 Dietenheim;
- Brennet, DE-79704 Bad Säckingen;
- Langheinrich, DE-36110 Schlitz.

[ 44, ÖKOPOL 2011 ]

**Reference literature**

[ 5, UBA 2001 ], [ 44, ÖKOPOL 2011 ], [ 93, Austrian EPA 2016 ], [ 243, OSPAR 1994 ]



## 4.5 Dyeing

### 4.5.1 General techniques

#### 4.5.1.1 Selection of dyes without dispersing agents

##### Description

Dyes with dispersing agents that are easily biodegradable (e.g. based on fatty acid esters) are selected.

##### Technical description

Dispersing agents (see Section 8.1.6.3) are present in disperse, vat and sulphur dye formulations (and they are further added in the subsequent steps) to ensure uniform dispersion throughout the dyeing and printing processes. Disperse dyes in powder or granulated form contain 40-60 % (in some cases up to 70 %) dispersing agents, whereas liquid formulations contain 10-30 % (see also Table 2.18 in Section 2.7.8). Usually, in the case of dark shades, no additional dosage of dispersing agents is required, whereas this may be necessary for pale shades. The quantities in vat and sulphur dyestuffs may be similar but precise information is not available.

Nowadays, pre-reduced liquid sulphur dyes without dispersing agents are provided for all kinds of fabric [ 44, ÖKOPOL 2011 ].

The dispersing agents do not have affinity for the fibres and they are therefore found in the final effluent. Due to the significant amounts applied and to their often low biodegradability/bioeliminability, they contribute to most of the recalcitrant organic load originating from dyeing and printing processes.

Improved dispersing agents are available that can substitute poorly biodegradable/bioeliminable dispersing agents in the dye formulations up to a maximum of 70 %. Two options are possible [ 5, UBA 2001 ]:

- Partial substitution of poorly biodegradable/bioeliminable dispersing agents with optimised products based on fatty acid esters  
A mixture of dispersing agents is used, where fatty acid esters represent the main components. The dispersing effect of the product is improved compared to poorly biodegradable/bioeliminable dispersing agents, which means that the amount of dispersing agent in the formulation can be significantly reduced. The tinctorial strength of the dye is also improved (from 100 % to 200 %) due to the correspondingly higher concentration of the dyestuff in the formulation [ 5, UBA 2001 ].
- Application of dispersing agents based on mixtures of the sodium salts of aromatic sulphonic acids These products are modified compounds of the common condensation products of naphthalene sulphonic acid with formaldehyde. This chemical modification leads to higher bioelimination rates because of the increased adsorption rate to the biomass. However, they remain non-biodegradable compounds [ 5, UBA 2001 ].

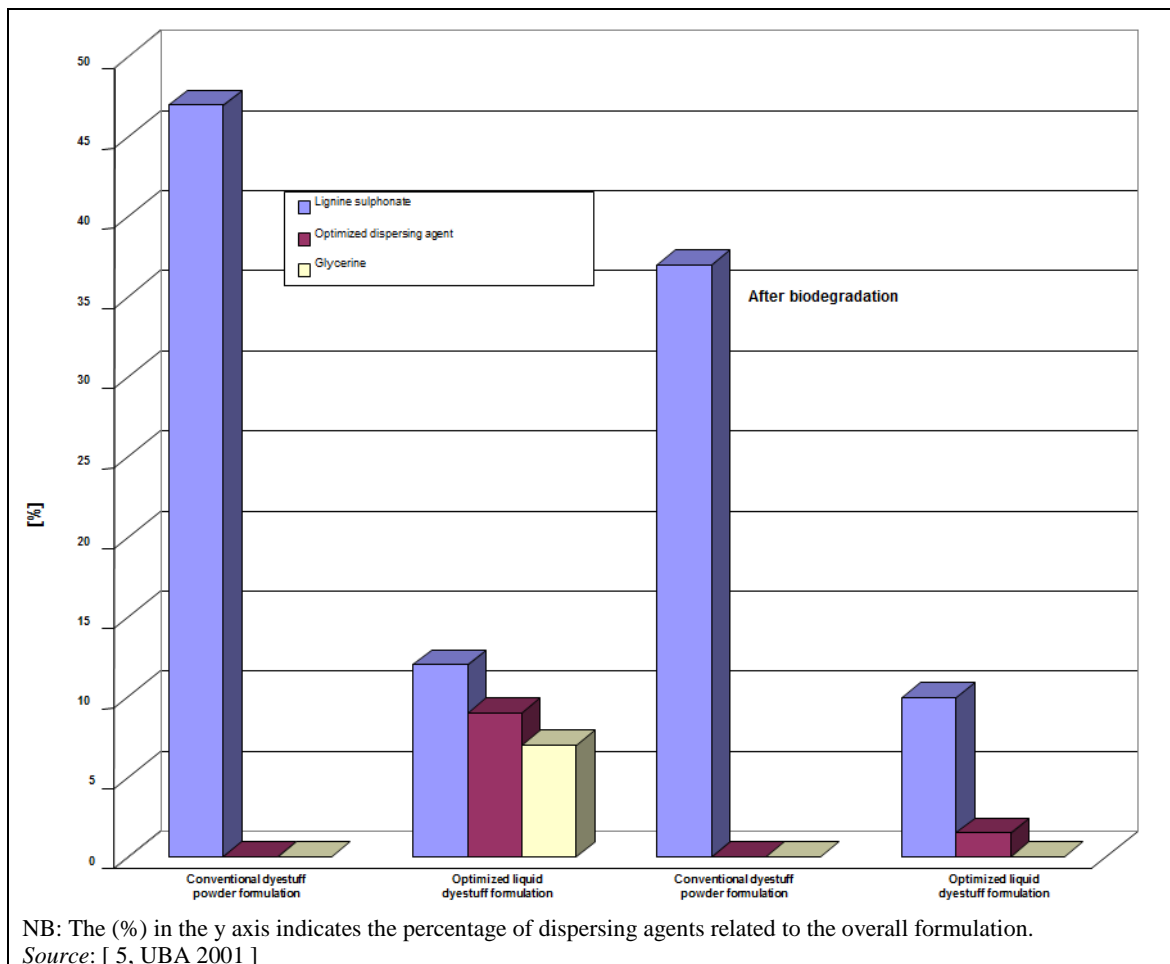
These dispersing agents can be used both for disperse and vat dyes (solid and liquid formulations).

##### Achieved environmental benefits

Reduction of emissions to water.

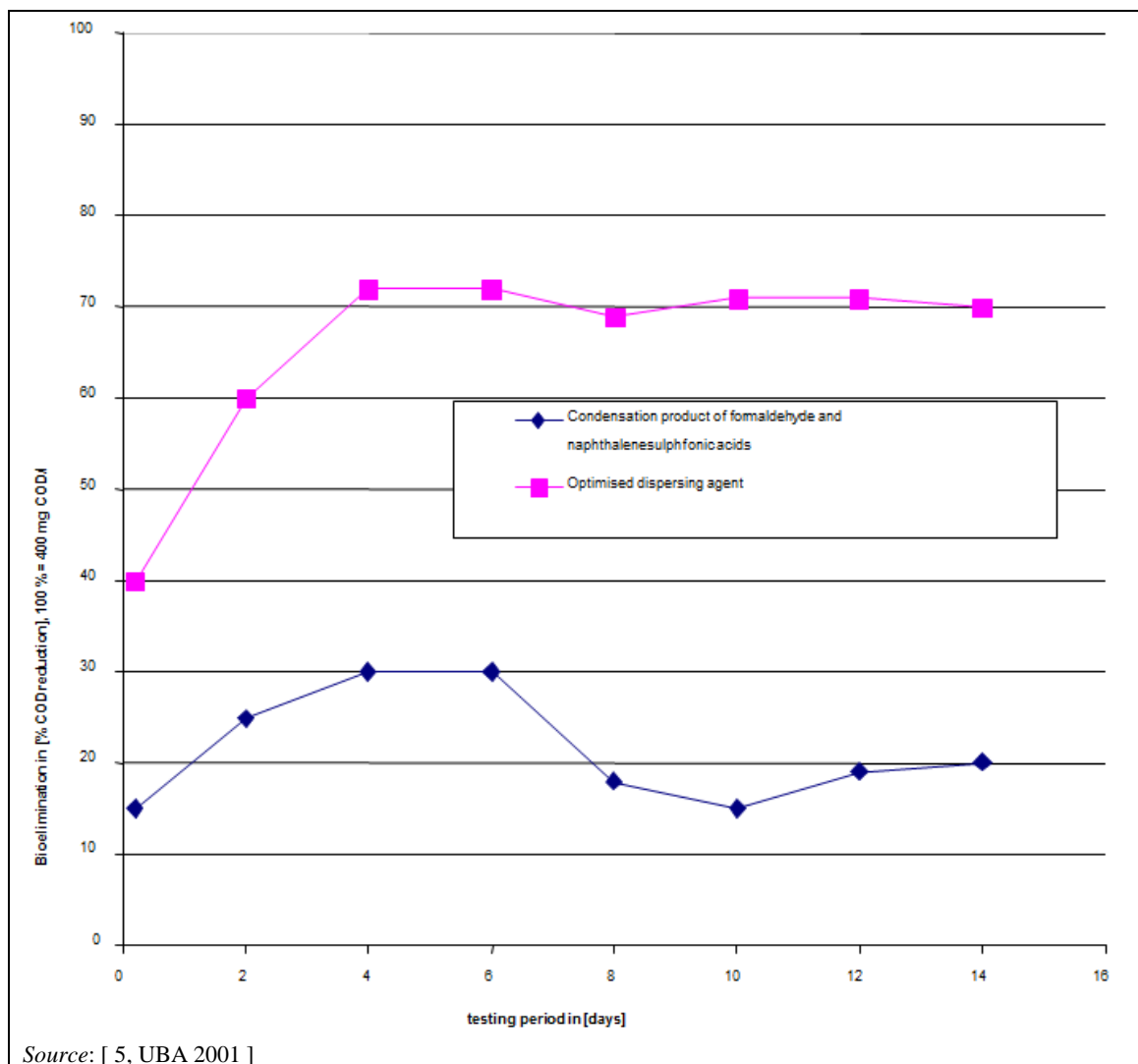
##### Environmental performance and operational data

Option a) According to the modified Zahn-Wellens Test (OECD 302 B), bioelimination rates are between 90 % and 93 %. A comparison between conventional disperse dyes (i.e. containing poorly biodegradable/bioeliminable dispersing agents) and optimised formulations (average values considering the whole dye range) is given in Figure 4.36.



**Figure 4.36: Comparison between the composition of conventional and new liquid formulations of liquid disperse dyes, before and after biological treatment**

Option b) Figure 4.37 compares the bioelimination rates of non-optimised dispersing agents and the modified optimised ones. The degree of bioelimination of the modified dispersing agents is about 70 % (test method according to OECD 302 B) compared to 20-30 % for the non-optimised ones.



**Figure 4.37: Comparison of the bioelimination rates of non-optimised and modified dispersing agents, both based on condensation products of naphthalenesulphonic acid with formaldehyde**

The application of environmentally optimised dispersing agents proposed does not imply changes in the process compared to the application of non-optimised products.

#### Cross-media effects

None identified.

#### Technical considerations relevant to applicability

Generally, there are no technical restrictions to the applicability of this technique.

#### Economics

Dye formulations containing dispersing agents with improved bioeliminability are in general more expensive than non-optimised ones [ 5, UBA 2001 ].

#### Driving force for implementation

Environmental legislation.

#### Example plants

Plants from the data collection: AT005, BE011, CZ020, IT064, IT068, IT071, IT072, IT077, IT078, IT089, IT090, PT099, PT105, PT115 and SE120.

**Reference literature**

[ 5, UBA 2001 ], [ 44, ÖKOPOL 2011 ]

**4.5.1.2 Dyeing with levelling agents made from recycled vegetable oil****Description**

Levelling agents that are produced from recycled vegetable oil are used in HT dyeing of polyester and in dyeing of protein and polyamide fibres.

**Technical description**

Vegetable oil (e.g. olive oil from restaurants) is used as a recyclable raw material to manufacture a levelling agent.

Levelling agents based on recycled vegetable oils are used under high-temperature (HT) conditions in exhaust dyeing of polyester and show dispersion and migration action comparable to standard dyeing.

In addition, dispersing and levelling agents based on recycled vegetable cooking oil are available for dyeing of protein fibres (wool or wool silk blends) with reactive, acid or metal complex dyes and polyamide with acid or metal complex dyes. They are applied to control the dye uptake during the heating phase, promoting a uniform distribution of the dyes.

**Achieved environmental benefits**

- Resource efficiency.
- Reduced emissions to water.

**Environmental performance and operational data**

Butylbenzoate and benzylbenzoate are typical carriers used for formulation of conventional levelling agents for polyester. Levelling agents based on recycled vegetable oils show less aquatic toxicity and achieve similar bioeliminability rates (see Table 4.65 and Table 4.66 below). Reduced waste water impact from dyeing can therefore be expected.

**Table 4.65: Aquatic toxicity (algae) of raw materials used for the formulation of levelling agents for PES dyeing**

Raw materials for formulation of levelling agents	Test method	EC50 after 72h <sup>(1)</sup>
Butylbenzoate CAS 136-60-7	OECD 201: Freshwater algae and cyanobacteria, Growth Inhibition Test	2.9 mg/l <sup>(2)</sup>
Benzylbenzoate CAS 120-51-4		0.475 mg/l <sup>(2)</sup>
Intermediate made from recycled vegetable oil (proprietary)		> 100 mg/l <sup>(3)</sup>
<sup>(1)</sup> Concentration bringing 50 % of inhibition of growth after 72 hours. <sup>(2)</sup> Source: ECHA. <sup>(3)</sup> Test has been carried out at LAUS GmbH on the raw materials used for the formulation. Source: [ 138, ECHA 2019 ], [ 244, UBA 2020 ]		

**Table 4.66: Bioeliminability of selected levelling and dispersing agents**

Type of levelling agent	Bioeliminability
Sodium or potassium salt of naphthalenesulphonic acid polymer with formaldehyde	70 % according to OECD 301A
Dispersing and levelling agent for polyester based on recycled vegetable oil	The degree of bioelimination reached was 60 % after 28 days (OECD 302B). <sup>(1)</sup>
Levelling agent for polyester based on ethoxylated castor oil	> 70 % according to OECD 302B

Type of (amphoteric) levelling agent for dyeing polyamide and protein fibres	50-60 % according to OECD 301F
Levelling agent for polyamide (slightly cationic)	92 % according to OECD 302B
Levelling agent based on recycled vegetable oil for dyeing protein and polyamide fibres	The degree of bioelimination reached was 79 % after 28 days (OECD 302B). The elimination is based on adsorption on the sludge. <sup>(1)</sup>
<sup>(1)</sup> Test has been carried out at LAUS GmbH on the final products. Source: [ 244, UBA 2020 ]	

Dyeing of polyester, protein fibres (wool or wool/silk blends also with reactive dyes that do not contain chromium) and polyamide using levelling agents made from recycled vegetable oil is carried out with no observed differences in application, dyeing conditions, temperature and energy demand, process time and dyeing results (e.g. fastness).

Dyeing recipes are also comparable in terms of dyes and auxiliaries consumption (see Table 4.67). Levelling agents from recycled vegetable oil can even replace mixtures containing smelly carriers or dispersing agents based on salts of naphthalenesulphonic acid polymer with formaldehyde.

**Table 4.67: Consumption of levelling agent made from recycled vegetable oil in dyeing recipes**

Substrate	Dyeing recipe with levelling agent made from recycled vegetable oil
Polyester	x % Disperse dye(s) pH 5 <b>0.5-1.5 g/l Dispersing/Levelling agent</b>
Polyamide	x % Acid or metal-complex dye(s) x g/l Acid donor <b>0.5-1.5 g/l Dispersing/Levelling agent</b>
Protein fibres (wool, wool/silk)	x % Acid or metal-complex dye(s) x g/l Acid donor <b>0.8-2 % Levelling agent</b>
Source: [ 244, UBA 2020 ]	

**Cross-media effects**

None identified.

**Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of levelling agents made from recycled vegetable oil compared to conventional levelling agents.

**Economics**

Costs for levelling agents based on recycled vegetable oil are comparable to conventional levelling agents considering the purchase costs and the costs for processing.

**Driving force for implementation**

Environmental legislation.

**Example plants**

Group Zegna Baruffa, group Giovanni Brugnoli and other plants in Italy.

**Reference literature**

[ 244, UBA 2020 ]

### 4.5.1.3 Selection of vat dyes

#### Description

Vat dyes that are not prone to emissions during the use phase of the textile are selected. Auxiliaries (e.g. polyglycols) are used to enable dyeing with less or no subsequent steaming, oxidising and washing, and to ensure appropriate colour fastness.

#### Technical description

The conventional pad-steam process with vat dyes (see Section 2.7.3) includes the following steps:

- padding of dyestuff pigments;
- intermediate drying;
- padding of chemicals/auxiliaries (reducing agents);
- steaming;
- oxidising;
- washing (several washing and rinsing steps).

In some cases, the process can be carried out without steaming and subsequent washing, according to the following simplified sequence (similar to the dyeing process with pigments):

- padding of dyestuffs and chemicals/auxiliaries in one step;
- drying;
- fixation.

Special selected vat dyes with a low tendency to migrate need to be used. Moreover, auxiliaries based on polyglycols and acrylic polymers are necessary to improve pad liquor stability and provide a high fastness level.

#### Achieved environmental benefits

Savings in water, energy and chemical consumption.

#### Environmental performance and operational data

A number of steps, in particular the washing operations, are avoided. As a result, only the residual padding liquors have to be disposed of at the end of the process and water consumption is minimised to approximately 0.5 l/kg of textile [ 5, UBA 2001 ].

Savings in chemicals and energy are also obtained.

A typical recipe for the padding liquor includes [ 5, UBA 2001 ]:

- binder: 30-40 g/l;
- sodium sulphate: 5-10 g/l;
- antimigrant: 10-20 g/l;
- dyestuff: up to 2.5 g/kg.

Among typical process parameters, the pick-up is as low as possible (50-65 %) and the liquor temperature is kept below 35 °C. Intermediate drying is carried out at 100-140 °C, while thermofixation conditions are typically 30 s at 170 °C for cellulose and 30 s at 190 °C for polyester/cellulose blends [ 5, UBA 2001 ].

#### Cross-media effects

None identified.

### Technical considerations relevant to applicability

The technique is suitable for cellulose and polyester/cellulose blends. The applicability, however, is restricted to pastel to pale shades (up to approximately 5 g/l of dyestuff at 50 % liquor pick-up). It may not be applicable to dyeing with dark shades.

### Economics

Significant benefits are achieved compared to the conventional pad-steam method, thanks to savings in energy, time, water and chemicals.

### Driving force for implementation

Savings in energy, time, water and chemicals.

### Example plants

Plant PT105.

### Reference literature

[ 5, UBA 2001 ]

#### 4.5.1.4 Minimisation of dye liquor losses in pad dyeing techniques

##### Description

The pad dye impregnation is carried out in a nip or in a trough with a reduced volume. This is combined with an on-line system for individual dosage of dyestuffs and auxiliaries and pick-up measurement devices for preparation of the next comparable batch.

##### Technical description

The main emission sources in pad dyeing processes arise from the discharge of the residual dyeing liquor contained in the pad, pumps and pipes at the end of each lot when a new colour is started (see Chapter 3 for further details about emission and consumption levels).

These losses can be reduced by carrying out the impregnation step in a nip (see configuration B in Figure 4.38 below) or by minimising the capacity of the dip trough with, for example, flex-shaft or U-shaft systems (see configuration A in Figure 4.38 below).

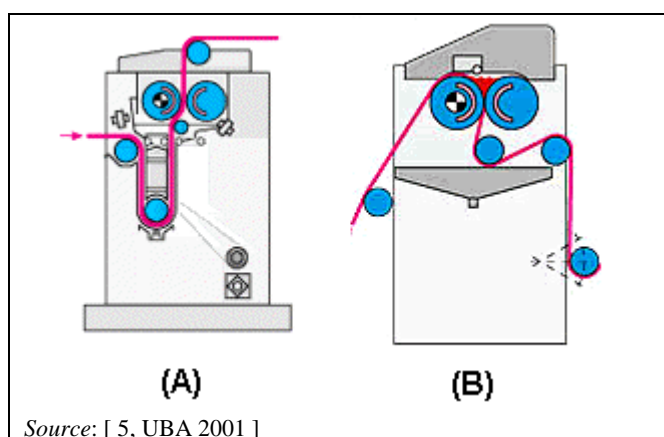


Figure 4.38: Representation of U-shaft (A) and nip (B) dye liquor application systems

U-shaft is used in semi-continuous dyeing of cotton fabrics with reactive dyes (cold pad-batch). Often the U-shaft is combined with a dosing system and, shortly before the application, dye and alkali solution are mixed together in a static mixer. In that case, the residual liquor is lost because, after mixing of dye and alkali solution, hydrolysis of the reactive dyes starts immediately and recovery for reuse is impossible [ 44, ÖKOPOL 2011 ].

Further reduction of losses can be achieved by the following means:

- Systems for controlled dosage of the input raw materials. The dyestuff solution and auxiliaries are dosed, based on the specific recipe, and are dispensed as separate streams, being mixed only immediately before being fed to the pad.
- Dosage of the padding liquor based on measurement of the pick-up. The amount of dyeing liquor consumed is measured by reference to the quantity of processed fabric by measuring the length of the fabric and multiplying it by its specific weight. The resulting values are automatically processed and used for the preparation of the next comparable batch in order to minimise residues of unused dyeing liquor. This system, however, cannot avoid the presence of residual dye liquor in the feeding tank. The rapid batch dyeing technique represents a further improvement in this respect. In this case, rather than prepared in one single step (for the whole batch) before starting the dyeing batch, the dyestuff solution is prepared just in time, in several steps, based on on-line measurement of the pick-up.

For more information on padding processes, see also Section 8.3.4.2.

#### **Achieved environmental benefits**

- Resource efficiency.
- Reduction of emissions to water.

#### **Environmental performance and operational data**

Conventional pad-bath troughs have a capacity ranging from 30 litres up to 100 litres. Changing over to U-shaft troughs (12-litre capacity) enables a reduction of the residues of unused liquor from 60 % to nearly 90 % per batch, compared to the conventional system. Correspondingly, in the case of nip dyeing (5-litre capacity), up to 95 % reduction is achieved.

Separate dispensing of chemicals and colourants avoids unnecessary wastage of raw materials that cannot be considered for further reuse, if already pre-mixed. The preparation of the dye liquor batch based on on-line measurement of the pick-up allows a reduction of the residual dye liquor in the feeding tanks from 150 litres down to 5-15 litres, and for very wide fabrics down to 50 litres [ 44, ÖKOPOL 2011 ].

Furthermore, modern dyeing ranges are operated with a minimised flow of rinsing water, which allows an additional 25 % water saving.

Routine maintenance is essential in order to ensure the precision and proper performance of the equipment. In particular, the precision of the dosage system (e.g. pumps) and pick-up measurement should be checked at regular intervals. In measuring the pick-up, the specific weight of the fabric has to be determined before dyeing and not before pretreatment.

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

The techniques described are applicable both for new and existing continuous and semi-continuous dyeing machines. However, it is often more convenient to install completely new machinery, rather than upgrading parts of the existing machine [ 271, Bettens L. 2000 ].

Dyeing in the nip is not suitable for light fabrics (below 220 g/m) or fabric with good wettability. With brushed or sheared textiles, the pick-up time may be too short and reproducibility is adversely affected [ 5, UBA 2001 ].

Due to the short contact time with the fabric liquor, dyeing in the nip is not widely used: based on a roller diameter of approximately 20 cm, the filling level for the liquor contact is only 10 cm



and the resulting contact time for a conventional production rate of 60 m/min is only 0.1 seconds) [ 44, ÖKOPOL 2011 ].

### **Economics**

The investment cost for an automated dosage system and a volume-minimised trough (e.g. U-shaft) is about EUR 85 000 (taking as a reference a width of 1 800 mm). On the other hand, annual savings of EUR 85 000 are already achieved in the case of finishing mills dyeing 15 batches per day (assuming savings of 50 litres per batch at a dye liquor cost of EUR 0.5/l). This means a short payback time [ 5, UBA 2001 ].

Furthermore, additional benefits are achievable thanks to the reduced volume of waste water to be treated.

### **Driving force for implementation**

Environmental legislation and savings in raw material.

Increased reproducibility (right-first-time) and productivity achieved thanks to improved process control.

### **Example plants**

Plants from the data collection: BE011, IT059, IT064, IT065, IT068, PT109, PT115 and UK127.

### **Reference literature**

[ 5, UBA 2001 ], [ 44, ÖKOPOL 2011 ], [ 243, OSPAR 1994 ], [ 271, Bettens L. 2000 ]

#### **4.5.1.5 Optimised removal of unfixed dyestuff in reactive dyeing**

##### **Description**

Unfixed dyestuff is removed from the textile materials by using enzymes (e.g. laccase, lipase) and/or vinyl polymers. This reduces the number of rinsing steps needed.

##### **Technical description**

Dyeing and printing with reactive dyes entails a number of soaping and rinsing steps to remove from the substrate the unreacted and hydrolysed dye. The removal of all unfixed dyestuff from the fibre is essential for obtaining optimum wet-fastness, while contributing significantly to the energy, water and chemical consumption of the overall dyeing process.

An enzymatic treatment removes the non-fixed dyestuff not only from the fibre, but also from the exhausted dye bath [ 5, UBA 2001 ]. Laccase is used to remove indigo pigments or reactive dyes from fibre and for decoloration of the effluents [ 245, Vigneswaran et al. 2014 ]. The effect of decoloration of indigo from denim is called ‘salt and pepper’, the process for reactive dyeing of cotton with laccase is called discharge printing [ 246, Ibrahim F.D. 2014 ]. Azo reductase is used to remove azo dyes [ 245, Vigneswaran et al. 2014 ].

In addition, newly developed products for after-soaping based on vinyl polymers (e.g. poly(vinylpyridine-N-oxide) and poly(vinylpyridine betaine) polymers) prevent renewed uptake of unfixed dyestuff on the fibre in shortened rinsing passages [ 247, Amin et al. 2015 ].

The number of rinsing baths depends on the depth of shade. Significant savings can be reached for light shades by minimising the number of rinsing baths [ 44, ÖKOPOL 2011 ].

The application of the enzymatic compounds usually takes place in the fourth or fifth rinsing step (see Table 4.68 below).

**Table 4.68: Comparison of the sequence steps between a conventional and an enzymatic after-soaping treatment (exhaust dyeing)**

Typical sequence in the case of conventional after-soaping	Sequence in the case of enzymatic after-soaping
5 min overflow rinsing 10 min 40 °C 10 min 40 °C; neutralisation 10 min 95 °C 10 min 95 °C 10 min 50 °C 10 min 30 °C	5 min overflow rinsing 10 min 40 °C; neutralisation 10 min 60 °C 10 min 95 °C 15 min 50 °C; enzymatic treatment 10 min 30 °C
<i>Source:</i> [ 5, UBA 2001 ]	

The application of the products based on vinyl polymers usually takes place in the third rinsing step (see Table 4.69 below) [ 44, ÖKOPOL 2011 ].

**Table 4.69: Comparison of the sequence steps between a conventional soaping treatment and a soaping treatment with vinyl polymers (exhaust dyeing)**

Typical sequence in the case of conventional after-soaping	Sequence in the case of optimised after-soaping with vinyl polymers
5 min overflow rinsing 10 min 40 °C 10 min 40 °C; neutralisation 10 min 95 °C 10 min 95 °C 10 min 50 °C 10 min 30 °C	10 min 30 °C 10 min 70 °C; neutralisation 10 min 95 °C; treatment with vinyl polymers 10 min 70 °C 10 min 30 °C
<i>Source:</i> [ 5, UBA 2001 ] [ 44, ÖKOPOL 2011 ]	

#### Achieved environmental benefits

- Reduction of emissions to water.
- Reduction of water consumption.

#### Environmental performance and operational data

As Table 4.68 and Table 4.69 show, one or two of the hot rinsing steps can be avoided when using enzymatic after-treatment or vinyl polymers respectively. In the latter case, overflow rinsing is also avoided. Savings in water, energy and detergent consumption are the main advantages achievable with this technique [ 5, UBA 2001 ].

The enzymatic treatment is carried out as follows (batch process) [ 5, UBA 2001 ]:

- filling with fresh water (50 °C);
- addition of a buffer for adjusting the pH;
- control of pH (addition of acetic acid, if necessary);
- addition of the enzymatic compound (0.25 g/l);
- running: 10 min;
- draining.

The treatment with vinyl polymers is carried out as follows (exhaust process): [ 44, ÖKOPOL 2011 ]

- filling with fresh water (30 °C);
- neutralisation with acetic acid to adjust to a pH value of 8;
- addition of after-soaping agent (1-3 g/l).

### Cross-media effects

None identified.

### Technical considerations relevant to applicability

The technique is already applicable to exhaust dyeing with reactive dyestuffs.

Most of the reactive dyestuffs can be enzymatically decolourised. However, a precautionary test on a laboratory scale is recommended.

### Economics

Savings in water and energy consumption and reduced process time are among the economic benefits achievable.

### Driving force for implementation

Cost-saving potential and improved quality (higher fastness) of the final product [ 5, UBA 2001 ].

### Example plants

Plants from data collection [ 50, TWG 2019 ]: IT089 and IT090.

### Reference literature

[ 5, UBA 2001 ], [ 44, ÖKOPOL 2011 ], [ 50, TWG 2019 ], [ 247, Amin et al. 2015 ]

#### 4.5.1.6 pH-controlled batch dyeing

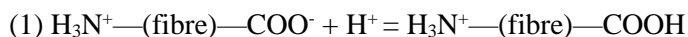
##### Description

For textile materials with zwitterionic characteristics, dyeing is carried out at constant temperature and controlled by gradually lowering the pH of the dyeing liquor below the isoelectric point of the textile materials, which avoids the use of levelling agents.

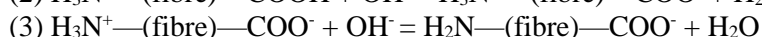
##### Technical description

Fibres such as wool, polyamide and silk contain weak acid and weak base groups (e.g. carboxylic and amino functions). Just like the parent amino acids from which all proteins are derived, these fibres show zwitterionic characteristics at pH values close to the isoelectric point (i.e. the pH at which the fibre contains equal numbers of protonated alkaline and ionised acidic groups).

At a pH below the isoelectric point, the carboxylate anions are progressively neutralised by the adsorption of protons and the fibre acquires a net positive charge (see equation 1):



Conversely, as the pH rises above the isoelectric point, the fibre becomes negatively charged as a result of the dissociation of the carboxylic acid groups (equation 2) and deprotonation of the amino groups by adsorption of hydroxide ions or other anions as shown below in equation 3:



Based on these reactions, fibres with zwitterionic characteristics can be dyed by imposing a pH profile at iso-temperature, instead of a temperature profile at iso-pH.

The dyeing process is started in alkaline conditions, above the isoelectric point. At this pH, the carboxylic groups become dissociated and the anionic charged groups repulse anionic dyes. This makes it possible to control the adsorption of the dye on the fibre by gradually decreasing the pH.

At a low enough pH when the number of cationic charges on the fibre increases, the dye becomes attracted to the fibre via coulombic interactions, which provides additional bonding forces that cannot be broken by thermal agitation.

At iso-pH, part of the carboxylic groups is neutralised and at higher temperatures, the dye can move rapidly and with minimal energy through the fibre.

The main difference between temperature- and pH-controlled dyeing is that in the temperature-controlled dyeing the process is controlled by the dye bath exhaustion and thermal migration of the dye, whereas with a pH-controlled profile the dyeing process is controlled by the adsorption of the dye onto the ionic fibre.

#### **Achieved environmental benefits**

- Reduction of emissions to water.
- Reduction of energy consumption.

#### **Environmental performance and operational data**

One of the advantages of iso-thermal dyeing is that the use of special organic levelling agents or retarders (typically added to the dye bath to allow even dyeing) can be avoided.

Time and energy use with pH-controlled dyeing is lower than with the temperature-controlled process. Energy is saved because the dye bath (and the machine) do not need to be heated from room temperature up to the migration temperature (above the optimum dyeing temperature). Time is saved because the heating and cooling phases are shorter and no extra time is required for the migration process.

Moreover, this technique offers new opportunities for recycling and recovery of spent dye baths. With a pH-controlled system, the hot spent bath can be recycled as such for the next batch, instead of being cooled down before reuse. This is not possible in a temperature-controlled dyeing system because in that case the dyeing cycle cannot be started at the so-called treatment temperature, but must be started at a lower temperature (e.g. 50 °C) in order to prevent uneven dyeing.

The pH steering during batch dyeing can be performed by fitting the machine with dosing systems for acids and alkalis. This is the best and most effective method because it minimises the amount of chemicals consumed to shift the pH. However, precise control of the pH profile with this method is difficult as the pH must be measured continuously and the bath must be fully homogenised. This technique is therefore limited to machines where the textile and liquor are well mixed, such as jets and modern carpet winches. Moreover, if a mineral acid (e.g. sulphuric acid) and an alkali are used, the salt content of the dye bath may increase above acceptable levels when recycling water.

Instead of using pH-measuring instrumentation, another technique is the generation of a pH buffer during the dyeing process. In this case, there is no need to measure the pH in a fully contained system. In fact, pH chemistry and dynamic mass-balancing can predict pH and, more importantly, can create a consistent, repeatable pH profile [ 28, GuT 2001 ]. For these reasons this technique, although more expensive (higher consumption of chemicals) and more polluting (higher organic load in the effluent), tends to be preferred by companies in the sector.

The use of decarbonated water is the best way to ensure optimal pH control, especially when weak acid donors are used (when process water is not decarbonated the acid will be consumed in the formation of CO<sub>2</sub> rather than for shifting the pH of the bath).

The pH-controlled dyeing process is less common for fibres with only alkaline or only acidic functional groups. Nevertheless, it is also advantageous for dyeing acrylic fibres with alkaline dyes and in principle it can be used for all types of fibres with 'neutral pH-dyeable' reactive dyes.

The referenced technique is generally considered the most valuable technique in batchwise and continuous carpet dyeing [ 271, Bettens L. 2000 ].

### **Cross-media effects**

Consumption of chemicals is a cross-media effect.

In addition, the thermal splitting of ammonium sulphate releases ammonia to the atmosphere.

### **Technical considerations relevant to applicability**

The pH-controlled process is applicable to fibres with zwitterionic behaviour such as wool, polyamide, silk, etc. The technique is commonly applied in uni-dyeing processes, whereas it presents some limitations when blends of fibres are dyed to obtain differential shades (differential dyeing). Here, if the two (or more) fibre types do not have compatible pH exhaustion and adsorption profiles, dyeing at iso-pH may be preferable.

### **Economics**

The bath does not need to be warmed up and cooled down according to a preset temperature profile. The resulting saving in energy and processing time is therefore one major economic advantage of this technique.

Investment costs, although fairly acceptable, are associated with fitting the dyeing machine with dosing and pH-control units.

No investment is needed when the pH control takes place via buffer systems or acid/alkali donors.

### **Driving forces for implementation**

Time and energy savings are the main driving forces for the implementation of this technique. Moreover, the technique overcomes the limited potential for dye bath recycling often found with temperature-controlled dyeing processes.

### **Example plants**

Plants from the data collection: AT005, BE007, BE008, BE011, CZ015, CZ017, DE034, DE042, DE047, FR133, IT064, IT067, IT068, IT070, IT078, IT089, IT090, IT094, PT098, PT099, PT109, PT115, SE119 and UK124.

### **Reference literature**

[ 28, GuT 2001 ], [ 271, Bettens L. 2000 ]

## **4.5.1.7 Optimisation of batch dyeing**

### **Description**

Optimisation of batch dyeing includes techniques such as:

- maintaining a constant and low liquor ratio;
- separating the exhausted dye bath and the rinsing water;
- mechanical or pneumatic extraction of the liquor from the fabric;
- shortening the dyeing cycle, e.g. by draining and filling baths with pumps, by using tanks to prepare the liquor in parallel with an ongoing cycle, using cooling water for rinsing;
- dispensing dye and chemicals automatically;
- controlling the liquor level and temperature automatically;
- using indirect heating and cooling systems;
- enclosing the dyeing machines.

**Technical description**

The **liquor ratio** is one of the parameters that influences the environmental performance of the batch dyeing processes. Terms like ‘low’ and ‘ultra-low’ liquor ratio are commonly used by equipment manufacturers to define the characteristics of batch dyeing machines (see Section 2.7.8.2 for the definition of these terms).

A feature of modern machines is that they can be operated at an approximately constant liquor ratio whilst being loaded at a level as low as 60 % of their nominal capacity (or even 30 % of their nominal capacity with yarn dyeing machines). Even small size lots can therefore be dyed at the optimal liquor ratio. This is particularly important especially for commission companies, which need high production flexibility.

Low-liquor-ratio dyeing machines conserve chemicals as well as water and energy and also achieve a higher fixation efficiency. However, as already explained in other parts of this document (see Section 4.1.3), the total water consumption is determined not only by the liquor ratio of the dyeing step, but also by the rinse and wash processes.

The correlation between liquor ratio and total water use is not always exact and factors other than liquor ratio are important when assessing the environmental performance of a batch dyeing machine.

One important factor is the maximum **cut-off between different batches** and, in particular, the maximum separation between the exhausted dye bath and the rinsing water.

In some modern batch dyeing machines, instead of rinsing by overflow or by draining the bath and refilling the vessel with rinsing water, the textile material is rinsed in a continuous mode in a separate stream, thus avoiding cooling or dilution of the exhausted bath. In this way, the hot exhausted dye liquor and the rinsing waters are kept as separate streams, which allows them to be reused or at least to be treated separately and thermal energy to be recovered.

Moreover, various techniques can be applied in order to increase **rinsing efficiency**. When applicable, mechanical liquor extraction is a possible method for reducing the unbound water retained by the fabric, which is otherwise carried over by the substrate to the next step. Suction and blowing air through the fabric are also available techniques. Vacuum technology is the most efficient, but it is not applicable to all types of fabric and it consumes more energy than mechanical extraction.

Another factor affecting specific water and energy consumption in dyeing processes is the **duration of the cycle**. Short cycle times mean not only higher productivity, but also a reduction in the electrical and thermal energy consumption. Various techniques can be applied to reduce downtimes in the working cycles. These typically include draining and filling (see Section 4.1.3.4.1) with pumps, charge tanks (which are used for the preparation of the liquor in parallel with other process operations), combined cooling and rinsing systems, etc. In the latter, the cooling water is passed through the machine heat exchanger during the cooling step and is then fed directly into the jet as hot, fresh rinsing water. The quantity of rinsing water can be controlled, depending on the end temperature, the desired rate of cooling and, in some machines, also on the desired quality of rinsing.

Further reduction of the cycle times can be achieved by improving the **textile/liquor contact** to achieve homogenisation of the bath more rapidly (i.e. by shortening the transition time) after a change in operating conditions (e.g. alkali/dyestuff injection, temperature increase/decrease).

Additional common features of modern batch dyeing machines include the following:

- **Automated systems for chemical and dye dispensing and dyeing cycle control:** this allows improvement of the efficiency and reproducibility of the process. In addition, overuse of chemicals, handling losses and equipment clean-up requirements are reduced.
- **Automatic control of liquor level and temperature:** where machines are equipped only with manual water control valves, there is potential for overfilling and unnecessary wastage of water during filling and rinsing operations. Spillage may also result from excessive boiling during the final stages of dyeing. Modern machines are fitted with process control equipment capable of accurately controlling the level of the liquor and the steam supply.
- **Indirect heating and cooling systems:** indirect heating and cooling is now common practice in modern batch dyeing equipment to overcome dilution and spillage of water.
- **Hoods and doors:** vapour losses can be significantly reduced by full closure of the machines.

### **Achieved environmental benefits**

The technological optimisation of dyeing machines described above leads to improved environmental performance in terms of both consumption of resources (water, energy and chemicals) and water pollution. Reduced spillages (overflows) also reduce potential emissions to soil and groundwater.

### **Environmental performance and operational data**

The environmental performance of these techniques is summarised in Table 4.70 below.

**Table 4.70: Environmental performance associated with optimisation of batch dyeing machines**

Technique	Conventional technology	Technological improvement	Environmental performance
Dosing of dyes and chemicals	Manual	Automated, microprocessor-controlled	Reduced spillage, handling and residues of chemicals which are ultimately discharged to water
Control of liquor level and temperature	Manual	Automated, microprocessor-controlled	Reduced spillage and wastage of water
Heating	Direct steam, boiling	Indirect heating	Reduced dilution and spillage of water
Hoods, doors	Open	Fully closed	Reduced energy and vapour losses
Liquor ratio	Higher	Lower	Reduced use of: <ul style="list-style-type: none"> <li>- water in the dyeing step;</li> <li>- energy to heat the dye bath;</li> <li>- chemicals in the dyeing step.</li> </ul>
Constant liquor ratio across variable load size	Machine needs to be filled with the same volume regardless of the size of the lot	The machine can maintain a constant liquor ratio whilst being loaded at a level as low as 60 % of its nominal capacity	Maintains the same benefits as those achievable with a low liquor ratio (see above) but at reduced loading
Sequence of the batches and rinsing operations	Mixed batches	Separate streams (maximum cut-off between different batches)	Avoids contamination of the rinsing water. Avoids contamination and cooling of the hot dye bath. Possibility of reuse of the dye bath <sup>(1)</sup> . Improved treatment of the concentrated streams.
Rinsing	By overflow or drain and fill techniques	High-efficiency rinsing techniques (e.g. by mechanical extraction)	Reduced water and energy consumption in rinsing operations. Lower volume of waste water.

<sup>(1)</sup> The full separation of exhausted hot bath from rinsing water is especially advantageous when dyeing under pH-controlled conditions. In this case, the hot exhausted bath can be directly reused for making up the next batch because dyeing is started at high temperature (see Section 4.5.1.6).

Source: [ 28, GuT 2001 ]

Most of the techniques described in this section are used for all types of batch dyeing equipment. The extent to which the liquor ratio can be reduced depends on the type of substrate to be processed. Nevertheless, equipment manufacturers can offer, for each substrate, machines with increasingly reduced liquor ratios compared to conventional machines, whilst maintaining the same quality standard of the final product.

More information can be found about different types of equipment in Sections 4.5.1.7.1 to 4.5.1.7.2.-.

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique. However, the use of auxiliary tanks needed for storage and reuse of spent process liquor or rinsing waters in the existing plants may be restricted by a lack of space. Furthermore, it may not be feasible to



adapt the existing machinery into low-liquor-ratio systems; typically it would need to be replaced by new machinery.

### Economics

Variable according to the type of equipment considered (more information can be found for the examples presented in Sections 4.5.1.7.1 to 4.5.1.7.2.2).

### Driving force for implementation

- High productivity and reproducibility of the process.
- Savings in water, chemicals and energy consumption.

### Example plants

Plants from the data collection: AT005, BE011, CZ015, FR131, FR133, IT059, IT064, IT067, IT068, IT070, IT071, IT072, IT077, IT078, IT082, IT085, IT087, IT089, IT090, IT091, IT092, IT094, IT096, IT097, PT099, PT109, PT114, PT115, SE119 and UK124.

### Reference literature

[ 5, UBA 2001 ], [ 28, GuT 2001 ], [ 248, MCS 2001 ], [ 249, Brazzoli 2001 ], [ 250, Bellini L. 2001 ], [ 251, VITO 2001 ]

#### 4.5.1.7.1 Optimisation of winch beck dyeing machines

##### Description

The principles described in Section 4.5.1.7 are applied to winch beck machines:

- indirect heating and cooling;
- improved liquor/goods contact;
- low and constant liquor ratio;
- extraction of the liquor from the goods by vacuum and reuse of the extracted liquor;
- enclosure with hoods;
- automated dosing and process control systems.

##### Technical description

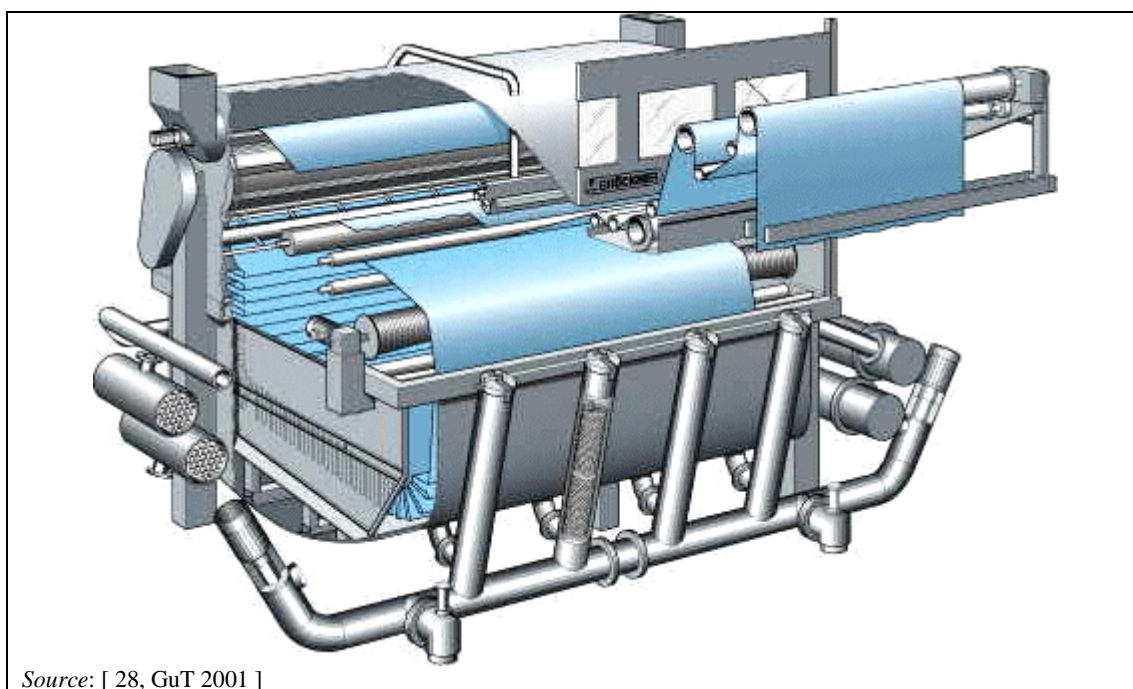
Winch beck dyeing machines are described in detail in Section 8.3.3.1.1 and represented in Figure 4.39 below. In many sectors of the textile industry they have been superseded by other types of equipment (e.g. jet), but winch dyeing still remains an important technology when dyeing voluminous textile pieces such as carpets, upholstery, terry towels and tubular fabrics. In these types of textiles, the softness is determined by the bulk given during dyeing and the winch machine has the advantage of imposing low tension on the fabric while maintaining great mechanical action.

A number of technological improvements have been introduced in this dyeing technique, principally in the following areas [ 28, GuT 2001 ]:

- **Heating:** the liquor in the early winches was usually heated by direct steam injection through a perforated pipe. This system provided both rapid heating and vigorous agitation in the beck, but the dilution effect has to be taken into account. Indirect heating/cooling is now more commonly used to overcome dilution and spilling water.
- **Liquor/textile contact:** in modern winches, both the liquor and the fabric are circulated to improve the liquor/textile exchange. The carpet is circulated through the dye liquor, which is in turn continually pumped through a drum filter to remove the lint. This circulation system ensures a more rapid homogenisation of the bath and an even distribution of the colour throughout the carpet.

- **Liquor ratio:** recent winch becks operate at liquor ratios that are significantly reduced compared to conventional machines. Moreover, an outstanding feature is that small batches can be dyed with approximately the same liquor ratio as for maximum load.
- **Rinsing:** modern winches are designed to remove the carpet without discharging the bath and to avoid cooling or diluting the bath with rinsing water. Thanks to the 'hot-drawing-out system', the carpet is automatically taken out of the beck and passed over a vacuum extractor which removes the unbound water. The recovered liquor is recirculated to the dye bath. The carpet is then sprayed and passed over a second suction section where the rinsing water is collected.

In addition to the above, modern winches are fitted with hoods to help maintain temperature and minimise losses. They are also equipped with automated dosing and process control systems for full control of the temperature profile and chemicals injection during the dyeing process.



**Figure 4.39: Supraflor carpet winch**

The advanced concept applied in this type of winch beck is that the rinsing step is no longer carried out in batch, but rather in continuous mode in a separate section of the equipment without contact between the substrate and the bath. In this way, there is no mixing between the rinsing water stream and the hot exhausted bath, which makes it possible to reuse both streams and to recover the thermal energy.

#### **Achieved environmental benefits**

Reduction of water, chemicals and energy consumption.

#### **Environmental performance and operational data**

Reductions of 40 % to 50 % in fresh water consumption for the total dyeing process (up to 94 % savings in rinsing water) and 30 % in electricity consumption are claimed by the machines' manufacturers [28, GuT 2001].

Liquor ratios used in carpet winches are typically 1:30 or higher. Recent open-width winch becks operate at liquor ratios of 1:15 to 1:20, depending on the substrate type, loading and fabric construction. A new type of winch beck for open-width dyeing of carpet operates at liquor ratios ranging from 1:9.5 to 1:19 and is used successfully in several installations.

In textile dyeing, liquor ratios for conventional winch becks are typically in the region of 1:15 to 1:25. Recent textile winch becks have a nominal liquor ratio as low as 1:5 to 1:8 (depending on the type of substrate) [ 28, GuT 2001 ].

### **Cross-media effects**

None identified.

### **Technical considerations relevant to applicability**

The fundamentals of the new equipment cannot be retrofitted onto existing dyeing machines, which need to be replaced. However, some types of older machines can be upgraded with the special 'hot-drawing-out system'. The use of auxiliary tanks needed for storage and reuse of spent process liquor or rinsing waters in existing plants may be restricted by a lack of space.

### **Economics**

No information provided.

### **Driving force for implementation**

- High productivity and reproducibility of the process.
- Savings in water, chemicals and energy consumption.

### **Example plants**

Plants from the data collection: BE008, IT059, IT070, IT071, IT072, IT077, IT089, IT090 and PT114.

### **Reference literature**

[ 28, GuT 2001 ]

#### **4.5.1.7.2 Optimisation of jet dyeing machines**

New concepts have been introduced in jet machines, which can significantly improve not only the productivity but also the environmental performance of the dyeing process for fabrics that are treated in rope form. Some examples of available techniques are presented in the following sections.

##### **4.5.1.7.2.1 Airflow jet dyeing machines**

### **Description**

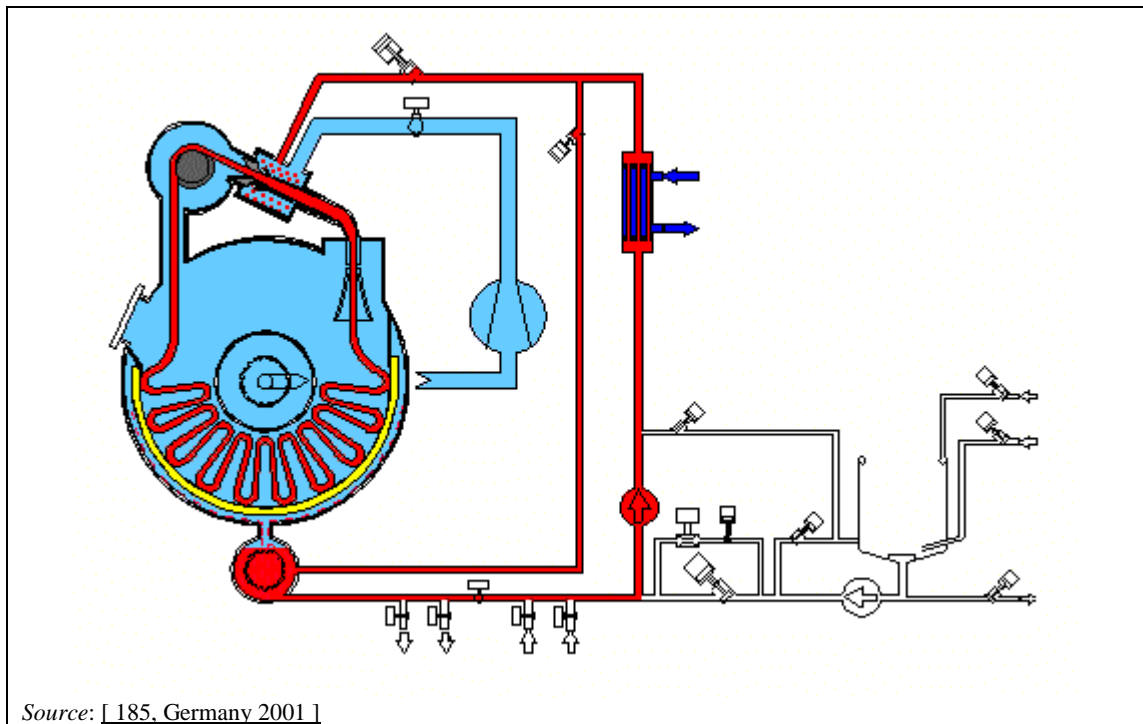
Dyestuffs are injected with air into the fabric, which is not in contact with the dye bath.

### **Technical description**

Jet dyeing is now a mature technology. There is, however, a fundamental innovation, which is the use of air, either in addition to or instead of water, as the motive force in driving the fabric rope (air-jet).

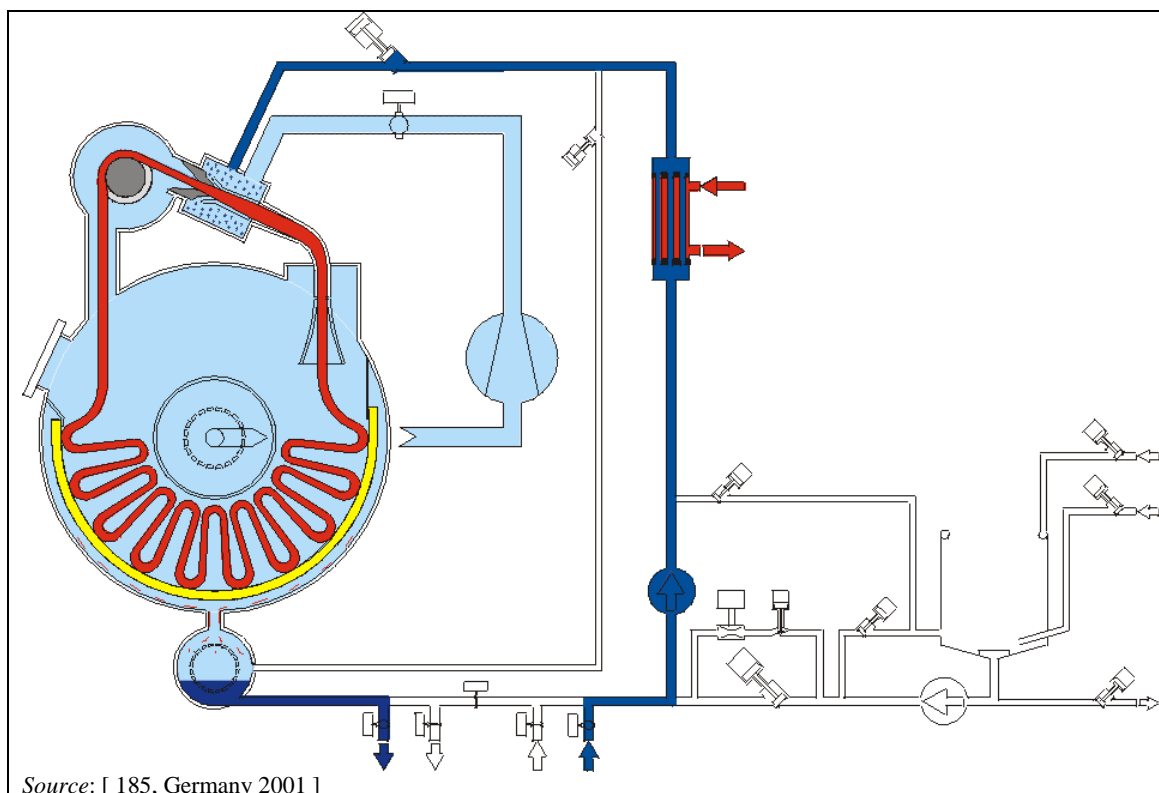
In the latest development, the fabric is moved by means of moisturised air, or a mixture of steam and air, in the total absence of liquid. The dyestuffs, chemicals and auxiliaries are injected into the gas stream. Liquor ratios of 1:2 may be reached for woven PES fabric, while 1:4.5 is the lowest limit achievable for woven cotton fabric with such air-jet machines.

Figure 4.40 below shows that the bath level is always below the level of the processed textile. The fabric no longer stays in contact with the liquor (the bath is below the basket holding the fabric in circulation). This means that the bath conditions can be changed without changing the process phase of the substrate (for example, cooling the bath while the substrate is still at high temperature for prolonged fixation, adding chemicals, interchanging the bath with another one).



**Figure 4.40: Illustration of an airflow dyeing machine with indication of air circulation and injection of the bath**

The bath-less dyeing operation is one of the main features of this machine; the other one is the separate circuit for liquor circulation without contacting the textile. By contrast with conventional machines, during the whole rinsing process (see Figure 4.41), the bottom valve is open and the rinsing water, initially sprayed onto the fabric when it enters the jet, is immediately drained without additional contact with the fabric. Thus, rinsing is no longer a batch operation, but instead offers all the potential advantages of continuous processing (time-saving, possibility of discharging the bath after high-temperature dyeing at 130 °C for optimum heat recovery, maximum cut-off between hot bath liquors and rinsing water, etc.).



**Figure 4.41: Illustration of the rinsing step in an airflow dyeing machine with indication of the open valve to achieve continuous rinsing**

#### Achieved environmental benefits

Reduced consumption of chemicals, energy and water.

#### Environmental performance and operational data

The extremely low liquor ratio and the continuous rinsing system result in a virtually non-stop process with:

- less energy needed thanks to quicker heating and cooling and optimum heat recovery from hot exhausted dye liquors;
- reduced consumption of those chemicals (e.g. salt) for which dosage is based on the amount of dye bath (about 40 % reduction); [ 5, UBA 2001 ]
- less water (up to 50 % water savings are achieved compared to conventional machines operating at a liquor ratio of 1:8 to 1:12) [ 5, UBA 2001 ].

In addition, the release of the exhausted dye bath at process temperature and without dilution by rinsing water opens the way for a very efficient and cost-effective degradation of the remaining dyes and other difficult-to-treat auxiliaries, using the advanced radical treatment process 'ETP & ETF' (Enhanced Thermal Fenton reaction and Enhanced Photo Fenton reaction).

Table 4.71 shows specific input data ranges for cotton dyeing with reactive dyestuffs in a conventional jet operating at a liquor ratio of 1:8 to 1:12 and in the airflow machine described above. The data are derived from measurements taken at production sites.

It is worth adding that the model of airflow described in this section is also designed to maintain its low liquor ratio even with the machine well underloaded.

**Table 4.71: Comparison of specific input data for cotton dyeing with reactive dyestuffs in a conventional jet (liquor ratio 1:8 to 1:12) and in the airflow machine described above**

Input	Unit	Conventional jet operating at liquor ratio 1:8-1:12	Airflow jet operating at liquor ratio 1:2-1:3 (PES)-1:4.5 (CO)
Water <sup>(1)</sup>	l/kg	100-150 <sup>(2)</sup>	20-80 <sup>(2)</sup>
Auxiliaries	g/kg	12-72	4-24
Salt	g/kg	80-960	20-320
Dyestuffs	g/kg	5-80	5-80
Steam	kg/kg	3.6-4.8	1.8-2.4
Electricity	kWh/kg	0.24-0.35	0.36-0.42

<sup>(1)</sup> Including rinsing.  
<sup>(2)</sup> The variation in water consumption is to be read as 20 l/kg in the case of PES and 80 l/kg in the case of cellulose. The airflow machine can use as little as 16 l/kg for peroxide bleaching against 32.5 l/kg for a conventional jet and 26.6 l/kg for reactive dyeing/wash-off against 43 l/kg for a conventional jet [ 251, VITO 2001 ].  
Source: [ 5, UBA 2001 ]

This machine can be used both for knitted and woven fabric and for nearly all types of fibres. Fabrics containing elastane fibres, which are always difficult to dye, due to dimensional stability, can be dyed successfully using the airflow system.

The technique has been tested for silk, but it is rarely applied.

A process has been developed to minimise the oxidation of vat and sulphur dyes by the oxygen in the injected air.

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

Limitations to the use of this machine are found with wool and wool blends with a percentage of wool higher than 50 % because of felting problems. This technique is not used for dyeing linen fabric because the linen lint causes scaling of the machine.

Existing machines cannot be retrofitted.

#### **Economics**

The cost for one machine ranges from about USD 190 500 to USD 362 000 (2005 value), depending on the number of storage chambers and total capacity, but due to the significant savings the payback period is relatively short [ 5, UBA 2001 ], [ 84, Hasanbeigi A. 2010 ].

#### **Driving force for implementation**

- High productivity and reproducibility of the process.
- Savings in water, chemicals and energy consumption.

#### **Example plants**

Plants from the data collection: IT070 and PT099.

#### **Reference literature**

[ 5, UBA 2001 ], [ 44, ÖKOPOL 2011 ], [ 84, Hasanbeigi A. 2010 ], [ 251, VITO 2001 ]

## 4.5.1.7.2.2 Soft-flow dyeing machines with no contact between the bath and the fabric

**Description**

Dyestuffs are injected with water into the fabric, which is not in contact with the dye bath.

**Technical description**

This model of jet uses water to keep the fabric in circulation. The concept that distinguishes this equipment from conventional jets operating with a hydraulic system is that the fabric rope is kept in circulation during the entire processing cycle (from loading to unloading) without stopping either the liquor or the fabric circulation for normal 'drain and fill' steps.

The principle behind this technique is that fresh water enters the vessel via a heat exchanger and arrives at a special interchange zone whilst at the same time the spent liquor is channelled to the drain without coming into contact with the fabric or with the new bath in the machine.

Rinsing is carried out in continuous mode, as in the airflow machine described earlier. The rinsing efficiency is increased thanks to the application of a special countercurrent system.

**Main achieved environmental benefits**

Reduction of water and energy consumption.

**Environmental performance and operational data**

The features of this machine lead to significant savings in processing time (17-40 %), water (about 50 %) and steam consumption (11-37 %), compared with other soft-flow machines of the same category (see Table 4.72 below).

The efficient separation of the different streams offers further advantages such as optimum heat recovery and the possibility of reuse or dedicated waste water treatment.

Table 4.72 shows the results of a comparison that has been made by running the same dyeing procedure on a conventional machine, on a new-generation machine (equipped with charge tanks, draining and filling carried out with pumps and continuous rinsing systems) and on the contactless soft-flow machine described above.

**Table 4.72: Comparison of the performance for cotton dyeing with reactive dyestuffs in a conventional machine, a new-generation machine and a contactless soft-flow machine**

Input	Unit	Conventional jet machine	New-generation jet machine	Contactless soft-flow machine
Water <sup>(1)</sup>	(l/kg)	82	87	42
Steam	(kg/kg)	3.95	4.84	3.07
Time <sup>(2)</sup>	min	472	341	284
<sup>(1)</sup> Including rinsing. <sup>(2)</sup> Including loading/unloading. Source: [ 251, VITO 2001 ]				

**Cross-media effects**

None identified.

**Technical considerations relevant to applicability**

Existing machines cannot be retrofitted.

**Economics**

No information provided.

**Driving force for implementation**

Increased productivity.

**Example plants**

Plants from the data collection: IT070 and PT099.

**Reference literature**

[ 251, VITO 2001 ]

## 4.5.1.7.2.3 Single-rope flow dyeing machines

**Description**

Only one fabric rope passes through all flow groups and compartments of the rope dyeing machine and returns to the first compartment to complete another lap.

**Technical description**

The configuration of this jet machine is reported in Figure 4.42. The way in which it handles the fabric and the dyeing cycle is very different from conventional rope dyeing machines. Firstly, there is only one fabric rope which passes through all flow groups and compartments, returning to the first compartment after the lap is complete.

The single rope approach ensures both the optimum uniformity of the system and the repeatability of the results.

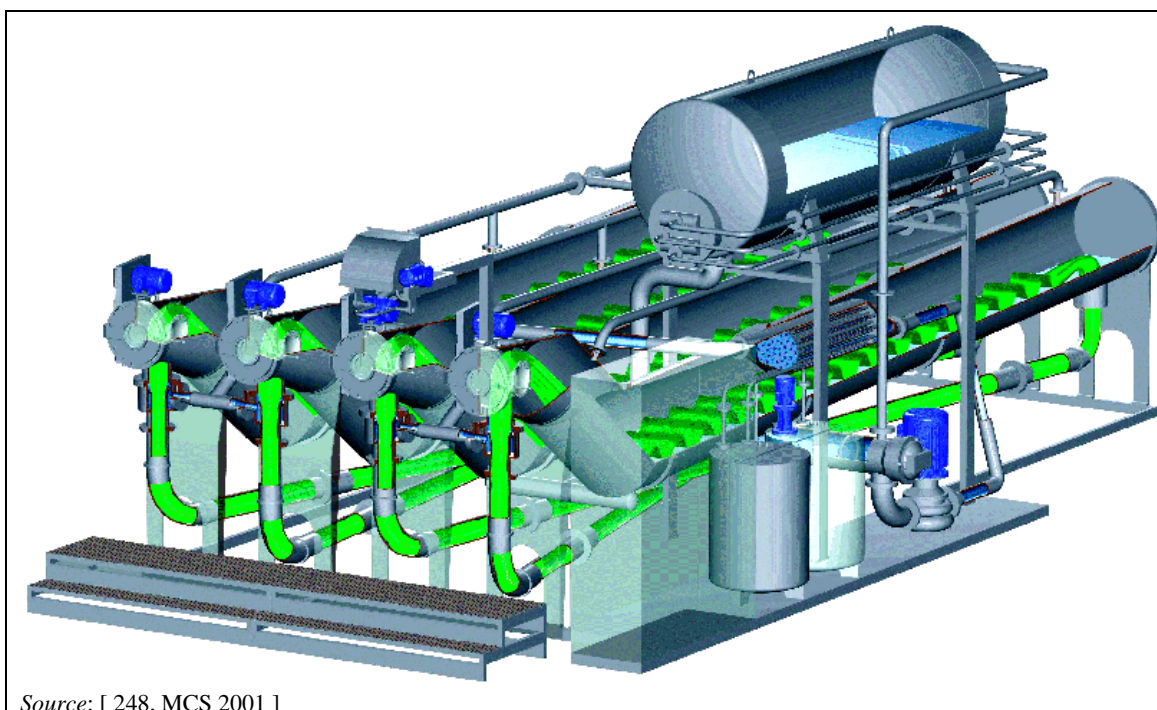
High uniformity is achieved because the fabric passes continuously through all the different nozzles and different troughs in each lap. Whilst in multi-rope machines different conditions are generated in each compartment for various reasons (e.g. different speed of the ropes due to different nozzle flows, etc.), the single-rope approach ensures homogeneous operating conditions in the system as a whole. This also means that the bath reaches equilibrium more rapidly when the operating conditions change (e.g. alkali/dyestuff injection, temperature increase/decrease). An immediate consequence is that chemical injection can be much faster and temperature gradients can be significantly increased without damage to the fibre.

This single-rope technique allows high repeatability by the use of the number of laps, rather than hold time, for controlling the process. Except for time for fixation, which remains a time-dependent parameter, addition of dyes and chemicals into the machine, temperature increase/decrease, etc. are done over a number of laps, instead of by a preset time. The counting of laps is very easy and ensures that from dye lot to dye lot the fabric always undergoes an equivalent process. Another advantage of the application of this lap-counting approach is that the cycle time is automatically adjusted to the speed of the rope and the load of the machine (the shorter the length of the rope, the lower the machine cycle time).

A lot of the latest time-saving devices are also incorporated, such as filling and draining carried out with pumping, a full volume heated tank, advanced rinsing programmes, etc.

The machine can maintain a constant liquor ratio (typically 1:6) whilst being loaded at a level as low as 60 % of its nominal capacity.





Source: [ 248, MCS 2001 ]

**Figure 4.42: Representation of the single-rope dyeing machine**

#### Achieved environmental benefits

Very short cycles and other features described above result in significant water and energy savings (up to 35 %) compared to conventional multi-rope machines.

#### Environmental performance and operational data

‘Right-first-time’ production is one of the most effective pollution prevention measures because it avoids additional consumption and waste of chemicals and resources for corrective measures such as rework, re-dyes, stripping, shade adjustments, etc. A reduction of reworks from 5 % to 2 % has been observed in companies where this technique is applied [ 248, MCS 2001 ].

The use of a single-rope machine reduces the amount of sewing and cutting at the end of each dyeing cycle. On average, 1-1.5 metres of fabric are wasted for each join. A typical three-rope machine performing three dyeing cycles per day for 300 days/year would waste 2 700 metres of fabric per year more than the same process carried out in a single-rope machine. For a medium-size finishing mill, this is equivalent to about 3 000-4 500 kg/year of wasted fabric [ 248, MCS 2001 ].

Table 4.73 below shows the results of the same dyeing process in a conventional machine (liquor ratio 1:10 to 1:12), a new-generation machine (with a liquor ratio of 1:8 and fitted with the latest time-saving devices) and the single-rope machine described above (liquor ratio 1:6). The data are derived from measurements taken at production sites.

**Table 4.73: Comparison of the performance for cotton dyeing with reactive dyestuffs in a conventional machine (liquor ratio 1:10-1:12), a new-generation machine (liquor ratio 1:8 and equipped with latest time-saving devices) and the single-rope machine**

Input	Unit	Conventional jet machine	New-generation jet machine	Single-rope jet machine
Water ( <sup>1</sup> )	l/kg	100-130	50-90	30-70
Auxiliaries	g/kg	15-75	8-40	5-25
Dyestuffs	g/kg	10-80	10-80	10-80
Auxiliaries	g/kg	100-900	80-640	60-480

Steam	kg/kg	4-5	2-3	1.5-2.5
Electricity	kWh/kg	0.34-0.42	0.26-0.32	0.18-0.22
Time (°)	min	510-570	330-390	210-220
(°) Including rinsing. (°) Including loading/unloading. Source: [ 248, MCS 2001 ]				

The single-rope machine is used successfully for processing both knitted and woven fabric of nearly all types of fibres. Unless the horizontal model of this machine is used, limitations are observed when dyeing wool, silk and blends of these two fibres.

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

Existing machines cannot be retrofitted.

#### **Economics**

Investment cost for this type of machine is 20-30 % higher compared to new conventional-type machines, but thanks to savings and the higher productivity the payback period can be less than 10 months.

#### **Driving force for implementation**

- High productivity and reproducibility of the process.
- Savings in water, chemicals and energy consumption.

#### **Example plants**

Plants from the data collection: IT082, PT114 and UK124.

#### **Reference literature**

[ 248, MCS 2001 ], [ 251, VITO 2001 ]

### **4.5.1.8 Reuse/recycling of spent baths in batch dyeing processes**

#### **Description**

Spent dye baths or spent rinse baths are reused for the next dye bath, after analysis and make-up if needed.

#### **Technical description**

Dye bath reuse is the process by which exhausted hot dye baths are analysed for residual colourant and auxiliary concentration, replenished and reused to dye further batches.

Two procedures are possible:

- The dye bath is pumped to a holding tank (or to a second identical machine) while the product is rinsed in the same machine in which it was dyed. The dye bath is then returned to the machine for the subsequent batch of material.
- The product is removed from the exhausted dye bath and placed in another machine for rinsing. In this case no holding tank is required, but the material needs additional handling.

Dye bath analysis can be performed using a spectrophotometer and/or may be determined by production experience based on exhaustion level, volatilisation and dye liquor drag-out [ 30, US EPA 1996 ].

Since the spent dye bath is usually hot, it is of course convenient to save time and energy by dye bath reuse. However, to assure even dyeing it is normally necessary to start the dyeing process at 50 °C. Therefore, the hot spent bath is cooled down and then warmed up again.

New technologies have been developed which allow dyeing to start at process temperatures. Instead of piloting the temperature, one can control the chemical potential of the dye (which is what happens, for example, by adding the sodium hydroxide to reactive dyes) (see Section 4.5.1.6). These techniques are suitable for wool dyeing with acid dyes, acrylic dyeing (this would exclude the addition of levelling agents) and for cotton in the case of sulphur dyeing or reactive exhaustion dyeing processes [ 253, Bettens L. 2000 ].

The second technique proposed here is similar, but this time the spent rinse bath is reused to form the next dye bath.

### **Environmental benefits**

- Reduction in water and chemical consumption.
- Energy saving (reuse of the hot dye bath) is also possible, in some cases (see above) when dye adsorption is controlled by pH and the bath becomes nearly completely exhausted without cooling down at the end of dyeing.

### **Environmental performance and operational data**

Operational data have been reported for a plant dyeing PES and loose wool fibre. Wool is dyed with after-chrome or with metal-complex dyes, whereas PES fibre is dyed with disperse dyes. Both dyes are characterised by high exhaustion rates, which allows reuse of the spent dye bath for the next batches. All dyeing machines with a capacity ranging from 50 kg to 100 kg (liquor ratio of 1:8) have been fitted with holding tanks, temperature and pH control devices and automated dosage systems for formic acid. Most of the holding tanks are constantly used for the same type of dyes and shades (e.g. after-chrome bath for dark shades). As a result of the improvements, the company has achieved a decrease in specific water consumption from 60 l/kg to 25 l/kg [ 5, UBA 2001 ].

Another operational experience has been reported for a mill dyeing loose wool fibre. The company operates conical pan-type machines and loads the fibre carriers with dry fibre. The mean specific water consumption figures for the conventional dyeing and rinse cycle are 9.5 l/kg and 7.8 l/kg, respectively (1.7 l/kg is retained by the fibre load between dyeing and rinsing). The overall water consumption for a conventional cycle would be 17.3 l/kg.

When reusing the rinse liquor for the next dyeing, it is necessary to add on average 1.7 l/kg fresh water to the dye to make up for the water lost when the wet fibre from the previous dyeing is removed. Experience indicates that on average only four cycles of the same shade can be sustained with reuse. The overall water consumption for this four-batch dyeing system is reduced by approximately 33 % when compared with the conventional cycle [ 184, ENCo 2001 ].

For reusing water in dyeing processes, holding tanks are normally needed to store the spent baths. Some models of modern batch dyeing machines (e.g. jiggers, jets and winches) have built-in holding tanks, thus allowing for uninterrupted automatic separation of concentrates from rinsing water.

When using top-loading dyeing machines (typically used for loose fibre and in some cases for yarn), the rinse bath can be retained in the machine at the end of the process and reused for dyeing the next lot of material without the need for holding tanks.

The reuse of dye baths and rinsing waters involves some fundamental differences to the use of fresh bath. The easiest systems to manage are dye classes which have high affinity (exhaustion) and which undergo minimum changes during the dyeing process. Examples are acid dyes for nylon and wool, basic dyes for acrylic, direct dyes for cotton and disperse dyes for synthetic

fibres. The easiest situation is to reuse a dye bath to repeat the same shade with the same dyes and equipment and the same fibre. Some production planning to progress from pale to deep shades is needed (which may somewhat limit the flexibility of batch dyeing operations).

The number of reuse cycles is limited by build-up of impurities from several sources. One source is represented by the impurities present on the textile material, which include natural impurities in cotton and wool, knitting oils, fibre preparation agents, etc. Impurities can also accumulate from components of dye formulations, auxiliaries (e.g. levelling agents), electrolytes, salt build-up from addition of acids and bases for pH control, etc.

In conclusion, the limitations are less severe where machinery is available for internal separation of contaminated spent bath and rinsing water, where trichromatic dye systems are used and dye adsorption is controlled by pH (saving the hot dye bath) and where the bath becomes nearly completely exhausted without cooling down at the end of dyeing [[253, Bettens L. 2000](#)].

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

#### **Economics**

Direct savings are related to both process water purchase price and effluent disposal costs. Prices vary from country to country. In the case of the first example plant described above, savings of EUR 3.20/m<sup>3</sup> have been reported (EUR 0.6/m<sup>3</sup> for fresh water, including treatment, and EUR 2.60/m<sup>3</sup> for disposal fee).

In the same plant, investment costs for the tanks, piping and control devices amounted to EUR 0.8 million [[5, UBA 2001](#)].

#### **Example plants**

Gerhard van Clewe, DE-46499 Dingden [[44, ÖKOPOL 2011](#)]

Plants from the data collection: BE011, CZ015, FR133, IT071, IT072, IT073, IT077, IT089, IT090, IT091, PT114 and PT115.

#### **Reference literature**

[[5, UBA 2001](#)], [[30, US EPA 1996](#)], [[44, ÖKOPOL 2011](#)], [[184, ENco 2001](#)], [[243, OSPAR 1994](#)], [[253, Bettens L. 2000](#)]

### **4.5.1.9 Spray dyeing**

#### **Description**

Dyes are applied by spraying on the textile material (fibre or fabric).

#### **Technical description**

In spray dyeing, the aerosols and droplets are formed through different physical mechanisms (e.g. through centrifugal forces on a rotating plate or through pressure difference on passing the liquid jet through a nozzle).

Spray dyeing can be used for many dye/fibre combinations. For example, for cellulose fibres dyeing with reactive dyes/pigments, no salt is needed for reactive and indigo dyeing; for dyeing synthetic fibre (PES and dispersive dyes, PA and acid or reactive dyes); for dyeing wool with acid and reactive dyes.

This technique can be used for spray coating/dyeing on warp yarn and fabric in dry-on-wet and wet-on-wet processes, in batch/semi-continuous processing (cold spray batch) in combination with autoclave fixation or in continuous processing. For more details on technology, see Section 8.3.4.2.7).

### **Achieved environmental benefits**

Reduced consumption of dyes, auxiliary chemicals and water.

### **Environmental performance and operational data**

Continuous spray dyeing uses significantly lower liquor volumes than conventional continuous dyeing. For example for indigo spray dyeing, the dyeing liquor volume is 90 litres (versus 10 000-50 000 litres with conventional slasher dyeing) and in sulphur spray dyeing 45 litres (versus 1 200-4 000 litres by using conventional boxes).

For spraying hazardous chemicals, collection of microdroplets/aerosols (e.g. enclosure and suction/exhaust fan) is needed to channel the potential emissions from the machinery that could contaminate the ambient air. The aerosols are separated from the air in a liquid mist separator (up to 99 %) to ensure a safe working environment (e.g. Imogo [ 254, Hansson S. 2021 ] [ 255, IMOGO 2019 ] or Rotaspray [ 167, ROTASPRAY 2019 ] machines). To avoid too light microdroplets/aerosols and uncontrollable mist, special chemical add-ons are used to form a controllable spray jet.

Spray dyeing can be very reliable, with exactly set pick-up.

### **Cross-media effects**

None identified.

### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

The continuous machinery can be retrofitted as well as designed as a 'baby slasher' using the advantages of minimised space use, investment costs and infrastructure needed.

### **Economics**

Lower costs of dyeing and effluent treatment.

According to [ 171, Cotton Incorporated 2018 ], investment costs are USD 80 000 or more with payback period of 1 year.

### **Driving force for implementation**

Economics (lower costs for dye or chemical consumption)

### **Example plants**

IT137 (Tessilquattro S.P.A., Rovetero, Italy) uses spray dyeing of fibre called space dyeing (e.g. with multiple colours).

SE120 (Sjuhäradsbygdens Färgeri AB) plant is upscaling to industrial production (Imogo units). Many plants in Europe, Türkiye and Asia (India, China, Pakistan) [ 167, ROTASPRAY 2019 ].

### **Reference literature**

[ 167, ROTASPRAY 2019 ], [ 171, Cotton Incorporated 2018 ], [ 254, Hansson S. 2021 ], [ 255, IMOGO 2019 ]

#### **4.5.1.10 Recovery and reuse of brines and/or salts from dyeing**

##### **Description**

Brine and/or salt is recovered from dyeing process liquors and/or effluents.

### Technical description

Some dyeing waste water streams may be recycled and reused directly, others may require additional treatments. Membrane filtration (e.g. UF/nanofiltration/reverse osmosis) alone or coupled with evaporation/crystallisation can be used to recover high concentrations of NaCl and clean water for direct reuse from dyeing process liquors or effluents.

For more details, see Section 4.1.7.4.4.

### Achieved environmental benefits

- Resource efficiency (lower water and salt consumption).
- Reduced brine discharge to waters.

### Environmental performance and operational data

Resource recovery achieved by membrane filtration technology [ 256, ZERO BRINE 2021 ]:

- 60 % of brine volume directly reused due to internal recycling/reuse;
- 20-25 % of brine volume recovered as NaCl solution;
- sodium chloride, NaCl demand reduced by 60-70 % (725 tonnes/yr);
- reduced freshwater abstractions by 6-7 % of total water consumption (120 000 m<sup>3</sup>/yr).

A further benefit is heat reuse and an associated reduction in GHG emissions.

### Cross-media effects

The extent of cross-media effects is different depending on whether the techniques are applied only to some segregated streams or the whole plant (e.g. like Zero Liquid Discharge treatment). In the latter case, they are bigger (e.g. energy consumption of the plant can increase by up to 20 % per year) [ 92, Inayath Hussain et al. 2018 ].

Energy consumption for ultrafiltration/reverse osmosis/evaporation/crystallisation can be substantial. According to [ 92, Inayath Hussain et al. 2018 ], the operation of a typical WWTP (pretreatment, biological treatment, settling, filtration) with an additional ultrafiltration/reverse osmosis/evaporation/crystallisation unit consumes up to 28 kWh/m<sup>3</sup> of electrical power and steam, with around 50 % consumed in the evaporation/crystallisation step.

Some concentrated liquid and solid waste may remain after treatment.

### Technical considerations relevant to applicability

The applicability of this technique is determined by a combination of factors like strict environmental standards (e.g. zero or low quantity of effluent discharge allowed, low salinity of effluent), water scarcity (e.g. fresh water required for dyeing not available) and economic circumstances (e.g. costs of investment, operation, price of salt and fresh water). The applicability may be limited for plants with smaller amounts of dyeing effluents and salt consumption (e.g. above 120 000 m<sup>3</sup>/yr of segregated waste water (brine) streams and more than 1 000 tonnes of NaCl/yr).

### Economics

- Cost savings from reduced water consumption (e.g. of EUR 120 000/yr for water price of EUR 1/m<sup>3</sup>) [ 256, ZERO BRINE 2021 ].
- Cost savings from reduced volumes of purchased salt are EUR 40 000-50 000/yr [ 256, ZERO BRINE 2021 ].

### Driving force for implementation

Economics (lower costs for salt and water consumption).

### Example plants

Zorlu Textile factory in Lüleburgaz, Türkiye [ 256, ZERO BRINE 2021 ], plant in Tamil Nadu, India [ 202, Tamil Nadu PCB 2019 ].

### Reference literature

[ 92, Inayath Hussain et al. 2018 ], [ 202, Tamil Nadu PCB 2019 ], [ 256, ZERO BRINE 2021 ]

#### 4.5.1.11 Optimisation of energy use in dyeing

##### Description

A set of technical measures identified in the energy efficiency plan (see Section 4.1.4.1) and which allow the reduction of the energy consumed by dyeing.

##### Technical description

A significant share of thermal energy in dyeing is lost through waste water discharge, heat released from equipment, exhaust gas loss, idling, evaporation from liquid surfaces, unrecovered condensate, loss during condensate recovery, and during product drying (e.g. by overdrying).

The factors which most affect the energy consumption for dyeing are the process temperature, the liquor ratio for batch dyeing, the type of fibre and the machine type.

[ 83, CITEVE 2014 ]

Techniques to reduce energy consumption include the following: [ 84, Hasanbeigi A. 2010 ]

- Using water for rinsing after dyeing at a reduced temperature of about 50 °C instead of 60 °C.
- Installation of covers or hoods on open batch dyeing machines.
- Avoiding overheating in open batch dyeing machines. The maximum achievable temperature in an atmospheric vessel is 95-100 °C. Once the dye liquor is boiling, further heat input will not raise the temperature, but will increase evaporation. Although a faster boil does lead to greater agitation of the fabric, this can be achieved more efficiently by installing a circulator. In addition, at temperatures above 80 °C, as much as 15 % of uncondensed steam can be lost in the case of direct steam heating with spargers.
- Using cold pad-batch dyeing for cotton fibres (see Section 2.7.3.1) [ 31, Cotton Incorporated 2009 ].

##### Achieved environmental benefits

Reduction of energy consumption.

##### Environmental performance and operational data

Using covers or hoods can reduce evaporative losses by approximately half. Evaporation is particularly important in processes with temperatures above 60 °C [ 84, Hasanbeigi A. 2010 ].

Table 4.74 shows the steam used by a jigger for direct heating at different temperature and enclosure conditions. The energy savings are significant.

**Table 4.74: Steam used by a jigger with different temperature and enclosure conditions (direct steam heating)**

Operating temperature (°C)	Typical steam use (kg/hour)	
	Open hood	Closed hood
80	50	23
90	61	28
95	73	34
100 (simmer)	91	55
100 (vigorous boiling)	218	127
<i>Source: [ 84, Hasanbeigi A. 2010 ]</i>		

Energy consumption can be reduced from about 20.9 MJ/kg of dyed fabric for winch dyeing to under 4.6 MJ/kg of dyed fabric for cold pad-batch dyeing with beam washing (a reduction of over 350 %) [ 84, Hasanbeigi A. 2010 ].

Concerning cold pad-batch, because processing occurs at room temperature, the reaction takes longer than at the higher temperatures used in jet processing. Although the dwell time for the cold pad-batch process is extended, staging of batching rolls in a separate area frees the pad for additional applications [ 31, Cotton Incorporated 2009 ].

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

#### **Economics**

Table 4.75 shows the capital cost and annual operating savings of cold pad-batch dyeing, which vary depending on the size of the plant.

**Table 4.75: Capital cost and annual operating savings of cold pad-batch dyeing**

<b>Capital cost</b>	USD 1 215 000 <sup>(1)</sup>
<b>Net annual operating savings</b>	USD 329 000 to USD 878 000 <sup>(1)</sup>
<b>Payback period</b>	1.4 to 3.7 years
<sup>(1)</sup> 2001 value. NB: Costs and savings are associated with the amount of production and not just for one machine. <i>Source: based on [ 84, Hasanbeigi A. 2010 ]</i>	

#### **Driving force for implementation**

Savings in energy consumption.

#### **Example plants**

Plants from the data collection using cold pad-batch dyeing are DE026, IT059, IT064, IT065, IT068, IT094 and PT114.

#### **Reference literature**

[ 31, Cotton Incorporated 2009 ], [ 83, CITEVE 2014 ], [ 84, Hasanbeigi A. 2010 ]



## 4.5.2 Dyeing of cellulose (cotton) fibres

### 4.5.2.1 Minimised use of sulphur-based reducing agents

#### Description

Dyeing is carried out without using sodium sulphide or hydrosulphite as a reducing agent. Where this is not possible, partially chemically pre-reduced dyes (e.g. indigo dyes) are used so that less sodium sulphide or hydrosulphite is added for dyeing.

#### Technical description

Sulphur dyestuffs are of great importance worldwide in dyeing cotton in medium to dark shades (especially black) with a high fastness to light and washing. Sulphur dyes are insoluble in water and they need to be converted to the water-soluble 'leuco-form' at some stage during the dyeing process (see also Section 8.2.9).

Conventional sulphur dyes are available in powder form. Before dyeing, they have to be reduced with sodium sulphide in alkaline conditions. Other typical sulphur dyes are the pre-reduced/ready-for-use dyes. They are supplied in liquid form and already contain the reducing agent in their formulation (the sulphide content may be higher than 5 % [5, UBA 2001]). This technique is especially common for indigo dyeing of denim fabrics [31, Cotton Incorporated 2009].

Excess of sulphide (from the dyestuff and reducing agent) is responsible for aquatic toxicity and odour nuisances in the workplace (see also 'Sulphur-containing reducing agents' in Section 2.7.8.1).

The ecological profile of sulphur dyeing has improved thanks to the introduction of new sulphur dyes and alternative reducing agents.

The classic powder and liquid sulphur dyes can be successfully replaced by [5, UBA 2001]:

- pre-reduced dyestuffs (liquid formulations with a sulphide content < 1 %);
- non-pre-reduced sulphide-free dyestuffs (water-soluble in the oxidised form);
- non-pre-reduced sulphide-free stabilised dispersed dyestuffs (in powder or liquid form);
- non-pre-reduced sulphide-free dyestuffs (stable suspension).

Unlike the old sulphur dyes with low reduction potential, all these types of dyestuffs can be used without any sodium sulphide (in the pre-reduced liquid formulations a low amount of sodium sulphide is still present in the formulation). The following binary systems are in use:

- combination of dithionite and glucose;
- combination of hydroxyacetone and glucose (seldom);
- combination of formamidine sulphinic acid and glucose (seldom).

Glucose is added to sodium dithionite to prevent over-reduction. The addition of glucose can be omitted when using stabilised sulphide-free dyestuff formulations. With the non-pre-reduced sulphur dyestuffs mentioned, the reduction step can be carried out with glucose alone.

In the past, an additional concern associated with sulphur dyeing was related to the use of sodium dichromate as an oxidising agent (applied to reconvert the dye to the original oxidised insoluble form, after adsorption onto the fibre). Sodium dichromate has now been fully replaced by hydrogen peroxide, bromate, iodate and chlorite.

Hydrogen peroxide is the preferred oxidising agent. Bromate, iodate and chlorite are detected as AOX. Nevertheless, they are not organohalogen compounds and they are not likely to give rise to hazardous organohalogen products (only certain chlorite products that contain Cl<sub>2</sub> or use chlorine as an activator are likely to give rise to hazardous AOX).

**Achieved environmental benefits**

- The sulphide content in waste water is minimised.
- Reduced emissions to water.

**Environmental performance and operational data**

In order to derive the maximum environmental and economic benefit from the technique, only the exact amount of reducing agent needed to reduce the dyestuff is added. Consumption of the reducing agent by the oxygen in the machine is therefore avoided as much as possible. One effective technique to ensure this is to use nitrogen to remove oxygen from the liquor and the air in the machine [ 257, VITO 2001 ].

A typical recipe for cotton dyeing in a jet machine (liquor ratio 1:6 to 1:8; dyeing for 45 minutes at 95 °C) is given below [ 5, UBA 2001 ] :

- non-pre-reduced sulphur dye: 10 %;
- wetting agent: 1 g/l;
- caustic soda solution (38 °Bé): 15-20 ml/l;
- soda ash: 8-10 g/l;
- salt: 20 g/l;
- glucose: 10-12 g/l;
- sodium dithionite: 8-10 g/l or hydroxyacetone: 4-5 g/l or formamidine sulphinic acid: 4-5 g/l.

The dyestuffs and reducing agents described in this section can be used in existing and new dyeing machines (exhaust dyeing as well as continuous techniques).

**Cross-media effects**

Using sodium dithionite as a reducing agent leads to sulphite content in waste water (see Section 2.7.8.1).

**Technical considerations relevant to applicability**

The applicability may be restricted by the product requirements as the use of alternative reducing agents may lead to differences of shade compared to common sulphur dyeing [ 5, UBA 2001 ].

**Economics**

Stabilised non-pre-reduced sulphide-free dyestuffs are more expensive than sulphur dyes. Detailed information is not available [ 5, UBA 2001 ].

**Driving force for implementation**

Workers health and safety, odour nuisance and waste water problems related to the presence of sulphides.

**Example plants**

Plants from the data collection: DE022, DE030, DE034, DE045, FR134, IT059, IT064, IT065, IT068, IT094, IT096, PT105, PT108, PT109, PT117 and UK126.

**Reference literature**

[ 5, UBA 2001 ], [ 31, Cotton Incorporated 2009 ], [ 243, OSPAR 1994 ], [ 257, VITO 2001 ]

#### 4.5.2.2 Use of concentrated alkali solution in cold pad-batch reactive dyeing

**Description**

Concentrated aqueous alkali solutions without sodium silicate are used for fixation of dyestuff.

### Technical description

Sodium silicate is often used in cold pad-batch dyeing, mainly to increase the pad liquor stability and to avoid selvaige carbonisation. On the other hand, sodium silicate gives rise to a number of problems such as the formation of silicate deposits on the textile surface and on the equipment, increased salt in the effluent, etc.

Silicate-free highly concentrated aqueous alkali solutions have been developed and are now available on the market. They are ready-made products (carefully adjusted mixture of alkali in aqueous solution), which can be easily applied with modern dosing systems. They are particularly suitable for the cold pad-batch process.

### Achieved environmental benefits

Reduced emissions to water.

### Environmental performance and operational data

The following advantages are achievable:

- no residues of alkali in the preparation tank because, unlike with sodium silicate, the alkali can be added as ready-made solution and does not need to be prepared;
- no formation of difficult-to-wash-off deposits on the substrate and on the equipment;
- no need for additional auxiliaries in the padding liquor to avoid the formation of deposits;
- lower electrolyte content in the effluent;
- possibility of using membrane techniques in waste water treatment (no crystallisation in filters, pipes and valves and no membrane blocking, which is the case with sodium silicate).

Membrane pumps such as the sera-pumps with a 4:1 ratio between the alkali solution and the dyestuffs solution are suitable for the application of the product [5, UBA 2001].

Figure 4.43 shows a typical dosing curve. Using a curve instead of the conventional alkali addition steps brings additional advantages in terms of increased reproducibility [5, UBA 2001].

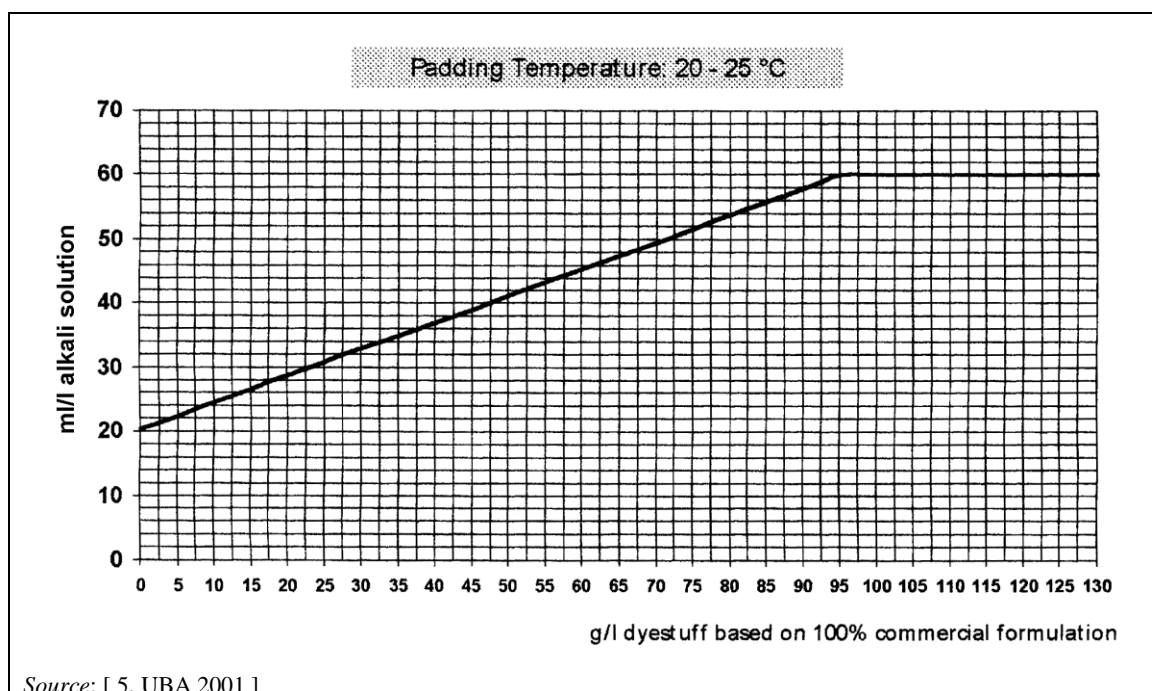


Figure 4.43: Dosing curve for ready-made alkali solution

The ready-made alkali solutions are designed for modern minimum-volume troughs (see Section 4.5.1.1), where the pad liquor exchange time is very short and where extremely long pad liquor stability is not needed, as the absence of sodium silicate affects the stability of the pad liquor. More efficient process control (e.g. temperature control of the dyeing liquor) is therefore required.

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

The technique is applicable to both existing and new installations [ 5, UBA 2001 ].

It may not be applicable for dyeing with dark shades, where an add-on of silicate to the formulation is needed [ 44, ÖKOPOL 2011 ].

#### **Economics**

Ready-made alkali solutions are more expensive than the conventional fixation methods and additional process control implies investment costs.

However, the following economic benefits are induced [ 5, UBA 2001 ]:

- The investment in advanced dosing systems is lower for the silicate-free method because only two dosing units are needed (one for the dyestuff solution and one for the ready-made alkali solution), while with the conventional fixation methods based on silicate, three dosing units are required (one for the dyestuff solution, one for the silicate and one for the alkali). The investment cost for one dosing unit is around EUR 12 000.
- There is no need to change the rubbers of the padder at short time intervals because of silicate deposit formation. The cost for removing the rubber of a padder is estimated at around EUR 7 000-10 000.
- The lower electrolyte content of the liquor reduces the substantivity of the hydrolysed dyestuffs, which is therefore easier to wash off. This results in lower energy and water consumption in the washing-off step of the process.
- The productivity of the padders and washing ranges is higher.
- There is a better reproducibility of the process thanks to monitored process conditions.

In conclusion, a reduction of the total process costs is achieved, compared to the conventional fixation methods.

#### **Driving force for implementation**

Product quality and reproducibility of the process.

#### **Example plants**

Plants from the data collection: FR131, IT059, IT070, IT094 and PT114.

#### **Reference literature**

[ 5, UBA 2001 ], [ 44, ÖKOPOL 2011 ]

### **4.5.2.3 Cationisation of cotton**

#### **Description**

The surface of cellulose fibres is chemically modified by a pretreatment step like cationisation or aminisation to increase their affinity for reactive dyes.

#### **Technical description**

Cotton is pretreated with a cationisation agent and caustic soda prior to reactive dyeing. The aim of cationisation is to produce cationic sites on the cellulose fibres by attaching cationic

monomers or polymers of low molecular weight to the cellulose molecules. The affinity of cotton fibre for reactive dyes and the exhaustion of those dyes in dyeing is thereby increased. Furthermore, the consumption of salt in reactive dyeing is greatly reduced.

The cationisation solution may be applied in different ways (exhaustion, pad-batch, pad-steam, pad-dry or a combination thereof) and to different substrates (fibre, yarn or fabric). The efficiency of the reaction and the resulting degree of cationisation are directly related to the amount of cationisation agent applied and the substrate and process utilised [ 258, Cottonworks 2019 ].

Typical cationic agents used are amines and/or quaternary ammonium compounds. Historically 3-chloro-2-hydroxy-propyltrimethylammonium chloride (CHPTAC) was used as the cationisation agent, but, due to the carcinogenic intermediate 2,3-epoxypropyltrimethylammonium chloride (EPTAC), the alternative substances such as chitosan derivatives with amino groups, polyamindiamine dendrimers (e.g. PAMAM, containing four amine groups), cationic polymers and others have been developed [ 259, Bhuiyan et al. 2014 ], [ 260, Choudhury A.K.R 2014 ], [ 261, Fu Sha 2016 ], [ 262, Blahutova M. 2021 ].

### **Achieved environmental benefits**

Reduced pollutant loads (i.e. salinity, dyes, and heavy metals) in the effluents from reactive dyeing of cotton.

### **Environmental performance and operational data**

The cationisation pretreatment allows reactive dyeing of cotton with low- or zero- salt or alkali consumption; due to higher dye fixation, the dosed dyes are almost completely exhausted. The salinity of the effluent and the load of the unfixed dyes (and consequently heavy metals as part of the dye molecules) are significantly reduced.

Polymer-type cationisation preparations are typically almost completely exhausted from the spent baths during the cationisation pretreatment step and only negligible amounts remain in the effluents. It is not clear if these remaining cationisation agents can produce intermediary substances that are hazardous or could be classified as carcinogenic. However, such intermediates are expected to be neutralised after mixing with effluents from other wet treatment processes in installation's common waste water treatment plant. Typically the remains of cationisation polymers would be neutralised to non-toxic compounds (e.g. salts) by reacting with the anionic species (e.g. from various anionic auxiliaries used in other wet treatment processes) [ 262, Blahutova M. 2021 ].

Typically, cationisation pre-treatment prolongs the total dyeing time. High reuse/recirculation of dyeing effluents due to the absence of salt and heavy metals is possible in the installations using this treatment step.

Since cationisation agents may be hazardous compounds additional advanced pretreatment (e.g. coagulation/flocculation, adsorption – for more details see Sections 4.1.7.2 and 4.1.7.4) would be used for their removal from the effluent prior to the biological treatment. For concentrated baths from pad-batch application separate collection and disposal of these waste water streams may be applied [ 263, Farrell et al. 2013 ], [ 261, Fu Sha 2016 ].

### **Cross-media effects**

Cationisation is additional operation in the dyeing process. Additional chemicals would be required for the cationisation pretreatment and advanced pretreatment of waste water streams may be required.

### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique. However, significantly reduced light fastness, especially dyeing with medium to high demands on light fastness, may not possible [ 58, EURATEX 2020 ].

**Economics**

The technique induces investment costs for the cationisation unit or purchase costs for the cationic cotton. The investment costs for the cationisation unit are less than USD 200 000 and the payback time is 2 years [ 31, Cotton Incorporated 2009 ].

The savings from reducing the consumption of dyes are around 40–45%, compared to conventional reactive dyeing, depending on the dyeing deepness (shade).

Further savings arise from reduced water consumption for the dyeing process, because of higher water reuse/recirculation due to absence of salt and heavy metals.

Additional costs may occur if advanced pretreatment of the waste water streams are required to remove the remaining cationisation agents and their degradation products.

**Driving force for implementation**

- Environmental legislation (emission limit values, environmental quality standards).
- Lower water consumption (due to higher water reuse/recirculation).
- Economics (reduced overall costs of dyeing).
- Improved product quality (colour levelness and fastness which are difficult or impossible to attain by conventional dyeing without this pretreatment).

**Example plants**

Cationisation preparations from several producers are available. Textile plants in Italy, the UK, the Netherlands, Spain and Portugal were applying this process at the time of drafting this document [ 262, Blahutova M. 2021 ].

**Reference literature**

[ 31, Cotton Incorporated 2009 ], [ 58, EURATEX 2020 ], [ 258, Cottonworks 2019 ], [ 259, Bhuiyan et al. 2014 ], [ 260, Choudhury A.K.R 2014 ], [ 261, Fu Sha 2016 ], [ 262, Blahutova M. 2021 ], [ 263, Farrell et al. 2013 ]

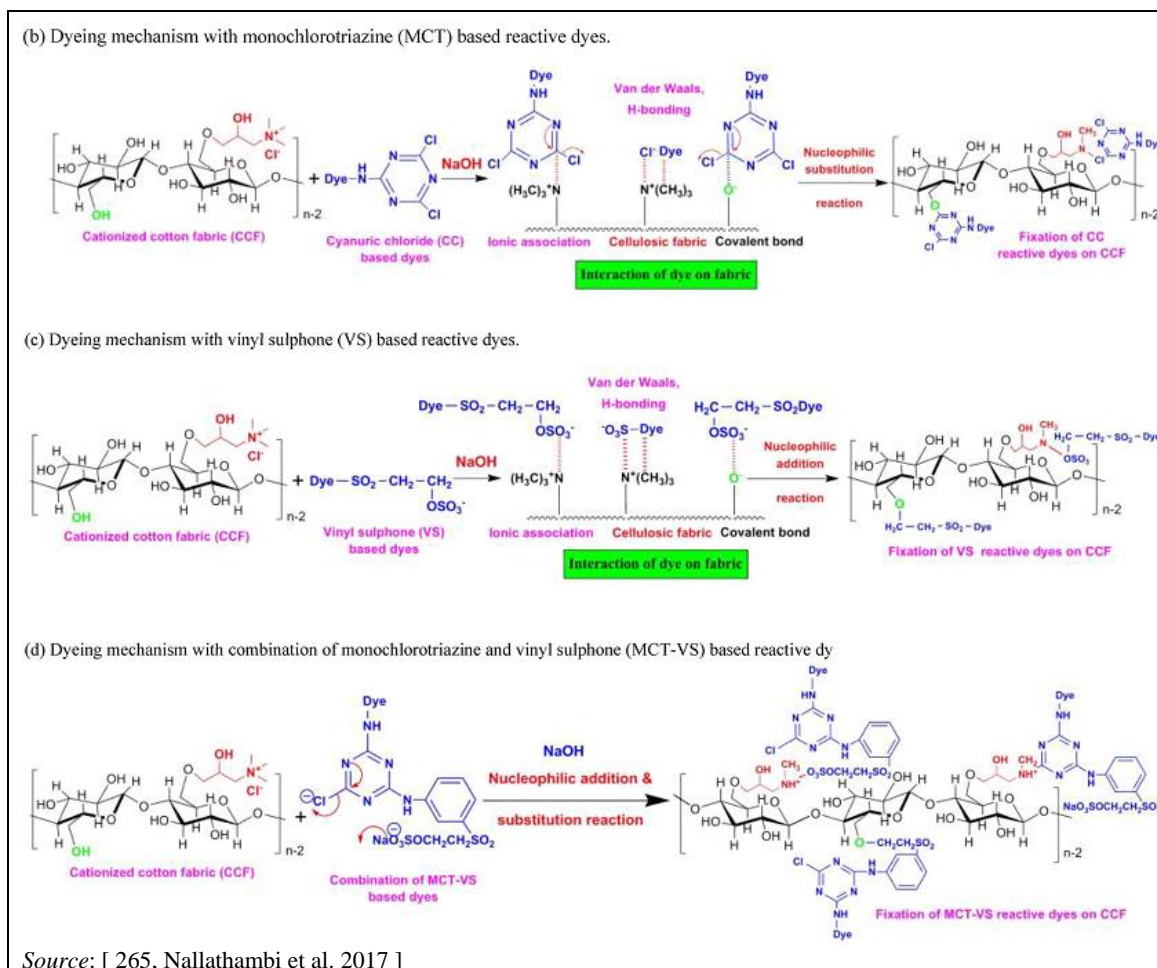
**4.5.2.4 Use of high-fixation polyfunctional reactive dyes****Description**

Use of polyfunctional reactive dyes with more than one reactive functional group to provide a high level of fixation in exhaust dyeing. These dyes require a lower salt concentration.

**Technical description**

Bifunctional (polyfunctional) reactive dyes, containing two similar or dissimilar reactive systems, offer very high levels of fixation in exhaust dyeing. Because of their two reactive groups, bifunctional reactive dyes have an increased probability of chemical reaction with cellulose fibres compared to monofunctional dyes with one reactive group. If one of the reactive groups hydrolyses during the dyeing process, the other one can still chemically react with the hydroxyl groups of cellulose. Moreover, combining two reactive systems in the same dye delivers the advantages of the two individual groups (e.g. high degree of fixation with high fastness levels and wash-off). However, polyfunctional dyes are not necessarily better. Only the right combination of reactive groups makes them superior to conventional monoreactive dyes.

Most of these dyes are bifunctional dyes with monofluorotriazine (MFT) and monochlorotriazine (MCT) functional groups, furthermore, for trifunctional reactive dyes, the vinyl sulphone (VS) functional group is included in combination [ 264, Choudhury A.K.R. 2006 ]. Figure 4.44 illustrates the examples of reactive dyeing mechanisms of polyfunctional reactive dyes.



**Figure 4.44: Examples of reactive dyeing mechanisms of polyfunctional reactive dyes**

Because of the reduced amount of salt needed for their exhaustion, low-salt dyes are more soluble and can be kept in solution at a higher concentration than necessary for low-liquor-ratio dyeing machines. This offers further possibilities for reducing the overall salt quantity, as illustrated in Table 4.76 below.

**Table 4.76: Quantities of salt required for dyeing 1 000 kg of fabric to a medium depth of shade**

	Winch (liquor ratio 1:20)	Jet (liquor ratio 1:10)	Low-liquor-ratio jet (liquor ratio 1:5)
Traditional reactive dyes (salt 60 g/l)	1 200 kg	600 kg	300 kg
Low-salt reactive dyes (salt 40 g/l)	800 kg	400 kg	200 kg

Source: [ 5, UBA 2001 ]

#### Achieved environmental benefits

- Reduction of unused dyestuff ending up in the waste water stream (reduced colour and organic load).
- Lower salinity of emissions to water.
- Reduction of chemical consumption.

#### Environmental performance and operational data

The fixation of a reactive dye with cellulose can be expressed either as a percentage of the total dye applied (fixation rate, sometimes also called absolute fixation) or as a percentage of the dye

exhausted (exhaustion rate, sometimes also called fixation efficiency). In the case of monofunctional dyes, the fixation rate is approximately 60 % (with an exhaustion rate of about 70 %), which means that 40 % of the dye applied is lost in the effluent. In the case of bifunctional reactive dyes, an 80 % fixation rate and over 90 % exhaustion rate are achieved.

This is particularly advantageous when advanced oxidation techniques are applied to treat the dye in the effluent (see Section 4.1.7.3.4.1). It has to be noted, however, that a lower amount of dye in the effluent does not necessarily produce a reduction in colour. The tinctorial strength of new reactive dyes has significantly improved. This means that deeper and more intense shades are possible with less dye than necessary with other dyes or dye classes. Less dye is therefore left in the effluent, but colour may be still high [ 266, VITO 2001 ].

With those dyes, post-rinsing to obtain the required level of wet-fastness can be performed quickly and with relatively little energy and water. This is partly a consequence of the high fixation yield of the bifunctional dyes (only a small amount of unfixed dye needs to be washed off). More important, however, is the fact that some new reactive dyes have molecules especially designed to show reduced affinity when they are in the hydrolysed form, which means that they have excellent wash-off properties.

A shorter processing time may be obtained on certain substrates by combining the pretreatment and dyeing steps using polyfunctional dyes that fix at 90 °C. Savings of up to 40 % in water and energy consumption and more than 30 % of salt consumption are claimed.

To facilitate selection and application, dye manufacturers introduced small dye ranges comprising highly compatible dyes with virtually identical behaviour in the dye bath. Each of these compact ranges is geared to specific application segments. Also, dyeing compatibility matrixes are provided. This is important in order to obtain high reproducibility, low dependency on dyeing conditions (e.g. liquor ratio, dyeing temperature, salt concentration) and therefore 'right-first-time' dyeing.

High-fixation reactive dyes can be applied in all types of dyeing machines, but offer a particular advantage on the most modern low-liquor-ratio dyeing machines fitted with multi-task controllers where additional advantages in terms of reduced energy and water consumption can be exploited [ 5, UBA 2001 ]. In particular, new reactive dyes with very good solubility can be applied at ultra-low liquor ratios [ 266, VITO 2001 ].

Salt consumption for exhaust dyeing of cellulose fibres is reduced by about one third of the quantity needed for conventional reactive dyestuffs, with positive effects on effluent salinity and smooth running of waste water treatment units [ 5, UBA 2001 ].

Low-salt reactive dyes are high-affinity dyes, which makes them less easy to wash off than low- or medium-affinity types. However, dyes with low affinity in the hydrolysed (unfixed) form are increasingly available, making post-rinsing operations much easier.

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

#### **Economics**

Compared to conventional reactive dyes, polyfunctional reactive dyestuffs are more expensive, but the higher fixation efficiency, the savings on salt usage and the reduced water and energy consumption lead to a significant reduction of the total cost.



Cost savings are achieved by the application of the new dyes, especially for dark, problematic dyes, e.g. royal blue, with regard to the following parameters:

- salt content: - 20%;
- amount of alkali: - 20%;
- fixation temperature: - 5%;
- low liquor ratio: 1:8;
- exhaust and fixation time: -15 minutes.

[ 44, ÖKOPOL 2011 ]

### Driving force for implementation

- Environmental legislation.
- Reduction of total processing costs achievable thanks to high dye fixation [ 5, UBA 2001 ].
- Water scarcity.
- Salt-induced corrosion.

### Example plants

Plants from the data collection: CZ019, DE051, FR133, IT059, IT064, IT065, IT067, IT068, IT070, IT077, IT078, IT082, IT085, IT087, IT092, IT094, IT096, IT097, PT099, PT114, PT115 and UK124.

### Reference literature

[ 5, UBA 2001 ], [ 44, ÖKOPOL 2011 ], [ 183, Spain 2001 ], [ 266, VITO 2001 ]

## 4.5.2.5 Optimised rinsing of cotton dyed with reactive dyes

### Description

Rinsing after dyeing with reactive dyes is carried out at a high temperature (e.g. up to 95 °C) and without using detergents. The heat of the rinsing water is recovered.

### Technical description

Both international literature and practical experience in textile mills show that detergents do not improve removal of hydrolysed reactive dyestuffs from the fabric.

On the contrary, high temperatures do have an impact on rinsing effectiveness. Tests carried out with rinsing at 90-95 °C have shown that rinsing is more effective and faster at high temperatures. About 30 % more unfixed hydrolysed reactive dyestuff is rinsed out after 10 minutes of rinsing at 95 °C than at 75 °C.

The high degree of fixation and good wash-off properties typical of some new low-salt, polyfunctional reactive dyes (see Section 4.5.2.2) are important factors that help to obtain sufficient wash fastness with hot rinsing without the need for detergents.

Many dyehouses already carry out hot rinsing without detergents after reactive dyeing. The product quality is not negatively affected. On the contrary, usually the fastness of the goods is better after the hot rinsing than after the traditional rinsing with detergents, complexing agents and neutralisation in the first rinse.

Energy is recovered when using large volumes of hot process water. Energy can be recovered either by heat exchange between the hot outgoing process water and the cold incoming fresh water or by reclamation of the hot water and reuse of both energy and water.

Chemicals to decompose reactive dyes are not used in the washing process, because they destroy the dye. If degradation is intended, surfactants are needed to transport the poorly soluble

dye fragments off the fibre and out of the washing bath. This is especially the case for discontinuous processes like jet or jig processes.

For continuous and semi-continuous processes, surfactants are not commonly used, because the dye formulations already contain tenside components (in this case the use of hard water influences the washing process positively) [ 44, ÖKOPOL 2011 ].

#### **Achieved environmental benefits**

The main benefit is the reduction in consumption of detergents and pollutant load discharged to the waste water.

#### **Environmental performance and operational data**

The experience of two dyehouses (one mainly dyeing knitted fabrics and the other dyeing garments) shows that the average potential load reduction can be in the order of 1 kg detergent, 1 kg complexing agent and 1 kg acetic acid per 100 kg of textile.

However, acetic acid is still used if the following finishing step is softening or adding crease resistance [ 44, ÖKOPOL 2011 ].

Additional advantages are the savings achievable in the amount of chemicals consumed to destroy reactive dyes by free radical treatment processes. In the Fenton reaction for example, since the OH\* radicals react very fast not only with the dyestuffs but also with many detergents, a large amount of expensive H<sub>2</sub>O<sub>2</sub> can be saved by avoiding the use of detergents.

It has been reported that difficulties might arise with accidental stops of the machinery. In such conditions, the high temperature of the rinsing water could cause irreversible cleavage of the bond between the reactive groups of the dye and the hydroxyl groups of cotton or viscose.

#### **Cross-media effects**

Substituting cold rinsing with hot rinsing leads to higher energy consumption, unless thermal energy from the rinsing effluent is recovered.

#### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

#### **Economics**

The only change in operating procedures is to avoid the addition of detergents. Savings will depend on the number of reactive dyeings carried out at the company.

#### **Driving force for implementation**

- Savings in chemical consumption.
- Environmental legislation.

#### **Example plants**

Plants from the data collection: FR131, IT064, IT068, IT077, IT078, IT089, IT090, IT091, PT099 and PT111.

#### **Reference literature**

[ 23, Schönberger H. 1994 ], [ 44, ÖKOPOL 2011 ], [ 267, Danish EPA 1999 ]

### **4.5.2.6 Steam fixation**

#### **Description**

The reactive dyes are fixed with steam, which avoids the use of chemicals for fixation.

### Technical description

The technique consists of a continuous dyeing process for cellulose fibres that uses selected reactive dyestuffs and which requires no additional substances such as urea, sodium silicate and salt, or long dwell time to fix the dyes, unlike the conventional pad/continuous dyeing systems. The recipe includes wetting agents and alkali but the other auxiliaries normally used in a conventional process are replaced by ensuring a controlled steam content during drying.

The dye liquor is applied to the textile using a padder (cotton is squeezed to about 70 % pick-up and viscose to about 80 %) and, after a short passage through air, the fabric is fed directly to the dryer (hot-flue), where it remains for 2 minutes.

In the conventional process, urea is used as solvent for the dye in the dryer. Urea melts at 115 °C and binds water above 100 °C, thus allowing penetration of the dyestuff in the fabric during fixation in the steamer. With the alternative process, this is not needed because the conditions in the dryer are set (120 °C and 25 vol-% steam content) so that the fabric remains at a specific temperature of 68 °C as long as it is damp.

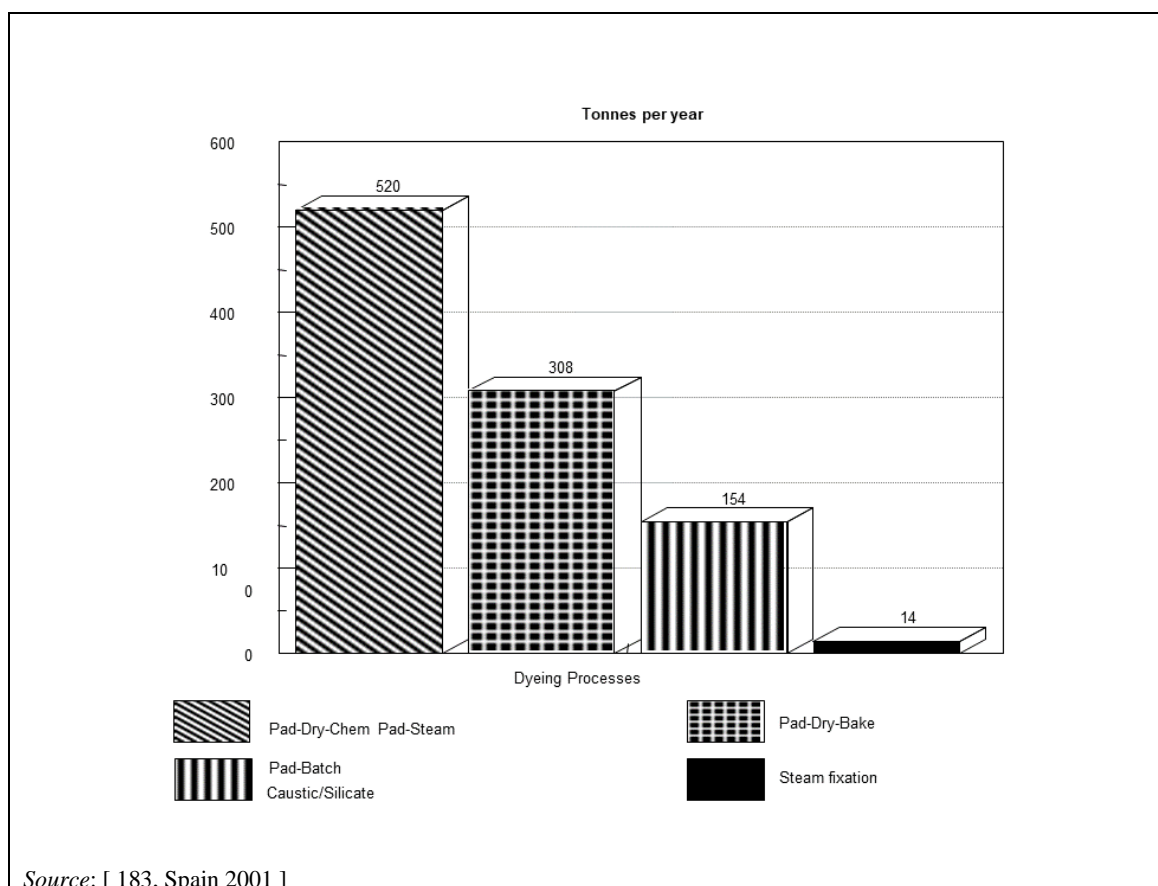
Since highly reactive dyes are used, only a low fabric temperature (68 °C), a weak alkali and a short time (2 minutes) are needed for fixation.

### Achieved environmental benefits

Reduction in chemical consumption and reduction of the pollutant load in the waste water.

### Environmental performance and operational data

A significant reduction in chemical consumption is possible, as shown in Figure 4.45.



**Figure 4.45: Basic chemical consumption per 10 million metres with pad-dry-pad-steam, pad-batch, pad-dry-thermofix and steam fixation**

No urea, salt (chloride/sulphate) or sodium silicate is consumed and the alkalinity is often lower (less NaOH, due to substitution with  $\text{Na}_2\text{CO}_3$  depending on the selected dyes).

One company operating a three-shift system for dyeing continuously by the pad-dry-thermofix process or the pad-dry-pad-steam process, at a rate of 40 m/min, would consume approximately 423 t/yr of urea or 540 t/yr of NaCl. On the other hand, a company operating the alternative technique on a three-shift basis would consume only 22 t/yr of sodium bicarbonate, which ends up in the effluent. In conclusion, the waste water from washing contains only 4-5 % of the chemical load produced by other dyeing processes carried out in accordance with the latest technology [ 266, VITO 2001 ].

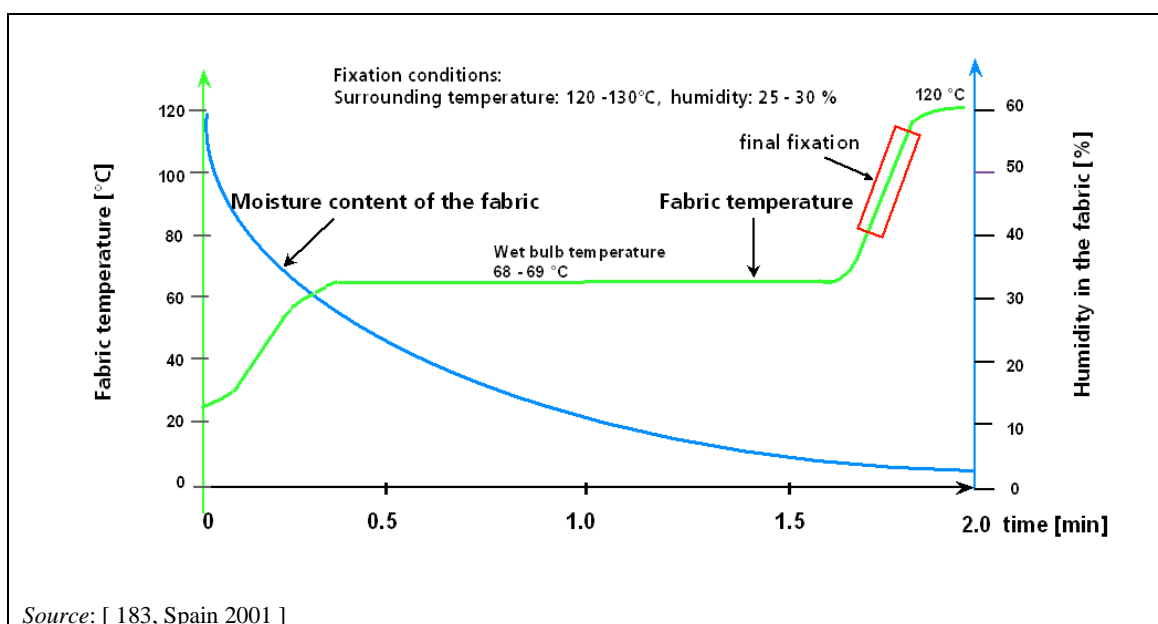
The elimination of urea, in particular, results in a lower amount of nitrogen-containing compounds in the waste water and avoids the presence of urea breakdown products in the exhaust air, typically found in pad-thermofix processes.

The absence of salt is advantageous not only because it results in a lower salt load in the final effluent, but also because without salt the unfixed dye is easier to wash off (less water and energy consumption in post-rinsing operations). In addition, dyes that have low substantivity in the hydrolysed form are now employed, which show very good washing-off properties.

Due to less add-on of chemicals and salts, water recycling is easier [ 44, ÖKOPOL 2011 ].

In addition, energy consumption is minimised through control of the exhaust air.

The temperature and humidity profile during the fixation process is illustrated in Figure 4.46 below.



**Figure 4.46: Fabric temperature and humidity during the dyeing process using steam fixation**

A dampening unit is used during start-up of the machine in order to ensure that ambient conditions in the chamber of the dryer are set at 25 vol-% steam content.

Sometimes, the amount of water released from very lightweight fabrics is not enough to keep the chamber at 25 vol-%. In this case, the steam injector is used to spray in the required amount of steam.

It has to be stressed that maximum performance is obtained only with the right choice of fabric pretreatment and well-engineered selected dye formulations.

In addition to high versatility and applicability to a wide variety of fabrics, a number of benefits are achieved in terms of fabric quality compared with other dyeing techniques. These include [ 183, Spain 2001 ]:

- soft handle due to mild fixing conditions;
- migration minimised by rapid fixation and humidity control (especially important on pile fabrics, where rub fastness is improved due to less dye migration to the tips);
- improved penetration in difficult fabrics (compared to pad-thermofix) due to the presence of humidity at high fabric temperatures;
- improved coverage of 'dead cotton' compared to pad-batch or exhaust dyeing;
- dyeing PES-viscose and PES-CO blends in a single bath .

#### Cross-media effects

None identified.

#### Technical considerations relevant to applicability

This process is limited to dyeing processes with defined reactive dyes and defined textures of the fabrics, not, for example, for high-grade dyeing of PES-CO working clothes (high-quality dyeing of polyester/cotton blends) [ 44, ÖKOPOL 2011 ].

#### Economics

No IR pre-dyer is needed, unless heavy fabric is being dyed. Nevertheless, the initial investment cost for new hot-flue dyer is around EUR 0.75 million, excluding the cost of an automatic dye kitchen [ 266, VITO 2001 ]. This investment cost, however, is compensated by savings in chemicals, energy, flexibility, higher productivity and environmental improvement (less emissions to air or waste water pollution to treat).

The lower chemicals costs arise from the avoidance of sodium silicate, sodium chloride and urea in the dyeing recipe. In many cases, the dye consumption is also reduced compared with the other processes such as pad-batch. This is illustrated in the example reported in Table 4.77 below.

**Table 4.77: Comparison between a conventional pad-batch process and the alternative technique applied to mercerised 100 % cotton twill, 300 g/m, 75 % pick-up**

	<b>Pad-batch/sodium silicate method</b>	<b>Alternative technique</b>	<b>Difference (%)</b>
Levafix Yellow CA	15.0 g/l	13.7 g/l	-8.7
Levafix Red CA	12.0 g/l	11.6 g/l	-3.3
Levafix Navy CA	10.4 g/l	10.1 g/l	-2.9
<b>Total dye</b>	<b>37.4 g/l</b>	<b>35.4 g/l</b>	<b>-5.3</b>
Urea	100 g/l	0 g/l	-100
Wetting agent	2 g/l	2 g/l	0
Sodium silicate 38 °Bè	50 ml/l	0 g/l	-100
Caustic soda 50 % <sup>(1)</sup>	14 ml/l	6 ml/l	-57
Sodium carbonate <sup>(1)</sup>	0 g/l	10 g/l	+100
<b>Total chemicals</b>	<b>166 g/l</b>	<b>18 g/l</b>	<b>-89</b>
Dwell time	12 hours	2 minutes	-99.7
<sup>(1)</sup> Differences in operation (depending on the selected dyes) may allow full substitution of caustic soda and sodium carbonate with sodium bicarbonate (lower alkalinity). Source: [ 183, Spain 2001 ]			

The increased productivity obtained by the elimination of long batch times produces significant savings in comparison to the traditional pad-batch process. Despite the much lower machinery costs for pad-batch equipment, this alternative process has shown to be more cost-effective in terms of total processing costs. Moreover, the demand for rapid response by the industry can be met more easily. Not having to wait until the next day to view shades means a much improved service and a faster delivery to the customer.

However, in Europe, this process has only been established where at the time of investment the size of orders justify a new large-scale plant investment [ 44, ÖKOPOL 2011 ].

#### **Driving force for implementation**

Minimised chemical consumption.

#### **Example plants**

Plants in Spain, Belgium (UCO Sportswear), Italy, Portugal, China, Türkiye, India, Pakistan and Korea are using this technique.

#### **Reference literature**

[ 44, ÖKOPOL 2011 ], [ 183, Spain 2001 ], [ 266, VITO 2001 ]

### **4.5.3 Dyeing of keratine (wool) fibres**

#### **4.5.3.1 Optimised reactive dyeing**

##### **Description**

Wool dyeing is carried out with reactive dyes without chromium mordant.

##### **Technical description**

Concerns associated with the use of sodium or potassium dichromate as mordant in wool dyeing with chrome dyes are already discussed in ‘oxidising agents’ in Section 2.7.8.1. Low-chrome dyeing techniques (see Section 4.5.3.1) allow a considerable improvement in the efficiency of this process, but they cannot avoid the presence of free chromium in the water effluent and in the sludge.

Furthermore, sodium and potassium dichromate are listed in Annex XIV to the REACH Regulation and the use of these substances is therefore subject to authorisation (see Section 2.7.4.2).

The use of chrome dyes was considered unavoidable for certain types of wool articles, in particular for dark shades, due to the excellent wet-fastness of these dyes. However, reactive dyestuffs have been put on the market that can provide levels of fastness comparable with those achievable with chrome dyes, even for dark shades [ 268, Huntsman 2019 ].

These colourants are bifunctional reactive dyestuffs generally containing bromo-acrylamide or vinyl sulphone reactive groups. The structure of a typical bifunctional reactive dyestuff of the bromo-acrylamide type is shown in Figure 4.47.

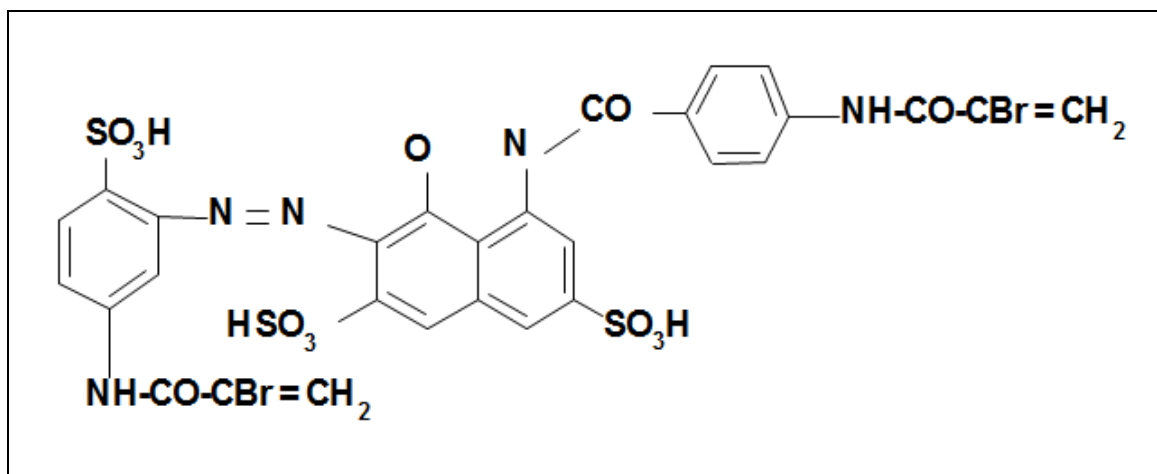


Figure 4.47: Structure of a typical bifunctional reactive dyestuff for wool of the bromo-acrylamide type

It should be noted that the formulated products also contain a variable amount of auxiliaries (e.g. anti-dusting agents) that are completely discharged with the exhausted liquor.

Thanks to the high fixation rate now achieved, the released dye only accounts for a minor amount of the total COD from dyeing, whereas the real contribution comes from the other constituents of the dye formulation and from the auxiliaries used in the process (e.g. levelling agents).

The general features of these reactive dyes, in comparison with chrome dyes, are reported in Table 4.78.

Table 4.78: Comparative analysis of the features of chrome dyes and reactive dyes for wool dyeing

	Chrome dyestuffs	Reactive dyestuffs
Fixation mechanism	Small acid dye molecule, which is complexed with chromium	Covalent chemical bond
Dye fixation rate	<ul style="list-style-type: none"> <li>Traditional chrome dyes: 83 %</li> <li>Optimised chrome dyes: &lt; 99 %</li> </ul>	Optimised reactive dyes: < 95 %
Formulation	Only one chromophore to yield black colour	Dye combination necessary to yield black colour
Levelling properties	Good levelling properties	Levelling properties depend on dyeing auxiliaries and combination reagents (levelling is difficult without assistance of auxiliaries)
Fastness properties	High standards of fastness	Fastness performance comparable with chrome dyes
Reproducibility	Shade matching difficult	Very good
Dyeing process	Two-step dyeing process (dyeing and chroming)	One-step dyeing process (but for dark shades an after-treatment is required)
Source: [ 5, UBA 2001 ], [ 269, VITO 2001 ]		

### Environmental performance and operational data

Emissions of Cr(VI) to water are reduced.

As far as waste water is concerned, the presence of chromium, not only in the chelated form, but more importantly as free metal, is avoided. In this respect, it has to be taken into account that dyehouses that do not use chrome dyes may still use metal-complex dyes. Nevertheless, in

metal-complex dyes the metal is present in the chelated form, which has less impact on the environment than the same amount of chromium released from afterchroming (see 'Heavy metals emissions' in Section 2.7.8.1).

Fastness properties can be very good and even comparable to those obtained with chrome dyes. However, the substitution of chrome dyes may not fulfil some product specifications. For example, if

- it is not possible to match the same shade;
- customers require the use of a specific class of dyestuffs.

Reactive dyestuffs described in this section are suitable for wool and polyamide in all make-ups and can be applied in all types of dyeing machines.

### **Cross-media effects**

#### Emission of colour to water

Reactive dyestuffs produce more highly coloured effluents than chrome dyes. This is attributable to the higher colour strength typical of these colourants. In quantitative terms, however, for the same level of colour the amount of dyestuff discharged may be comparable or even less than traditional dyes [ 32, Bettens L. 1999 ]. EU research shows that effective and economically viable routes (Enhanced Thermal Fenton ETF & Enhanced Photo Fenton reaction EPF) are available for destruction of the residual dyestuff [ 269, VITO 2001 ].

#### Emission of COD to water

The dyestuff itself, thanks to its relatively high fixation rate, makes only a minor contribution to the organic load in the final effluent. On the other hand, the organic load produced by the levelling agents added to the dye liquor is significant in the overall balance. These are fatty amine ethoxylates, which are poorly biodegradable and only 60-70 % bioeliminable. Since these compounds have affinity for the wool, it is estimated that 50 % of the amount applied will remain on the fibre, while the remaining 50 % will end up in the waste water or in the sludge (i.e. transferred to other media). Nevertheless, at a minimum application level of 1 % o.w.f. (10 g/kg fibre), 1.5 g/kg of COD from the levelling agent would still be released into the waste water (10 g/kg x 0.5 x 0.3 x 1 025 mg COD/g), unless free-radical destruction methods are applied.

Dyeing with a pH-controlled profile (starting in acidic conditions when reduced reaction occurs and shifting to alkaline pH as soon as the boiling temperature is reached, see Section 4.5.1.6) would allow optimum dye exhaustion with a lower environmental impact (no need for levelling agent). A pH buffer can be used as alkali spender, instead of neutralising the acid bath with alkali (which would give uneven results). However, these compounds also need to be assessed for their hazardousness and the possible formation of harmful products.

#### Emission of AOX to water

In the case of reactive dyes, the AOX found in the waste water is not the result of a haloform reaction and therefore it represents a much lower level of risk for the environment. Furthermore, AOX originating from reactive dyes is not persistent in the environment because of hydrolysis (see also Section 2.7.8.1).

Note also that most navy and black dyestuffs (shade range in which chrome dyes are most used) do not contain AOX at all [ 185, Germany 2001 ].

#### Water and energy consumption

When dyeing with reactive dyes, two rinsing steps at about 80 °C are normally carried out after dyeing, in order to remove the unfixed dye. This leads to higher consumption of water (approximately 30 % more [ 270, CRAB 2001 ]) and energy.



However, in most cases the after-clearing process can be carried out directly in the exhausted dye bath, thus saving water and energy (specific water consumption figures of about 25 l/kg are reported) [ 185, Germany 2001 ].

### Technical considerations relevant to applicability

Generally, there are no technical restrictions to the applicability of this technique.

### Economics

UBA states that costs are comparable with the chroming method when taking into account the overall process costs [ 5, UBA 2001 ].

According to CRAB, Italy, on the other hand, dyeing with reactive dyes is more expensive than with chrome dyes [ 270, CRAB 2001 ].

### Driving force for implementation

- REACH Regulation.
- Environmental legislation.

### Example plants

Plants from the data collection: CZ017, CZ020, IT070, IT071, IT072, IT078, IT082, IT089, IT090, IT092, IT096, IT097, PT098 and PT111.

### Reference literature

[ 5, UBA 2001 ], [ 32, Bettens L. 1999 ], [ 243, OSPAR 1994 ], [ 268, Huntsman 2019 ], [ 270, CRAB 2001 ], [ 271, Bettens L. 2000 ]

## 4.5.3.2 Optimised metal-complex dyeing of wool

### Description

Dyeing is carried out with metal-complex dyes under optimised conditions in terms of pH, auxiliaries and acid used, in order to increase the exhaustion of the dyeing liquor and the fixation of the dyes.

### Technical description

Dyeing of loose wool fibre and combed tops is still often carried out using afterchrome or metal-complex dyestuffs. Afterchrome dyestuffs can be substituted by metal-free reactive dyestuffs in many cases. However, when substitution is not possible, another alternative is to use metal-complex dyes under optimised conditions (especially pH control).

In the case of 1:2 metal complex dyestuffs (see Section 2.7.4), the dyeing process can be improved by:

- using a special auxiliary (mixture of different fatty alcohol ethoxylates with high affinity for the fibre and the dyestuff);
- replacing acetic acid with formic acid.

The optimised process is the '*Lanaset TOP process*', launched by a dyestuffs and textile auxiliaries supplier in 1992. The control of the pH and the application of a mixture of different fatty alcohol ethoxylates shorten the dyeing time drastically compared to the conventional process. In addition, the exhaustion rate is almost 100 %, which makes dyeing in a standing bath easier [ 5, UBA 2001 ].

In addition to environmental advantages, the process enables reproducible dyeings with very high fastness properties.

### Achieved environmental benefits

- Reduced emissions to water.
- Because of the higher exhaustion and fixation rate, the amount of dye in the exhausted liquor is reduced, which directly correlates with the lower chromium content of the effluent.

### Environmental performance and operational data

Residual chromium levels down to 0.1 mg/l have been reached in the exhausted dye bath in a laboratory test for a marine shade (i.e. a dark shade). Such low values were confirmed as achievable. However, concerning daily practice in companies, higher values of 1 mg/l are considered more realistic. Emission factors of 10-20 mg/kg of treated wool can therefore be achieved, which correspond to 1-2 mg/l of chromium in the spent dye bath when a 1:10 liquor ratio is used [158, Germany 2002]. Such low concentration levels open the way for dyeing in a standing bath without the negative effects arising from build-up of chromium.

The substitution of acetic acid (which has a specific COD of 1 067 mg O<sub>2</sub>/g) by formic acid (which has a specific COD of only 235 mg O<sub>2</sub>/g and is a stronger acid than acetic acid) contributes to lowering the COD load in the effluent.

An additional benefit is achieved due to the reduction of the dyeing cycle time. When applying this technique, the boiling time can be shortened to one third that of the conventional process, which saves energy as well as time.

Figure 4.48 shows the dyeing curve for the conventional process and the optimised process (Lanaset TOP process).

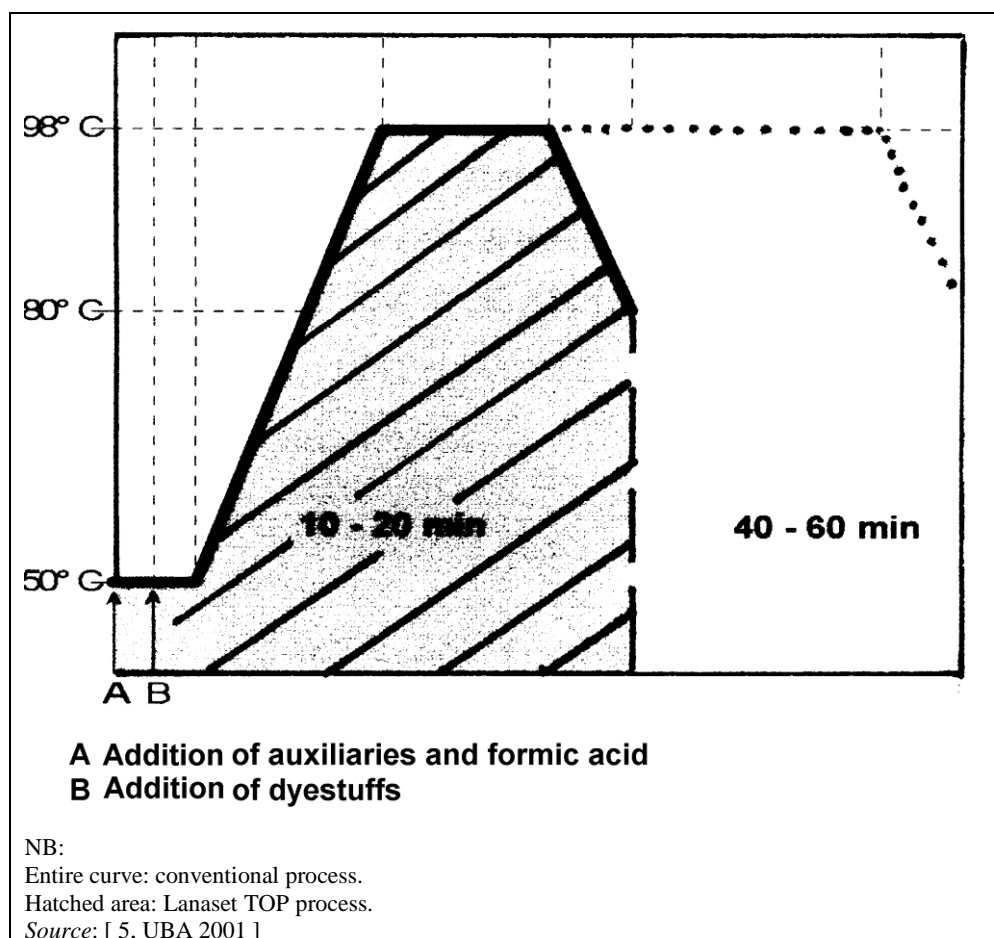


Figure 4.48: Dyeing of loose wool fibre and combed tops: comparison between the dyeing curve for the conventional process and the optimised process (Lanaset TOP process)

The technique is applicable in new and existing installations. It is mainly applied for dyeing loose wool fibre and combed tops, which still represent about half of the wool fibre processed annually.

### **Cross-media effects**

None identified.

### **Technical considerations relevant to applicability**

May not be applicable to very dark shades.

### **Economics**

Savings are achieved due to the shorter process time and lower amount of rinsing water.

### **Driving force for implementation**

- Environmental legislation.
- Productivity gains.

### **Example plants**

Plants from the data collection: AT005, BE011, CZ020, IT064, IT067, IT068, IT071, IT072, IT077, IT078, IT082, IT085, IT089, IT090, IT097 and UK121.

### **Reference literature**

[ 5, UBA 2001 ], [ 158, Germany 2002 ]

#### **4.5.3.3 Minimised used of chromates (low-chrome and ultra-low-chrome afterchroming methods for wool)**

##### **Description**

If chromium-free dyeing and metal-complex dyeing are not applicable, then chromium dyeing can be used, in which the use of sodium or potassium dichromates as mordant is authorised and dichromates are dosed as a function of the amount of dye taken up by the wool. Dyeing parameters (e.g. pH and temperature of the dyeing liquor) are optimised to ensure that the dyeing liquor is exhausted as much as possible

##### **Technical description**

Chrome dyeing of wool may still be used to obtain deep full shades at an economical price and with excellent fastness properties but in the EU sodium and potassium dichromate are classified as CMR (see Section 2.7.8.1) and the use of sodium or potassium dichromate for dyeing is subject to authorisation according to the REACH Regulation (see Section 2.7.4.2).<sup>4</sup> ]

The afterchrome method (see also Sections 2.7.4 and Section 8.2.6) is used for the application of chrome dyes, and chromium (as sodium or potassium dichromate) is the metal used as mordant. In the application of chrome dyes, inefficient chroming methods can lead to the discharge of chromium in spent dye liquors (see also ‘oxidising agents’ in Section 2.7.8.1).

In order to minimise the amount of residual chromium in the final effluent, much attention is given to the low-chrome (stoichiometric) and ultra-low- (substoichiometric) chrome dyeing techniques, where only the minimum amount of dichromate required to form the dye complex in the fibre is dosed.

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<sup>4</sup> At the time of writing this document (in 2021), only two applications for authorisations had been made [ 275, ECHA 2019 ]. It should be taken into account that when using chromates under authorisation operational conditions and risk management measures approved, as well as any other authorisation condition are mandatory.

The so-called *low-chrome* dyeing technology consists of the stoichiometric dosage of chrome (up to a maximum of 1.5 % o.w.f.) together with careful pH control (3.5-3.8) and addition of a reducing agent, which assists in the conversion of Cr(VI) to Cr(III) and promotes its exhaustion onto the fibre [ 273, VITO 2001 ].

By the use of low-chrome techniques it is possible to reduce residual Cr(III) in the spent chroming bath from about 200 mg/l (typical of the conventional process) to about 5 mg/l in practical mill conditions. Residual Cr(VI) is almost eliminated. In the laboratory, lower residual Cr(III) concentrations (about 1 mg/l) can be achieved but, although such results are reported in the literature, they are not regularly achievable in practice [ 273, VITO 2001 ].

*Ultra-low-chroming* techniques are applied to achieve even lower residual chromium levels or in particular cases when low-chroming techniques cannot guarantee residual chromium levels below 5 mg/l in the spent chroming bath (e.g. wool that has to be dyed in deep shades). Chrome is dosed substoichiometrically, based on the dye uptake of the fibre.

With ultra-low-chroming techniques additional measures are applied, compared to the low-chrome process, in order to ensure maximum exhaustion of the dye bath. If the dye bath exhaustion is incomplete before chroming, the residual dye in the liquor will be chromed and remain in the liquor, adding to the discharged chromium. By ensuring maximum dye exhaustion, contamination from this source can be reduced and this will also give maximum fastness performance. Dye bath exhaustion can be improved by ensuring that the dye bath pH is sufficiently low or by allowing the dye bath to cool to 80-90 °C at the end of the dyeing stage. Optimum results are obtained by draining the dye liquor and setting a fresh bath for chroming [ 273, VITO 2001 ].

#### **Achieved environmental benefits**

Reduction of chromium emissions to water, in comparison with the normal afterchroming method.

#### **Environmental performance and operational data**

First of all, as mentioned above, the use of sodium or potassium dichromate for dyeing is subject to authorisation according to the REACH Regulation.

An emission factor of 50 mg chromium per kg of wool treated is achieved, which corresponds to a chromium concentration of 5 mg/l in the spent chroming bath when a 1:10 liquor ratio is used [ 273, VITO 2001 ].

In order to ensure accurate dosing and minimum handling of hazardous chemicals by the operator, the application of the low-chroming or ultra-low-chroming techniques requires the use of an automated dosing and dispensing system for dichromate and dyes and for pH control. The required amount of dichromate is fed directly to the dyeing machine through pipework (no manual transfer, no human contact, no losses). The system is fitted with control devices for the volumetric control of the delivered quantities, which switch the entire system into emergency mode if normal operating parameters are breached [ 270, CRAB 2001 ].

In addition, special safety precautions are recommended for the storage of dichromate. The containers for the solution of sodium dichromate are stored within isolated bunded areas in order to contain potential spillage and avoid interaction with other chemicals (in case of spillage).

For maximum chroming efficiency, it is essential to eliminate from the chroming bath any chemicals that will inhibit the chromium/dye interaction. Two main classes of chemicals can have this effect. The first class includes all chemicals that can form soluble complexes with chromium, thereby holding the metal in solution in the bath and adding to the effluent load. Examples of such products are sequestering agents and polycarboxylic acids, such as citric acid.

The second class of compounds are those that inhibit the exhaustion of the dichromate anion; the most common example is the sulphate anion. The use of sodium sulphate and sulphuric acid are therefore generally avoided [ 273, VITO 2001 ].

Too low amounts of dichromate may adversely affect the required reproducibility of shades [ 185, Germany 2001 ].

### **Cross-media effects**

If a fresh bath is set for chroming, as required with the ultra-low-chroming technique, the additional water consumption has to be taken into account [ 185, Germany 2001 ].

In addition, this technique will still generate chromium emissions to water, even if lower than the normal afterchroming method.

### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

### **Economics**

The addition of reducing agents increases costs because of the longer dyeing cycles and the resulting reduced productivity [ 270, CRAB 2001 ]. The same is valid for the setting of a fresh bath for the chroming step, as required by the ultra-low-chroming techniques [ 185, Germany 2001 ].

### **Driving force for implementation**

- Environmental legislation.
- Chemical legislation (e.g. REACH).

### **Example plants**

Plants from the data collection: IT067, IT071, IT072, IT085, IT089 and IT090.

### **Reference literature**

[ 5, UBA 2001 ], [ 185, Germany 2001 ], [ 243, OSPAR 1994 ], [ 270, CRAB 2001 ], [ 273, VITO 2001 ], [ 275, ECHA 2019 ]

## **4.5.3.4 Use of liposomes in acid dyeing of wool**

### **Description**

Dyeing with acid dyes is carried out using liposomes as auxiliaries, which increases the exhaustion rate.

### **Technical description**

The use of liposomes as auxiliary products in wool dyeing with acid dyestuffs allows good dye bath exhaustion at 80 °C and in 40 minutes. The advantages are:

- lower superficial damage of the wool fibre (due to the lower operating temperature the hand feel (handle) of the fabric is softer);
- energy savings;
- no electrolyte use;
- lower COD load in the waste water.

With wool/polyester mixtures, in order to allow the diffusion of disperse dye into the polyester fibre, it is necessary to operate at higher temperatures (100 °C), and to add a low concentration of carriers. Liposomes have the effect of increasing the diffusion of disperse dyestuffs into the wool fibre (see Section 2.7.7). It is therefore important to carry out selection tests of the suitable disperse dyestuffs in order to avoid negative effects on the fastness properties of the dyed product.

**Achieved environmental benefits**

- Energy savings.
- Lower COD load in the waste water.
- Lower conductivity of the waste water.

**Environmental performance and operational data**

Wool dyeing with acid dyes in the presence of liposomes is carried out at 80 °C for 40 minutes, in a bath containing [ 225, Spain 2002 ]:

- liposome 0.1-0.2 % o.f.w.;
- formic acid;
- acid dyestuff.

**Cross-media effects**

None identified.

**Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

**Economics**

Energy savings and better quality of the fabric compensate for the cost of the liposomes [ 225, Spain 2002 ].

**Driving force for implementation**

Improved product quality.

**Example plants**

Two plants in the Barcelona region are reported to have implemented this technique [ 225, Spain 2002 ].

**Reference literature**

[ 183, Spain 2001 ], [ 225, Spain 2002 ]

**4.5.4 Dyeing of synthetic fibres****4.5.4.1 Use of no or environmentally friendly dyestuff carriers in batch dyeing****Description**

Batch dyeing of polyester and wool-free polyester blends is carried out at high temperature (e.g. 130 °C) without the use of dyestuff carriers. Batch dyeing of wool-polyester blends is carried out with chlorine-free readily biodegradable and bioeliminable carriers.

**Technical description**

Due to the high glass transition point of polyethyleneterephthalate, which is in the range of 80-100 °C, the diffusion rate of disperse dyestuff molecules into the standard PES fibres (PET-based) at normal dyeing temperatures is very low. As a result, dyeing conditions typically used for other types of substrates are not applicable. Exhaust dyeing of single polyester and polyester blends can be carried out either in autoclaves at high temperature (HT dyeing at 130 °C, which is usually applied for pure PES and wool-free PES blends) or at normal dyeing temperatures (95-100 °C, which is applied for PES-WO blends) with the help of so-called carriers (see also Sections 2.1.1.1, 2.7.6.2, 2.7.7 and 8.1.6.7).

Yarn dyeing of polyester and polyester-elastane blends at 120°C up to dark shades has recently become possible [ 276, CHT 2020 ].

Carriers are absorbed to a great extent onto the PES fibre. They improve fibre swelling and encourage colourant migration. In dyeing and rinsing, a significant amount of carriers is emitted to waste water. The fraction that remains on the fibre may be emitted to air during subsequent drying, heat-setting and ironing.

Active substances used in historical carrier formulations included:

- chlorinated aromatic compounds (mono-chlorobenzene, trichlorobenzenes, etc.);
- o-phenylphenol;
- biphenyl and other aromatic hydrocarbons (trimethylbenzene, 1-methylnaphthalene, etc.);
- phthalates (diethylhexylphthalate, dibutylphthalate, dimethyl phthalate).

Human and aquatic toxicity, high volatility and high odour intensity are the main concerns associated with the use of the above-mentioned substances (see also Section 2.7.8.1) and some phthalates are listed in Annex XIV and/or Annex XVII to the REACH Regulation [ 7, EU 2006 ].

Not only do water and air become contaminated by the emissions, but it is increasingly suspected that consumer health problems can be caused by remobilisation of halogenated carriers (e.g. 1,2,4-trichlorobenzene which is listed under entry 49 in Annex XVII to the REACH Regulation) in the treated textiles [ 7, EU 2006 ], [ 19, Jacobs et al. 1998 ].

The application of HT dyeing processes avoids the use of carriers. This technique is currently widely applied when dyeing pure polyester and wool-free PES blends.

However, due to the sensitivity of the wool substrate to high temperatures, it is still necessary to use carriers when dyeing polyester blends and, in particular, polyester/wool blends. In these cases, hazardous carriers have been replaced by chlorine-free substances with improved toxicological and environmental characteristics. These carriers are based on:

- benzylbenzoate;
- aromatic carboxylic acid esters [ 44, ÖKOPOL 2011 ].

### **Achieved environmental benefits**

Emissions to water are reduced.

In the case of HT dyeing processes, the waste water and off-gas are carrier-free. The quantity of environmentally problematic substances is reduced.

In the case of chlorine-free carriers, the emissions to air and to water are reduced.

### **Environmental performance and operational data**

PES/WO blends may be dyed with benzylbenzoate-based carriers; benzylbenzoate is a readily biodegradable substance (the degree of mineralisation for the benzylbenzoate is 79 % [ 5, UBA 2001 ]). Moreover, because of their low volatility, odour nuisance (especially in the workplace) is negligible.

Both substances show great affinity for the aqueous medium, which makes them easy to prepare (without the need for emulsifying and dispersing agents) and easy to remove at the end of the dyeing process (with lower water consumption).

In the case of benzylbenzoate carriers, applied concentrations range between 2 g/l and 4 g/l (dyeing at boiling temperature; average liquor ratio) [ 5, UBA 2001 ], [ 44, ÖKOPOL 2011 ].

Application of HT dyeing to PES blends depends on the sensitivity to high temperature of the fibres in the blend, being particularly critical for PES/WO blends.

**Cross-media effects**

When dyeing in HT conditions a higher quantity of oligomers tends to migrate to the surface of the fibre.

Dyeing at high temperature also requires higher energy consumption. The balance between the different effects involved (the effects of the hazardous carriers on the environment and the effects of higher energy consumption) is, however, still largely in favour of the application of this technique [ 5, UBA 2001 ].

Benzylbenzoate-based carriers are less effective than conventional carriers. They have a reduced penetrating and swelling effect. As a result, a longer residence time and higher amounts (about three times as much as conventional carriers) are needed to achieve the same effect.

**Technical considerations relevant to applicability**

Dyeing with optimised carriers is applicable to all PES blends.

Generally, there are no technical restrictions to the applicability of this technique.

**Economics**

Optimised carriers described in this section cost approximately the same as common carriers [ 5, UBA 2001 ].

**Driving force for implementation**

- Environmental legislation.
- REACH Regulation.
- Workers' health and safety.

**Example plants**

A total of 47 plants from the data collection apply this technique.

**Reference literature**

[ 5, UBA 2001 ], [ 7, EU 2006 ], [ 19, Jacobs et al. 1998 ], [ 32, Bettens L. 1999 ], [ 44, ÖKOPOL 2011 ], [ 271, Bettens L. 2000 ], [ 276, CHT 2020 ]

**4.5.4.2 Optimised desorption of unfixed dye in batch dyeing****Description**

Optimised desorption of unfixed dye in batch dyeing of PES and its blends with cellulosic fibres (PES-CO) is achieved by:

- using a desorption accelerator based on carboxylic acid derivatives;
- using a reducing agent that can be used in the acidic conditions of the spent dyeing liquor;
- using disperse dyes that can be desorbed in alkaline conditions by hydrolysis instead of reduction.

**Technical description**

Conventional discontinuous dyeing processes for PES-CO blends with disperse and reactive dyestuffs are carried out in two baths. Optimised auxiliaries based on carboxylic acid derivatives are used as desorption accelerator for clearing. The fastness of the PES fraction and its blends will be optimised effectively by the withdrawal of unfixed dyestuff.

The use of these new auxiliaries allows some processing steps to be avoided as shown in Table 4.79 below.



Table 4.79: Comparison of dyeing sequences with and without optimised desorption accelerator

Conventional two-bath treatment	Two-bath treatment with the optimised desorption accelerator, without intermediate clearing for dark shades	One-bath treatment with the optimised desorption accelerator (for medium and dark shades)
Disperse dyeing of PES Intermediate clearing, often alkaline reduction Rinsing and neutralisation Reactive dyeing of CO Rinsing/soaping process Optional: cationic after-treatment of CO	Disperse dyeing of PES Reactive dyeing of CO <sup>(1)</sup> Rinsing (and neutralisation if needed) Soaping with optimised desorption accelerator Rinsing Optional: cationic after-treatment of CO	High-temperature dyeing of PES and CO in one bath Rinsing Soaping with optimised desorption accelerator Rinsing
<sup>(1)</sup> Recommendation for reactive dyeings: 40 °C or 60 °C. Source: [ 44, ÖKOPOL 2011 ]		

A major problem in the dyeing of PES fibres and PES blends using disperse dyestuffs is wash fastness. In order to meet washing fastness requirements, an after-treatment step is carried out, which removes the non-fixed disperse dyes from the fibre. Reductive after-clearing is normally preferred over simple washing with surfactants because disperse dyestuff molecules absorbed on the surface are broken down into smaller, often colourless and more readily water-soluble fragments (see Section 2.7.6.2). The precondition is that no dyestuffs susceptible to reduction have been used for dyeing.

In the conventional process, after dyeing the polyester at 130 °C, the dye bath (acidic) needs to be cooled down to 70 °C before draining, in order to bring the fibre below its glass transition temperature. The reductive after-treatment is carried out in a new bath using hydrosulphite and a dispersing agent in alkaline conditions (the temperature is raised again to 80 °C during the process). Afterwards, the bath is drained and one or two more rinsing steps are needed in order to remove the remaining alkali and reducing agent. The pH of the textile before entering the steamer needs to be between 4 and 7 in order to avoid yellowing. Rinsing is therefore carried out in acidic conditions.

Besides the environmental concerns involved with the use of hydrosulphite as a reducing agent (see Section 2.7.8.1), this process entails three bath changes (including temperature raising/cooling cycles) and two changes in the pH of the treatment baths: from the acidic pH of the dyeing liquor to the high alkalinity of the after-treatment bath and back again to acidic levels in the rinsing baths. The double change produces higher consumption of water, energy and chemicals, greater demands on time and increased levels of salt in the effluent.

Two different alternative options are possible:

- Using a reducing agent based on a special short-chain sulphinic acid derivative that can be added directly in the exhausted acidic dye bath  
This reducing agent is liquid and can therefore be metered automatically. Moreover, it has very low toxicity and is readily biodegradable [ 5, UBA 2001 ], [ 269, VITO 2001 ].
- Using disperse dyes that can be cleared in an alkaline medium by hydrolytic solubilisation instead of reduction  
These are azo disperse dyes containing phthalimide groups [ 277, VITO 2001 ]. However, phthalimide groups are not stable to hydrolysis and are not the preferred solution [ 44, ÖKOPOL 2011 ].

### Achieved environmental benefits

- Reduction of water and energy consumption.
- Reduction of emissions to water.
- Reduction of the amount of waste water generated.

### Environmental performance and operational data

The reduction of processing steps results in savings of three to five baths, which correspond to water savings of approximately 45-75 l water/kg of fabric [ 44, ÖKOPOL 2011 ]. This technique is used in discontinuous HT processes.

#### Option a)

First of all, because this reducing agent can be applied in the acidic pH range, significant water and energy savings can be achieved. Compared to the conventional process, water savings of up to 40 % can be-achieved.

Moreover, these aliphatic short-chain sulphinic acid derivatives are readily biodegradable (the product is non-volatile and water-soluble, with more than 70 % DOC reduction within 28 days, under the OECD test 302B). The sulphur content of the product is approximately 14 %, compared to 34 % with sodium dithionite and the amount of by-products (sulphites and sulphates) can be reduced by half in comparison with the conventional process (see Table 4.80 below).

It is also worth noting that, unlike sodium dithionite, the product is non-corrosive, non-irritant, non-flammable and does not have an unpleasant odour. As a result, workplace safety compared to with sodium dithionite is improved and odour nuisances minimised.

**Table 4.80: Sulphur and sulphite concentration and load in the mixed effluent from typical processes using sodium-dithionite- or sulphinic-acid-based reducing agents**

Recipe	Sulphur concentration in mixed effluent <sup>(1)</sup> (mg/l)	Specific sulphur load <sup>(2)</sup> (mg/kg PES)	Maximal sulphite concentration in mixed effluent <sup>(1)</sup> (mg/l)	Maximal specific sulphite load <sup>(2)</sup> (mg/kg PES)
Sodium dithionite (3 g/l) 2 rinsing baths	260	4 100	640	10 300
Sulphinic acid (3 g/l) 2 rinsing baths	100	1 700	130	2 000
Sulphinic acid (3 g/l) 1 rinsing bath	200	1 700	260	2 000

<sup>(1)</sup> Mixed effluent: sum of the exhausted dye bath, the clearing bath and the number of rinsing baths.  
<sup>(2)</sup> Data are calculated assuming a liquor ratio of 1:4.  
Source: [ 5, UBA 2001 ]

In most cases, concentrated hydrosulphite can be replaced by the same quantity of the optimised reducing agent. In a typical process, 1.0-1.5 ml/l reducing agent (for medium shades) and 1.5-2.5 ml/l (for dark shades) are added to the exhausted dye bath. The process is carried out for 10-20 minutes at 70-80 °C. Hot and cold rinsing follow [ 5, UBA 2001 ].

In order to derive the maximum environmental and economic benefit from the technique, it is important that only the strict amount of reducing agent needed to reduce the dyestuff is used. Consumption of the reducing agent by the oxygen in the machine is therefore avoided as much as possible. One effective technique to ensure this is to use nitrogen to remove oxygen from the liquor and the air in the machine [ 277, VITO 2001 ].

For some types of polyesters that show a higher percentage of oligomer migrating to the surface during the dyeing process, it is advantageous to carry out the after-treatment in a fresh bath.

The technique can be used in all types of dyeing machines, not only for polyester fibres, but also for PAC, CA and their blends.

Option b)

With alkali-dischargeable dyes the use of hydrosulphite or other reducing agents can be avoided, which means a lower oxygen demand in the final effluent.

There is the possibility of dyeing PES-CO blends using a one-bath two-step dyeing method, as alkali-clearable dyes can be applied in the same bath with cotton-reactive dyes. This brings about additional environmental benefits in terms of water and energy consumption.

Table 4.81 below gives a comparison between two equivalent recipes, one with alkali-clearable dyes and the other with standard disperse dyes.

**Table 4.81: Recipe with alkali-clearable dyes and recipe with standard dyes**

Recipe with alkali-clearable dyes	Recipe with standard dyes
Dye 40 g/kg pH stabiliser 25 g/kg Equalisation agent 10 g/kg	Dye 55 g/kg Acetic acid 25 g/kg Equalisation agent 10 g/kg Levelling agent 5 g/kg Dispersing agent 12 g/kg Detergent 12 g/kg
<i>Source: [ 277, VITO 2001 ].</i>	

With alkali-clearable disperse dyes, there is no need for levelling agents, dispersing agents or detergent. Moreover the amount of dye used is reduced.

Alkali-clearable dyes are currently applied for both for PES and PES-CO blends, with greater environmental and economic advantages being achieved with PES-CO blends.

**Cross-media effects**

Option a)

When the product is used in the dye bath, the unfixed dispersed dye particles are destroyed by reduction so the effluent is largely free of colour. On the other hand, the by-products of the reductive reaction may be more hazardous than the original dyestuff (e.g. aromatic amines originating from reduction of azo dyes). The effluent therefore needs to be treated before being discharged (for polyester oligomers and aromatic amines).

Moreover, low temperatures and acidic conditions result in oligomer deposition on the fabric, batching tanks, and parts of the machines [ 44, ÖKOPOL 2011 ].

Option b)

None identified.

**Technical considerations relevant to applicability**

Option a)

The use of reducing agent in acidic conditions may not be applicable to polyester-elastane blends.

Application of sulphinic acid in the case of PAN is difficult because the operational temperature is close to the glass transition point [ 44, ÖKOPOL 2011 ].

Furthermore, complete substitution of sodium dithionite is technically not possible. For aftercleaning of PES, pre-cleaning with sodium dithionite or a mixture of sodium dithionite with substitutes is essential [ 44, ÖKOPOL 2011 ].

Option b)

The use of dyes desorbable in alkaline conditions may be restricted by product specifications as the dyes do not cover all shades.

In addition, the technique may not be applicable for disperse dyes with very high fastness requirements. In this case (e.g. for dyes specially developed for the automotive industry), the application is carried out in the conventional acidic medium.

[ 44, ÖKOPOL 2011 ]

### **Economics**

Shorter processing time and savings in water and energy consumption are the main economic advantages achieved.

Option a)

Products based on sulphinic acid are considerably more expensive. However, savings can be achieved as a result of higher productivity, reduced consumption of energy, water and chemicals and the lower burden in the waste water [ 5, UBA 2001 ], [ 44, ÖKOPOL 2011 ].

Option b)

The use of alkali-clearable dyes implies higher recipe costs compared to conventional disperse dyestuffs (about twice as much: the total cost of a recipe with alkali-clearable dye is about EUR 0.5/kg, whereas with standard disperse dyes this is in the order of EUR 0.2/kg). However, option b is expected to bring savings in time (higher productivity) and to reduce water, energy and chemical costs (particularly when these dyes are applied for PES-CO blends).

### **Driving force for implementation**

- Savings in energy and water consumption.
- Higher productivity and product quality.
- Environmental legislation.

### **Example plants**

A total of 19 plants from the data collection reported using one of the two options mentioned above.

Multiple plants in Germany use desorption accelerators based on carboxylic acid derivatives.

Option a)

The proposed technique is applied in at least five finishing mills in Germany and worldwide as well [ 5, UBA 2001 ].

It is also applied in Plant IT091.

Option b)

Many plants in Europe.

### **Reference literature**

[ 5, UBA 2001 ], [ 44, ÖKOPOL 2011 ], [ 225, Spain 2002 ], [ 269, VITO 2001 ], [ 271, Bettens L. 2000 ], [ 277, VITO 2001 ]

#### 4.5.4.3 Supercritical CO<sub>2</sub> disperse dyeing of synthetic fibre

##### **Description**

Supercritical CO<sub>2</sub> is used as a dyeing medium instead of water in a closed-loop process to transport disperse dye into the polyester fibres

##### **Technical description**

The technique uses pressurised CO<sub>2</sub> in a supercritical (SC-CO<sub>2</sub>) fluid stage, a phase with characteristics between a liquid and a gas. In this state CO<sub>2</sub> has a very high solvent power, allowing the dye to dissolve easily. The dyes are transported easily and deeply into fibres thanks to the high permeability of CO<sub>2</sub>.

The CO<sub>2</sub>, which takes on liquid-like properties, is contained in stainless steel chambers. After the dyeing cycle, the CO<sub>2</sub> becomes gasified and dye within the cotton fibres condenses as it separates from the gas. The CO<sub>2</sub> is then recycled, pressurised and pumped back into the dyeing vessel.

##### **Achieved environmental benefits**

No water or chemicals are required; therefore no water effluents are generated. The CO<sub>2</sub> used can be a by-product (waste gas) reclaimed from existing industrial processes; it is used in a closed-loop system with a 95 % recycling rate.

Moreover, emissions to water are reduced.

##### **Environmental performance and operational data**

Lower loads of auxiliary chemicals and additives: SC-CO<sub>2</sub> dyeing does not need additional chemicals to dissolve dyes. This technology uses pure dyes (preparations with 100 % dye) and with more than 98 % uptake. Energy consumption is 20-50 % lower compared to other water-based dyeing. Dyeing times are shortened due to the high dye diffusivity resulting in high extraction rates.

Dyeing of polyester and polypropylene fibres with SC-CO<sub>2</sub> is performed under isothermal and isobaric conditions.

Safety risks caused by the use of CO<sub>2</sub> under high pressure need to be considered.

##### **Cross-media effects**

None identified.

##### **Technical considerations relevant to applicability**

The technique is generally applicable to synthetic fibres, currently used mainly for polyester fibres (e.g. PET, PTT) and its blends with synthetic fibres (e.g. polypropylene). It is only applicable to new plants or major plant upgrades.

SC-CO<sub>2</sub> dyeing on a laboratory scale has been successfully applied to polypropylene and polyamide fibres.

Natural fibres such as cotton and wool can be damaged undergoing a similar process. SC-CO<sub>2</sub> dyeing of polar fibres like cotton and wool are problematic due to the polarity of the dyestuff used in the dyeing of these fibres.

##### **Economics**

Investment in such equipment is costly (high investment but relatively low operating costs). SC-CO<sub>2</sub> dyeing reduces operational costs to 20 % in comparison with water-based dyeing. SC-CO<sub>2</sub> dyeing utilises pure dyes and their cost ranges from USD 0.76 to USD 1.37 per kg of dyed PES

fabric, lower than the costs of dyes for traditional water-based dyeing. Other reasons for the lower costs per kg of dyed fabric include the shorter dyeing time (almost halved in comparison with water-based dyeing technologies) and the absence of chemicals, for instance dispersing agents, levelling agents and carrier agents.

**Driving force for implementation**

SC-CO<sub>2</sub> dyeing eliminates the need for water, reduces the energy demand and reduces CO<sub>2</sub> emissions. Short batch cycles, efficient dye use and no waste water treatment all contribute to significantly reduced operating costs.

**Example plants**

An Adidas supplier in Thailand (Yeh Group) and a plant in Taiwan (Far Eastern New Century Corp.) apply this technique. Both are dyeing 100 % polyester (polyethylene terephthalate – PET) at a pressure of 250 bar and a temperature of 120 °C.

**Reference literature**

[ 35, RICARDO 2019 ], [ 278, Gashti et al. 2011 ], [ 279, Liao et al. 2012 ], [ 280, DyeCoo 2019 ], [ 281, Schumacher C. 2016 ]

## 4.6 Printing

### 4.6.1 General techniques

#### 4.6.1.1 Reduction of water consumption in cleaning of printing equipment

##### Description

There are several ways of reducing water consumption when cleaning the equipment used with the printing machine (e.g. screens, buckets and the print paste feed system):

- automatic start/stop control of cleaning water supply (for cleaning the printing belt);
- mechanical removal of printing paste;
- reuse and recycling of the cleanest part of the rinsing water from the cleaning of the squeegees, screens and buckets;
- reuse and recycling of the rinsing water from the cleaning of the printing belt.

##### Technical description

- Automatic start/stop control of cleaning water supply (for cleaning of the printing belt)  
In many cases, water dosage for the cleaning of the printing belt continues when the fabric and therefore the printing belt are stopped for whatever reason. Start/stop control of the water dosage can be automatically connected to the start/stop control of the printing belt.
- Mechanical removal of printing paste  
Large amounts of water for cleaning of squeegees, screens and buckets are used within the print house. Improved printing paste removal before flushing this equipment reduces the amount of water needed for flushing. Physical devices for removal of dye from buckets are available (e.g. scrapers). Modern printing machines have a built-in system for removal of residual printing paste from pipes and hoses with compressed air [ 44, ÖKOPOL 2011 ].
- Reuse and recycling of the cleanest part of the rinsing water from the cleaning of the squeegees, screens and buckets  
Typically, the first half of the effluent from the washing equipment is heavily loaded with printing paste and is discharged as waste water. The water used for this first stage does not, however, need to be of a high quality, which means that recycled water can be used. In the second half of the washing process, clean water is used, but the effluent can be collected for reuse, potentially as first rinsing water in the next cycle.
- Reuse and recycling of the rinsing water from the cleaning of the printing belt  
The rinsing water from the cleaning of the printing belt is only slightly coloured and contains small amounts of fibres (depending on the fabric) and very small amounts of glue. The rinsing water can be mechanically filtered, collected in an overflow vessel and reused for the same purpose if minor amounts of fresh water are added to the recycling system.

##### Achieved environmental benefits

The environmental benefit is a reduction in water consumption and waste water generation.

##### Environmental performance and operational data

In a Danish pigment print house, the implementation of all the above options has reduced the annual consumption of water by approximately 25 000 m<sup>3</sup> (55 % reduction). For option a alone, the savings are estimated at approximately 2 m<sup>3</sup> for every hour the printing machine is stopped and the water dosage for cleaning of the printing belt is still running for whatever reason. For option c, 50 % of the water can be reused. For option d, approximately 70 % of the water can be recycled [ 157, Danish EPA 2001 ].

**Cross-media effects**

None identified.

**Technical considerations relevant to applicability**

All of the above options can be implemented in all types of textile companies involving a printing section: new or existing, large or small. Space availability is a minor factor: the company only needs space for collection tanks (options c and d). However, older printing machines can probably not be retrofitted with a device for mechanical removal of the residual printing paste from pipes and hoses in the printing machine as suggested in option b [ 157, Danish EPA 2001 ] (see Section 4.6.1.6).

**Economics**

In the Danish case mentioned above, the total capital costs (tanks, mechanical filters, pumps and pipes) for all options are estimated at approximately DKK 100 000 (EUR 13 500). Options c and d together amount to approximately DKK 95 000 (EUR 12 825). Option a costs approximately DKK 5 000 (EUR 675) and the cost of option b is negligible. Changes in operating costs (before and after implementation) for all options are negligible. The costs for fresh water and waste water discharge are DKK 9 and DKK 18 per m<sup>3</sup> respectively (EUR 1.2 and EUR 2.43 per m<sup>3</sup>). Hence the total annual savings are approximately DKK 67 5000 (EUR 90 000). For the case study considered here, the payback time for all options together is estimated at about 2 months [ 157, Danish EPA 2001 ].

**Driving force for implementation**

The high costs of waste water discharge and, in some countries, of fresh water are the main driving forces for implementing the measures described.

**Example plants**

Plants from the data collection: BE009, DE032, IT063, PT099 and UK127.

**Reference literature**

[ 44, ÖKOPOL 2011 ], [ 157, Danish EPA 2001 ]

**4.6.1.2 Digital jet printing of carpet and bulky fabric****Description**

Computer-controlled contact-free injection of dye into carpet and bulky fabric.

**Technical description**

The principles of jet printing and the latest developments in this technique are described in Section 2.8.2.

Jet printing is a fully digital technique (right from the design stage to industrial production). The designer makes the sample on the computer and from this digital information the sample can be exactly reproduced on an industrial scale without the need for corrective adaptation/measures.

**Achieved environmental benefits**

Resource efficiency.

**Environmental performance and operational data**

In digital jet printing, selected trichromatic dyes are dosed on-line, based on computed requirements. The colour is applied on demand. This avoids dye losses or printing paste residues at the end of the process, which represents a significant change from conventional printing methods (flat-screen and rotary screen).



Another big advantage of this technique is that the amount of thickeners can be reduced depending on the type of substrate because the dye is shot directly deep into the face of the fabric.

Further environmental advantages are [ 28, GuT 2001 ]:

- reduced water consumption (only 20 % compared with conventional printing);
- less trial-and-error sampling (one of the most important sources of pollution, often forgotten in evaluations);
- the printing process can be carried out in the final stage of the manufacturing chain (reduction of material losses, particularly of coloured fabric).

### **Cross-media effects**

Compared to analogue printing techniques, no negative cross-media effects have been identified.

However, it is important to point out that the substrate must still undergo fixation and after-washing. Therefore emissions to water cannot be completely avoided.

### **Technical considerations relevant to applicability**

This technique is only applicable to new plants or major plant upgrades.

Digital jet printing can be applied to carpet and bulky fabrics. It is also applicable for patterning runners, mats and tiles, in which case the operation is done at the end of the process on the ready-made product (which does not need to be washed afterwards).

There is still room for developments in [ 28, GuT 2001 ]:

- increasing productivity;
- wider application (uneven pile density, pile height, blends, unfixed structure);
- reducing investment costs;
- expanding the dye range to cover more, if not all, shades and depths.

### **Economics**

The relatively high investment cost (no precise information given) of this sophisticated equipment makes this technique more appropriate for large-volume print houses. Nevertheless, digitally controlled printing and processing offers several economic advantages. First of all, this technique allows the flexibility necessary to satisfy customer and retailer demands with just-in-time delivery (quick reaction to customers' orders, alterations easily made). Equally, the storage of finished goods becomes unnecessary as goods are produced to order. As designs are stored in an electronic format there is no need for a large screen storage facility [ 28, GuT 2001 ].

### **Example plants**

Plant BE009.

### **Reference literature**

[ 28, GuT 2001 ]

#### **4.6.1.3 Ink-jet digital printing for flat fabric**

##### **Description**

Computer-controlled contact-free application of dye on the surface of flat fabric.

##### **Technical description**

Ink-jet digital printing (see Section 2.8.2) is increasingly used for light fabrics such as those that are typically printed in the textile finishing sector, and is now widely used. The dye can be

applied on the fabric directly, or indirectly where the dye is first applied on an intermediate carrier (such as paper) and then transferred to the fabric.

Production velocities for ink-jet printing of flat fabrics and knitwear increased enormously between the years 2000 and 2010 and fabrics may be printed at a speed of up to 480 m<sup>2</sup>/h.

Via piezo-printheads a quality corresponding to 720 dpi can be achieved, resulting in the design of realistic photo motives.

Normally, the printing equipment consists of a fabric feeder printer and hot air jet stenter. The process runs automatically. Pretreated standard fabrics are fed to the capsuled head of the machine via a printing blanket. Humidity and temperature are controlled in the printing room. At first, the printed fabric is dried by hot air (80-120 °C). The energy is supplied to the dryers in the form of electricity (for small equipment), steam or gas. Subsequently, the fabric is rolled up for further treatments like the standard processes' fixation (PES: superheated steam, temperatures between 170°C and 180°C; CO, CV, SE: saturated steam, 102 °C), washing and finishing. Before refeeding, the printing blanket is cleaned automatically.

Substrate pretreatment is necessary because the printing inks contain only the highly purified dyestuff. For printing of cotton, viscose and silk, the impregnation for reaction as well as for the improvement of colour intensity is based on urea and sodium bicarbonate plus thickeners (e.g. alginate) to improve the contour definition. The corresponding pretreatment for PES fabrics is just performed with additional thickeners for increasing the dye adhesion as well as the contour definition. The fabric surface needs to be very smooth to avoid contact between the fabric and the printhead [ 44, ÖKOPOL 2011 ].

A suitable set of dyes with affinity for the fabric is required such as acid, reactive and disperse dyes. Pigment formulations are also available but their part in classical textile printing is marginal. Pigment inks are mainly used for adjusted printing on T-shirts.

The most important segment for reactive and acid inks is sophisticated articles of cotton, silk, polyamide, and blends with elastane. Disperse inks are mainly used for flags and banners as well as popular promotional items and sophisticated synthetic fibre articles, preferably PES [ 44, ÖKOPOL 2011 ].

The cleaning of the printheads is done automatically with a rubber wiper moistened with distilled water.

#### **Achieved environmental benefits**

Dye residues are minimised to small amounts the cartridge. There are no printing paste residues and no printing paste preparation tanks to be cleaned at the end of each run. The environmental advantage over conventional analogue printing techniques is noticeable when processing small lots, when the printing paste losses are particularly high for analogue machines.

Water consumption for cleaning the printing blanket is low. Emissions to water are low too due to the relatively small amount of dye uptake on the surface.

In pigment printing, the digital technique is even more advantageous because no after-washing is needed.

#### **Environmental performance and operational data**

The speed of commercial ink-jet textile printing machines could be in the range of 30 m<sup>2</sup> to 480 m<sup>2</sup> of fabric per hour, and more specifically: [ 44, ÖKOPOL 2011 ]

- 360 x 540 dpi 1-pass, bi-directional 480 m<sup>2</sup>/h;
- 360 x 360 dpi 2-pass, bi-directional 360 m<sup>2</sup>/h;
- 360 x 360 dpi 4-pass, bi-directional 160 m<sup>2</sup>/h;

- 720 x 720 dpi 2-pass, bi-directional 180 m<sup>2</sup>/h.

According to EURATEX the actual printing speed on the industrial scale may be lower [ 282, Kohla M. 2021 ].

The speed is halved by unidirectional printing. Printing widths up to 320 cm are possible.

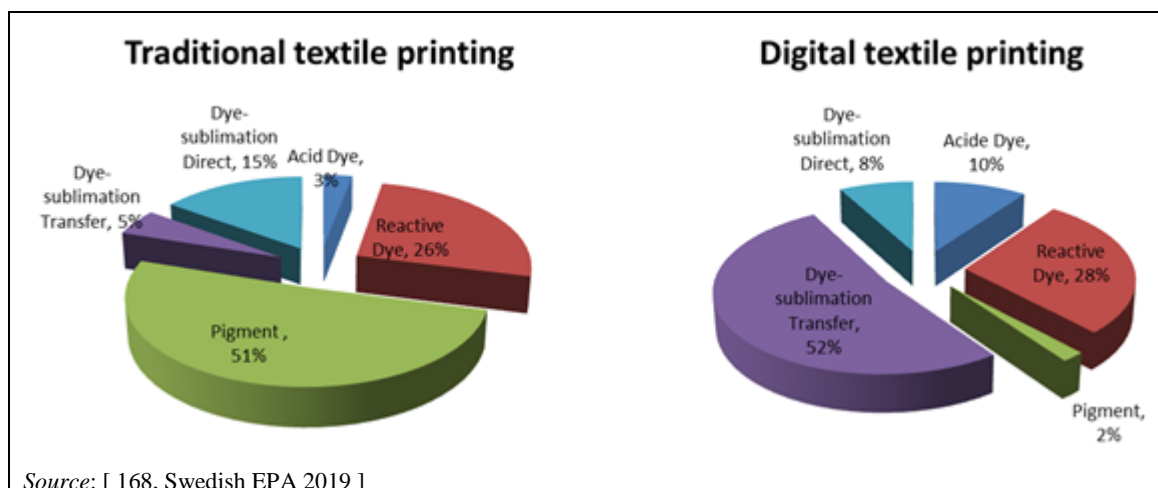
The energy consumption is around 15-17 kW. Dye uptake depends on the absorptive capacity of the fabric. For instance:

- reactive dyes on CO: 18 g/m<sup>2</sup>;
- disperse dyes in sublimation printing: 10-12 g/m<sup>2</sup> or in direct printing: 14-15 g/m<sup>2</sup>;
- acid dyes on PA: 10-15 g/m<sup>2</sup>.

Digital printing machines can work 24 hours a day and, unlike analogue printing, no extra time needs to be spent on cleaning operations when changing from one product to another.

Printhead maintenance is important. Depending on the type of printhead, repetitive contact may destroy the nozzle line.

Figure 4.49 gives an overview of the inks used in digital printing. The majority of digital printing is done by transfer printing on polyester (see Section 4.6.1.4) [ 168, Swedish EPA 2019 ].



**Figure 4.49: Overview of inks used in textile printing**

Ink-jet printing cannot replace flat and rotary screen printing completely because printing speeds up to 2 000 m<sup>2</sup>/h are out of reach. To choose the right printing technology, speed as well as print design are important considerations, e.g. printing of spots and stripes is more cost-effective in flat or rotary screen printing.

[ 44, ÖKOPOL 2011 ]

### Cross-media effects

In contrast to the cleaning and reuse of feeding tanks in analogue printing, in digital printing waste of cartridges can occur especially for small aggregates.

All large-scale plants use cans (10 l up to maximum 120 l) which are returned to plastic recycling after cleaning. Some producers offer special recycling for cans.

**Technical considerations relevant to applicability**

Ink-jet printing is suitable for flat, woven and knitted fabrics. Fabrics with smooth surfaces can be used more easily than fabrics with rough surfaces. This technique is only applicable to new plants or major plant upgrades.

**Economics**

Investment ranges from EUR 100 000 for smaller equipment with velocities up to 30 m<sup>2</sup>/h to between EUR 300 000 and EUR 800 000 for large-scale plants. It is reported that the improved flexibility and promptness in satisfying customer and retailer demands compensate the machine costs [ 183, Spain 2001 ].

Smaller lot size is the most important argument for ink-jet implementation. Creating a master for rotary screen printing, i.e. creating the screen, is time-consuming and costs up to EUR 400 per screen. Additionally, screens are provided in standardised dimensions. In this case digital printing is more flexible, supporting textile designers with new design possibilities.

**Example plants**

- Erler+Pless GmbH, DE-22043 Hamburg.
- Fahnen Herold - Wilhelm Fraunhoff GmbH & Co. KG, DE-42398 Wuppertal.
- KBC Manufaktur Koechlin, Baumgartner - Cie. GmbH, DE-79540 Lörrach.
- Textildruck Imst GmbH & Co, AT-6460 Imst.
- WTG Westfälische Textilgesellschaft Klingenthal & Co mbH, DE-46397 Bocholt.

[ 44, ÖKOPOL 2011 ]

Plants from the data collection: CZ015, DE042, DE049, FR131, IT063, PT099 and PT108.

**Reference literature**

[ 44, ÖKOPOL 2011 ], [ 168, Swedish EPA 2019 ], [ 183, Spain 2001 ], [ 253, Bettens L. 2000 ], [ 282, Kohla M. 2021 ], [ 283, SPGPrints 2020 ]

**4.6.1.4 Transfer printing****Description**

The design (pattern) is first printed on an intermediate substrate (e.g. paper) using selected disperse dyes and is subsequently transferred to the fabric by applying high temperature and pressure (e.g. using a heat press or a calender).

**Technical description**

When the transfer paper is put into contact with the material in a very hot press, the ink embedded within the paper is converted to a gas (sublimation) and penetrates directly into the fibres of the substrate. The ink becomes physically part of the material as the fibres are slightly melted.

**Achieved environmental benefit**

Reduced water and energy consumption

**Environmental performance and operational data:**

In transfer printing, there is no need for further treatment such as steaming or washing, which allows savings in energy and water consumption, although some energy is also needed for the heat press or the calender.

At temperatures above 200 °C, the ink on the transfer paper and the polymer fibres within the substrate are heated, enabling the transfer of ink to media. After 1 minute the heat press is removed, and the transfer paper is peeled off, leaving behind a permanent, full-colour graphic on the substrate. To ensure correct ink transfer, smooth saturation and fine image quality, a coated sublimation transfer paper with excellent ink absorption and high ink release is required.

Technology has also been developed for transfer printing on cotton fibres under ambient conditions [ 171, Cotton Incorporated 2018 ].

According to some voluntary certification schemes [ 284, bluesign 2019 ], two options for reducing VOC emissions from transfer-paper printing are available:

- using solvent-free inkjet printing;
- using ethanol-based printing systems and replacing methanol (CAS 67-56-1) with ethanol (CAS 64-17-5) when it is used, together with regenerative thermal oxidation for the off-gas cleaning [ 284, bluesign 2019 ].

### **Cross-media effects**

- Energy required for the heat press.
- Used transfer paper as waste.

### **Technical considerations relevant to applicability**

This technique is only applicable to new plants or major plant upgrades.

Transfer printing is used only for synthetic fibres. Furthermore, it may be challenging to achieve the required properties (e.g. shade of colours, fastness) due to the limited number of dyestuffs available [ 282, Kohla M. 2021 ].

### **Economics**

For transfer printing, the investment costs are in the order of USD 20 000 per printer [ 35, RICARDO 2019 ].

Investment costs for double-sided transfer printing at room temperature are over USD 500 000 [ 171, Cotton Incorporated 2018 ].

### **Example plants**

Plants from the data collection: DE042 and FR131. Another example plant from Germany is Transfertex (Kleinostheim).

### **Reference literature**

[ 35, RICARDO 2019 ], [ 36, Sinocolor 2019 ], [ 168, Swedish EPA 2019 ], [ 171, Cotton Incorporated 2018 ], [ 282, Kohla M. 2021 ], [ 284, bluesign 2019 ]

#### **4.6.1.5 Optimised use of printing paste**

##### **Description**

Design and operational techniques to minimise the losses of printing paste residues include:

- minimisation of the volume of the printing paste supply system (e.g. minimising pipe lengths and diameters);
- ensuring a uniform paste distribution over the whole width of the printing machine;
- stopping printing paste supply shortly before the end of the printing;
- manual addition of printing paste for small lots.

##### **Technical description**

A typical printing paste supply system for textile rotary screen printing machines is illustrated in Figure 2.21. The volume depends on the diameter of the pipes and squeegee as well as on the pump design and the length of the pipes.

Printing paste supply systems, of which there may be up to 20 per printing machine, have to be cleaned at each change of colour or pattern and a considerable amount of printing paste finds its way into the waste water. As, for fashion patterns, the typical number of different colours per

design is 7 to 10, minimising the system volume has major effects in reducing printing paste emissions to waste water.

Diameters of pipes and squeegees have been reduced to 20-25 mm, leading to substantial reductions.

Along with minimum-volume supply systems, paste residues can be minimised by improving paste recovery from the supply system itself. New pumps can be operated in both directions. Thus, at the end of each run, the printing paste can be partly pumped back into the drum. The problem of air being drawn in via the holes in the squeegee can be solved by applying the technique described in Section 4.6.1.6.

Additional measures are as follows:

- Using squeegees with an even paste distribution over the whole width (minimisation of residual printing pastes in the screens). This is combined with an even paste distribution inside the stencil.
- Manual stopping of printing paste supply shortly before finishing a run in order to minimise the residual printing pastes in the rotary screens.

For short run lengths in particular, the following measures may also be considered:

- not using the supply system, but instead injecting small quantities of printing paste (1-3 kg) directly into the squeegee manually or by manual insertion of small troughs (with a cross-section of 3x3 cm or 5x5 cm);
- minimisation of pipes by supplying the printing pastes through funnels positioned directly above the pumps.

#### Achieved environmental benefits

- Reduced generation of waste and of waste water.
- Resource efficiency.

#### Environmental performance and operational data

System volumes and consequent losses can be reduced significantly, depending on the age of the equipment [ 5, UBA 2001 ].

Table 4.82 below shows the typical volumes in conventional and optimised printing paste supply systems as well as the reduction of printing paste losses. Note that the figures given in this section are not applicable to carpet rotary screen printing (the screens in carpet rotary screen printing are much bigger – 5-6 m in width – and the volumes of printing paste to be delivered are much higher than in most textile printing applications).

**Table 4.82: Volume of conventional and optimised printing paste supply systems in rotary screen printing machines for textiles**

Printing width (cm)	Conventional system <sup>(1)</sup> (litres)	Optimised system <sup>(1)</sup> (litres)	Reduction of printing paste losses (%)
164	5.1	2.1	59
184	5.2	2.2	58
220	5.5	2.3	58
250	5.8	2.4	59
300	6.2	2.6	58
320	6.5	2.7	58
<sup>(1)</sup> Including pipes, pump and squeegee. Source: [ 5, UBA 2001 ]			

Measures such as the manual injection or insertion of printing paste and the manual stopping of the printing paste supply system shortly before the end of the run need trained and motivated staff. Some companies have put in practice the manual injection of printing paste, but others report that, even for small lots (up to 120 m), the technique is difficult to apply. Reproducibility may be affected because the quantity of printing paste to be injected varies according to the pattern, which is difficult for the staff to manage. Moreover, a constant level of printing paste within the screen cannot be maintained, which may affect the constancy of the printing quality.

### **Cross-media effects**

None identified.

### **Technical considerations relevant to applicability**

The measures described are applicable to both existing and new installations. Generally, there are no technical restrictions to the applicability of this technique.

### **Economics**

The installation of 12 sets of volume-minimised pipes and squeegees requires an investment of about EUR 25 000.

### **Driving force for implementation**

- Minimising production costs by minimising printing paste losses and costs associated with waste water treatment.
- Environmental legislation.

### **Example plants**

Plants from the data collection: BE009, DE025, IT063, PT108 and SE118.

### **Reference literature**

[ 5, UBA 2001 ], [ 44, ÖKOPOL 2011 ], [ 243, OSPAR 1994 ]

## **4.6.1.6 Recovery of residual printing paste in rotary screen printing**

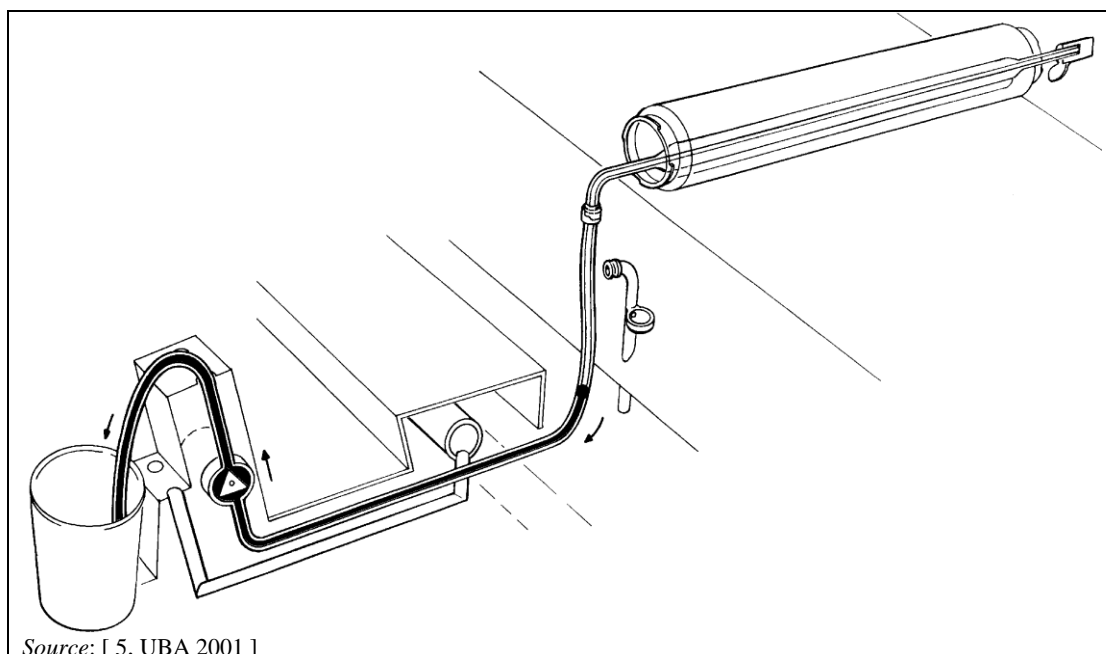
### **Description**

Residual printing paste in the supply system is pushed back to its original container (e.g. by a ball controlled by air pressure).

### **Technical description**

This technique allows the recovery of the printing paste remaining in the supply system in rotary screen printing machines at the end of each run. Before filling the system, a ball is inserted in the squeegee and then transported by the incoming paste to its end. After finishing a print run, the ball is pressed back by controlled air pressure, pushing the printing paste in the supply system back into the drum for reuse. Systems available for reusing residual printing paste are described in Section 4.6.1.7.

The technique is illustrated in the figure below, showing the ball during the phase in which the pump is transporting the paste back to the drum.



**Figure 4.50: Recovery of printing paste from the paste supply system by back-pumping an inserted ball**

#### **Achieved environmental benefits**

Reduced generation of waste and of waste water.

#### **Environmental performance and operational data**

Printing paste losses are reduced dramatically. In textiles, for instance, at a printing width of 162 cm, the loss is reduced from 4.3 kg (in the case of a non-optimised printing paste supply system) to 0.6 kg.

To achieve maximum benefit from this measure, printing machines with minimum-volume feed systems are used (see Section 4.6.1.5).

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

Applicability in existing plants may be restricted by the equipment (e.g. new rotary screen printing machines). Certain existing machines can be retrofitted.

As mentioned earlier, the technique is applied in textile finishing mills (for flat fabrics). In principle this system can also work for carpets, but it is not applied for various reasons. The main reason is related to the type of thickeners most commonly used in carpet printing pastes. These are based on guar gum, which is relatively inexpensive, but has a limited shelf life and therefore cannot be stored for a long time before reuse (it is biodegradable and the growth of bacteria and other organisms such as yeasts rapidly alters the viscosity).

#### **Economics**

The investment for retrofitting this recovery system to a rotary screen printing machine with 12 new squeegees and pipes (for a printing width of 185 cm) is about EUR 42 000. Table 4.83 below shows the savings achievable in a typical mill.



**Table 4.83: Calculation of savings achievable in a typical textile mill by installing a printing paste recovery system**

Number of changes of printing pastes per day	8
Number of working days per year	250
Average number of printing pastes per design	7
Printing paste saved per supply system	3.7 kg
Price of printing paste	EUR 0.6/kg
<b>Saving per year</b>	<b>EUR 31 080/yr</b>
NB: The number of changes as well as the number of printing pastes per design may be higher in industrial practice. <i>Source: [ 5, UBA 2001 ]</i>	

The example does not include the investment cost of new pumps, so a certain range of viscosity needs to be maintained. When a wide viscosity range is required, the pumps have to be replaced. The total investment cost is then reported to range between about EUR 90 000 and EUR 112 000.

A payback time of about 2 years can therefore be considered realistic, but only when all of the recovered printing paste is reused. In practice this does not happen, especially with mills that use several different types of printing pastes. In such mills, due to logistical problems (limited storage and handling capacities), reuse rates of only 50-75 % are reported, which significantly extends the payback period [ 5, UBA 2001 ].

#### **Driving force for implementation**

Reduction of printing paste losses for economic and environmental reasons.

#### **Example plants**

Plants from the data collection: DE032 and PT108.

#### **Reference literature**

[ 5, UBA 2001 ], [ 183, Spain 2001 ]

### **4.6.1.7 Reuse of residual printing pastes**

#### **Description**

The residual printing paste is collected, sorted by type, stored and reused. The degree of reuse of printing paste is limited by its perishability

#### **Technical description**

Printing pastes are highly concentrated preparations that consist of dyestuff, thickener and various other auxiliaries according to the different types of pastes (e.g. pigment, reactive, vat and disperse printing pastes). Printing paste residues can reach levels as high as 40-60 % in non-optimised equipment. A large portion of these residues is still discharged to the effluent, thus causing considerable waste water problems (see Section 2.8.3).

For a long time, printing pastes were prepared manually, which meant that residues were reused, but the extent and manner of that reuse were highly dependent on the staff responsible and on the production schedule. Today, computer-assisted systems offer more opportunities for recycling printing pastes. In most companies, printing pastes are prepared with computerised systems (each printing paste has its specific recipe which is saved electronically). At the end of a run, each residual paste is weighed and sent to a defined location in a storage facility. The composition is saved electronically and computer programs calculate the formulation of new printing pastes, taking account of the amount, composition and durability (which is not normally a problem) of the residues to be reused.

Another option is to empty all drums with residual printing paste and sort it according to its chemical characteristics (i.e. type of dyestuff and thickener). The drum is cleaned with a scraper to minimise the printing paste loss, then is washed and reused for the preparation of new printing pastes.

#### **Achieved environmental benefits**

The quantity of residual printing pastes to be disposed of is significantly reduced both as waste water and solid waste.

#### **Environmental performance and operational data**

Textile finishing mills that have applied these techniques report that such systems need some time for implementation in daily routine, but that, after managing any teething problems, they work satisfactorily. The recycling systems described here are most efficient in companies with only one or two kinds of printing pastes (e.g. pigment and reactive printing pastes). In companies using various different types of printing pastes, the management of a large number of different mixtures may be difficult (logistical problems, limited capacity of the storage area, etc.) In these cases, the recycling rate may be in the range of 50-75 % only [5, UBA 2001].

In the example plant A), the amount of paste washed out from the paste containers was reduced by 50 %. It was possible to recover more than 90 % of the printing paste residues.

In the example plant B), the recovery rate is 75 % after 5 years of implementation, applying four pigment types and about 12 different printing paste systems. In the beginning, only one printing paste system was used, leading to a recovery rate of 90 %. The remaining waste amount depends significantly on the lot size [44, ÖKOPOL 2011].

Trained and motivated personnel are needed for manual operations, such as scraping buckets, aimed at increasing the paste recovery rate. Printers claim that specialised personnel are not willing to scrape buckets, especially given the number of buckets a day that need to be scraped for a typical 12-position printer that has to be changed every 600-800 metres on average. Operating with modern printing machines with a built-in system for mechanical removal of printing paste from the pipes and hoses of the feeding system will increase the amount of printing paste that can be collected and reused (see Section 4.6.1.6).

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique; however, some printing pastes may lose usability due to chemical reactions (e.g. hydrolysis of reactive dyes). Systems for recycling printing pastes are applicable in the textile industry both in existing and new installations. However, for totally computerised systems, the printing section must have a minimum size of three rotary screen and/or flat screen printing machines [5, UBA 2001].

This technique is not used in the carpet industry for the same reasons explained in Section 4.6.1.6.

#### **Economics**

Investment costs are about EUR 0.5-1 million, depending on the size and number of different printing pastes to be recycled. Payback periods are reported to vary between 2 and 5 years depending on individual circumstances [5, UBA 2001].

#### **Driving force for implementation**

Economic considerations in terms of savings in printing paste supply and costs related to residual printing paste disposal [5, UBA 2001].

### Example plants

Many plants in Europe and worldwide.

Example plant A) Plant DE032 of the data collection.

Example plant B) KBC, DE-79540 Lörrach.

[ 44, ÖKOPOL 2011 ]

Plants from the data collection: CZ019, DE025, PT099, SE118 and UK127.

### Reference literature

[ 5, UBA 2001 ], [ 44, ÖKOPOL 2011 ], [ 157, Danish EPA 2001 ]

## 4.6.2 Printing with dyes

### 4.6.2.1 Reduction of urea content in printing pastes

#### Description

Reactive printing is carried out with a reduced amount of urea by controlling the moisture content of textile materials.

#### Technical description

The urea content in reactive printing paste can be up to 150 g/kg of paste. Urea is also used in printing pastes for vat dyes, but in much lower concentrations (about 25 g/kg of paste). Urea is applied to:

- increase the solubility of dyestuffs with low water solubility;
- increase the formation of condensate, which is necessary for allowing migration of the dyestuff from the paste to the textile fibre;
- form condensates with a higher boiling point (115 °C) which means that requirements for constant operating conditions are lower (non-constant operating conditions can negatively affect reproducibility if urea is not used).

Urea is partially substituted by controlled addition of moisture for printing on cotton, viscose or cotton blends (moisture content of 10 wt-% for cotton fabric, 20 wt-% for viscose fabric and 15 wt-% for cotton blends).

Moisture is applied either as foam or by spraying a defined quantity of water mist.

In many cases, it is possible to reduce the urea content in reactive printing paste by optimised dosing without additional technical equipment when using silk and viscose fabric [ 44, ÖKOPOL 2011 ].

#### Achieved environmental benefits

Emissions to water and air are reduced.

In the textile finishing industry, the printing section is the main source of urea and its decomposition products ( $\text{NH}_3/\text{NH}_4^+$ ). During waste water treatment, the nitrification of the excess ammonia involves high energy consumption. Discharge of urea, ammonia and nitrate contributes to eutrophication and aquatic toxicity.

The presence of urea in the textile substrate also leads to ammonia emissions to air from the thermal treatment which follows printing.

Minimisation/elimination of urea at source significantly reduces these adverse effects.

**Environmental performance and operational data**

In reactive printing, the urea content in the printing paste can be reduced from 150 g/kg of paste to zero by application of moisture. In the case of phthalocyanine complex reactive dyes, however, reduction is possible only to 40 g/kg of paste because of the bad migration properties typical of these large-molecule dyestuffs [ 5, UBA 2001 ].

By avoiding the use of urea in reactive printing pastes, the ammonia concentration in the mixed effluent of a finishing mill with a significant printing section decreased from about 90-120 mg  $\text{NH}_4^+\text{-N/l}$  to about 20 mg  $\text{NH}_4^+\text{-N/l}$  [ 5, UBA 2001 ].

Even without using this technique, the amount of urea consumed can be reduced in reactive paste from about 150 g/kg to about 50 g/kg of printing paste for silk and 80 g/kg for viscose, and still maintain the quality standards.

**Cross-media effects**

The application of moisture needs energy, but this consumption is significantly lower than the energy required for the production of urea [ 5, UBA 2001 ].

**Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

The foam and the spraying systems are applicable to both new and existing plants performing reactive printing [ 5, UBA 2001 ].

For silk and viscose articles, however, it is not possible to completely avoid the use of urea with the spraying system. Indeed, the technique is not reliable enough to ensure a uniform dosage of the low-moisture add-on required for these fibres and, especially for fine articles, cases have been reported where spraying systems did not meet the quality standards.

In contrast, the foaming system has proven successful for several years for viscose without the need for urea [ 5, UBA 2001 ].

Moisture application in unfixed printing is technically challenging and requires close quality control. In some installations, in particular in short steamers, the reduction of urea is not possible for quality reasons [ 44, ÖKOPOL 2011 ].

**Economics**

The investment costs for spraying equipment including on-line moisture measurement are about EUR 30 000, but the foam system is significantly more expensive. Approximately EUR 200 000 are required for a foaming machine which relates to a production capacity of up to about 80 000 linear metres per day. The foaming technique has been operated under economically viable conditions in plants with a capacity of about 30 000 linear metres, 50 000 linear metres and 140 000 linear metres per day.

**Driving force for implementation**

Stringent limits applied by local authorities for  $\text{NH}_4^+\text{-N}$  in waste water, due to eutrophication and aquatic toxicity in surface water, have promoted the introduction of this technique.

The application of this technique is also very attractive for mills discharging to a municipal waste water treatment plant. Because of the high energy consumption for biological nitrification, many municipalities now charge indirect dischargers for nitrogen emissions.

**Example plants**

Plant DE049.

**Reference literature**

[ 5, UBA 2001 ], [ 44, ÖKOPOL 2011 ]

#### 4.6.2.2 Two-step printing with reactive dyes

##### **Description**

Printing is carried out without urea by two padding steps with intermediate drying and addition of fixation agents (e.g. sodium silicate).

##### **Technical description**

As already described in Section 4.6.2.1, in conventional one-step printing with reactive dyes, urea is used to increase the solubility of the dyestuffs and to improve dyestuff migration from the printing paste to the textile fibre.

Minimisation or even substitution of urea is possible in the one-step method by controlled addition of moisture.

Another option is the two-step printing method, involving the following steps:

- padding of the printing paste;
- intermediate drying;
- padding with alkaline solution of fixating agents (especially water-glass);
- fixation by means of overheated steam;
- washing steps (to remove thickeners and improve fastness properties).

The process is carried out without urea.

##### **Achieved environmental benefits**

A significant reduction of the ammonia content in waste water and reduced waste gas problems are the main environmental benefits. In addition, the lifetime of printing pastes is lengthened, which increases the opportunities to recycle the residual printing pastes [5, UBA 2001].

##### **Environmental performance and operational data**

Fixation is carried out by means of overheated steam (90 s at 125 °C).

It should be noted that this technique is more complex and slower than the one-phase process.

##### **Cross-media effects**

Intermediate drying requires additional energy and is therefore associated with the environmental impacts of energy production [44, ÖKOPOL 2011].

##### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

Two-step reactive printing can be carried out on cotton and viscose substrates. Application of the fixation liquor needs the combination of an impregnation device with a steamer. Overheated steam is necessary. Reactive dyes based on monochlorotriazine and vinyl sulphone types can be used [5, UBA 2001].

##### **Economics**

No information provided.

##### **Driving force for implementation**

Environmental legislation and quality aspects are the reasons for implementing a two-step printing method.

##### **Example plants**

Many plants in Europe and worldwide.

**Reference literature**

[ 5, UBA 2001 ], [ 44, ÖKOPOL 2011 ]

**4.6.3 Printing with pigments****4.6.3.1 Use of printing chemicals with improved environmental performance****Description**

Use of printing chemicals with improved environmental performance includes:

- thickeners with no or low contents of volatile organic compounds;
- fixation agents with low potential for formaldehyde release;
- binders with low contents of ammonia and low potential for formaldehyde release.

**Technical description**

The final stages in pigment printing consist of drying and fixing the printed fabric with hot air. In both stages, emissions of volatile organic compounds to air may be significant (see also Sections 2.8.3 and 8.1.7.2).

White spirit used for emulsion thickeners was a major source of volatile organic compounds in the past. Water-in-oil (full emulsion) thickeners seem no longer to be applied in Europe and half-emulsion printing pastes (oil in water) are only occasionally used. Hydrocarbons (predominantly aliphatic) are still found in exhaust air, however, mainly arising from mineral oil contained in synthetic thickeners. Their emission potential can be up to 10 g C/kg textile.

New-generation thickeners contain minimal amounts of volatile organic solvents. They are based on polyacrylic acid or polyethylene glycol compounds instead of mineral oils. Products have also been developed that do not contain any volatile solvent. They are supplied in the form of non-dusting granules or powders.

According to the Ecolabel criteria for textile products, the printing pastes used shall not contain more than 5 % w/w VOCs [ 112, COM 2014 ]. Additionally, according to the CLP Regulation, formaldehyde triggers labelling of the mixture as a carcinogen 1B as of 0.1% w/w.

Another potential source of emissions to air in pigment printing is fixing agents. The cross-linking agents contained in these auxiliaries are largely based on methylol compounds (melamin compounds or urea-formaldehyde pre-condensates) that give rise to formaldehyde and alcohols (mainly methanol) in the exhaust air. New low-formaldehyde products are now available. Acrylate dispersions used as binders and in some cases synthetic thickeners may also be sources of formaldehyde emissions. The development of a formaldehyde-free printing system based on helizarin binders allows the high quality standard of pigment printing to be maintained without the development of formaldehyde emissions [ 44, ÖKOPOL 2011 ].

Furthermore, optimised printing pastes are APEO-free (pigment printing auxiliaries may be found in the waste water as a result of cleaning operations, etc.) and have a reduced ammonia content. Ammonia is used as an additive in binders and is also a source of air pollution.

**Achieved environmental benefits**

- Reduction of emissions of organic compounds, formaldehyde and ammonia to air.
- When using formaldehyde-free pigment printing systems, formaldehyde emissions are completely prevented.

**Environmental performance and operational data**

Table 4.84 below shows for three typical thickeners the emissions of VOC that may arise from drying and fixing.

Table 4.84: Volatile organic compound emissions in pigment printing

Operation	Pigment print recipe I (g C/kg textile)	Pigment print recipe II (g C/kg textile)	Pigment print recipe III (g C/kg textile)
Drying	2.33	0.46	0.30
Fixing	0.04	0.73	0.06
Total	2.37	1.19	0.36

Source: [ 5, UBA 2001 ]

Recipe I is an already optimised thickener, but still containing hydrocarbons. In the optimised recipe II the mineral oil is replaced by polyethylene glycol, while recipe III uses a powder thickener. With recipe III formaldehyde emissions can be kept below 0.4 g CH<sub>2</sub>O/kg of textile (assuming 20 m<sup>3</sup> air/kg of textile). As a result, the carry-over of volatile substances from printing to finishing processes can also be reduced to < 0.4 g C/kg.

Using optimised printing pastes, ammonia emissions can also be reduced below 0.6 g NH<sub>3</sub>/kg of textile (assuming an air-to-textile ratio of 20 m<sup>3</sup>/kg).

There has been no evidence of variations in operating conditions, product quality or process control [ 183, Spain 2001 ].

#### Cross-media effects

Thickeners based on powders may generate dust or block the stencils [ 5, UBA 2001 ].

#### Technical considerations relevant to applicability

Generally, there are no technical restrictions to the applicability of this technique.

#### Economics

The higher costs of the printing pastes are offset by the reduced air treatment costs (lower emissions of volatile organic compounds) [ 5, UBA 2001 ], [ 183, Spain 2001 ].

#### Driving force for implementation

Environmental legislation (regarding, in particular, emission limits set for volatile organic compounds, formaldehyde and ammonia) is the main motivation for the use of optimised printing pastes [ 5, UBA 2001 ].

#### Example plants

Plants from the data collection: DE049, PT108, PT099 and UK127.

#### Reference literature

[ 5, UBA 2001 ], [ 32, Bettens L. 1999 ], [ 44, ÖKOPOL 2011 ], [ 112, COM 2014 ], [ 183, Spain 2001 ], [ 243, OSPAR 1994 ]

## 4.7 Finishing

### 4.7.1 General techniques

#### 4.7.1.1 Laser and/or plasma surface treatment of fabrics and garments

##### Description

Laser and/or plasma treatments are used to modify the fibre surface of fabrics and garments by high-energy heat and/or reaction with charged gaseous species (e.g. ions, radicals) to achieve the required functional properties.

##### Technical description

Surface properties like adhesion, wetting properties (hydrophilicity, hydrophobicity, oleophobicity), fire retardancy and anti-microbial properties are improved by modifying the surface of fabrics and garments with the heat of a laser beam (UV) and/or dielectrical discharge plasma in normal atmosphere (i.e. corona) or inert or reactive gas plasma (e.g. nitrogen, argon and carbon dioxide gas).

Heat provided by a laser beam erodes a pattern on the surface of the textile. A mechanical frame holds the textile fabric or product to enable the laser beam perform the heat treatment. The laser beam is manipulated to treat the whole surface or certain focused areas (e.g. to produce a pattern). Intense heat from the laser beam modifies (melts or vapourises) the surface of the fibre in a very short time period.

In plasma treatment, the surface properties ( $< 0.1 \mu\text{m}$  depth) of the textile fabric or product are enhanced due to the reaction (e.g. oxidation, degradation, cross-linking) with charged particles (for example, ionised gases (e.g. oxygen, nitrogen, argon), free radicals and neutrals) in a controlled environment of selected gases. The plasma is generated by different types of power supply: low frequency (LF, 50 kHz to 450 kHz), radio frequency (RF, 13.56 MHz to 27.12 MHz) and microwave (MW, 915 MHz to 2.45 GHz). The types of plasma used in textile treatment are cold plasma, which can be broadly classified as low-pressure plasma (LPP) and atmospheric-pressure plasma (APP). Atmospheric pressure plasma is further divided into corona discharge, dielectric barrier discharge (DBD) and atmospheric pressure glow discharge (APGD).

Textile fabrics or garments pretreated with laser and/or plasma treatments require less or no finishing treatment and demonstrate improved dyeability (e.g. shorter times, greater exhaustion).

##### Achieved environmental benefits

- Reduced energy consumption.
- Reduced effluent.
- Reduced chemicals (finishing agents) consumption.

##### Environmental performance and operational data

The lasers used are CO<sub>2</sub>-gas-based (wavelength of 10 nm - ultraviolet). The degree of surface treatment depends upon the wavelength, power density, and pulse width of the laser beam. The productivity of laser technology is up to three times higher than that possible with conventional machines.

A variety of low-pressure (e.g RF-powered) and atmospheric-pressure plasma machines for batch (off-line) and/or in-line processing of specific textile products are commercially available.

Also, laser and/or plasma technology makes wetting, drying and effluent treatment operations obsolete, and consequently uses less energy and chemicals than conventional wet processing techniques.



Lasers should be shielded to protect workers and to efficiently exhaust fine dust during the process.

### **Cross-media effects**

The laser beam and plasma decompose the fibre surface and may result in some vapours (fumes, waste gases) which need to be exhausted and may require emission abatement.

### **Technical considerations relevant to applicability**

The technique is generally applicable to all types of fibres (cotton, wool, synthetic) of fabrics or garments. However, cotton fibres with a high elastane content may be damaged and, depending on the type and power of laser, some of the following materials may not be suitable [ 238, bluesign 2019 ]:

- leather and artificial leather that contains chromium (VI);
- carbon fibres (carbon);
- polyvinyl chloride (PVC);
- polyvinyl butyral (PVB);
- polytetrafluoroethylenes (PTFE/Teflon);
- any materials containing halogens (fluorine, chlorine, bromine, iodine and astatine), epoxy or phenolic resins; and
- if manganese, chromium, nickel, cobalt, copper or lead is processed.

### **Economics**

Investment costs are estimated to be between USD 200 000 and USD 500 000 for laser equipment [ 171, Cotton Incorporated 2018 ].

The operational costs of energy consumption in laser treatment are lower than the operational costs of drying and the water treatment of finishing effluents from conventional finishing.

### **Driving force for implementation**

- Higher productivity.
- Economics (reduced costs for energy, water and chemical consumption).
- Environmental legislation.

### **Example plants**

Many plants around the world use laser technology to treat denim fabric or garments (e.g. several hundred machines operate in Bangladesh [ 285, TextileToday 2017 ]).

Plant DE042 (corona treatment, for PES finishing).

### **Reference literature**

[ 35, RICARDO 2019 ], [ 171, Cotton Incorporated 2018 ], [ 238, bluesign 2019 ], [ 278, Gashti et al. 2011 ], [ 285, TextileToday 2017 ], [ 286, Lawrance C. 2017 ], [ 287, Industry Innovation Centre 2015 ]

## **4.7.1.2 Surface treatment with air micro- or nano-bubbles**

### **Description**

Finishing agents or dyestuffs are transported to the surface of the fibres with the flow of micro- or nano-size air bubbles in a minimal liquid bath.

### **Technical description**

Chemical products for finishing (softeners, easy-care/wrinkle-free resins, resins for 3D effects, liquid-repellents, antimicrobials, dyes, etc.) are brought into contact with the fabric or garments

with a minimal amount of water, being transported to the fibres by a flow of micro- or nano-bubbles of air.

#### **Achieved environmental benefits**

- Reduced water consumption and effluent.
- Reduced energy consumption.
- Reduced chemicals (finishing agents) consumption.

#### **Environmental performance and operational data**

[ 242, Puchol et al. 2017 ]

For the softening process for garments (cotton, polyester, synthetic blends), the treatment time is less than 25 minutes (for 50 kg of textile) and the liquor ratio 1:0.3 for lightweight garments and 1:0.5 for heavy clothing (11.5 % better than the traditional process).

For DWOR (Durable Water- and Oil-Repellents) treatment of garments (protective clothing made of cotton and cotton/polyester blends) with C6 fluorocarbon, the treatment time is less than 40 minutes (50 kg of textile) and the liquor ratio 1:0.8. The process consumes 20 % less C6 fluorocarbon than the traditional process.

In exhaustive dyeing with reactive dyes (dyeing technique that produces irregular effects known by the Italian expression *maltinto*), no salt is needed and dyeing proceeds at an ultra-low liquor ratio.

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

Generally applicable to denim.

#### **Economics**

High initial investment costs, but substantial savings on costs for water and chemical consumption and effluent treatment.

#### **Driving force for implementation**

- Higher productivity.
- Economics (reduced costs for energy, water and chemical consumption).
- Environmental legislation.

#### **Example plants**

No information provided.

#### **Reference literature**

[ 35, RICARDO 2019 ], [ 242, Puchol et al. 2017 ], [ 288, JEANOLOGIA S.L. 2015 ]

## **4.7.2 Easy-care**

### **4.7.2.1 Use of cross-linking agents with no or low potential for formaldehyde emissions to air**

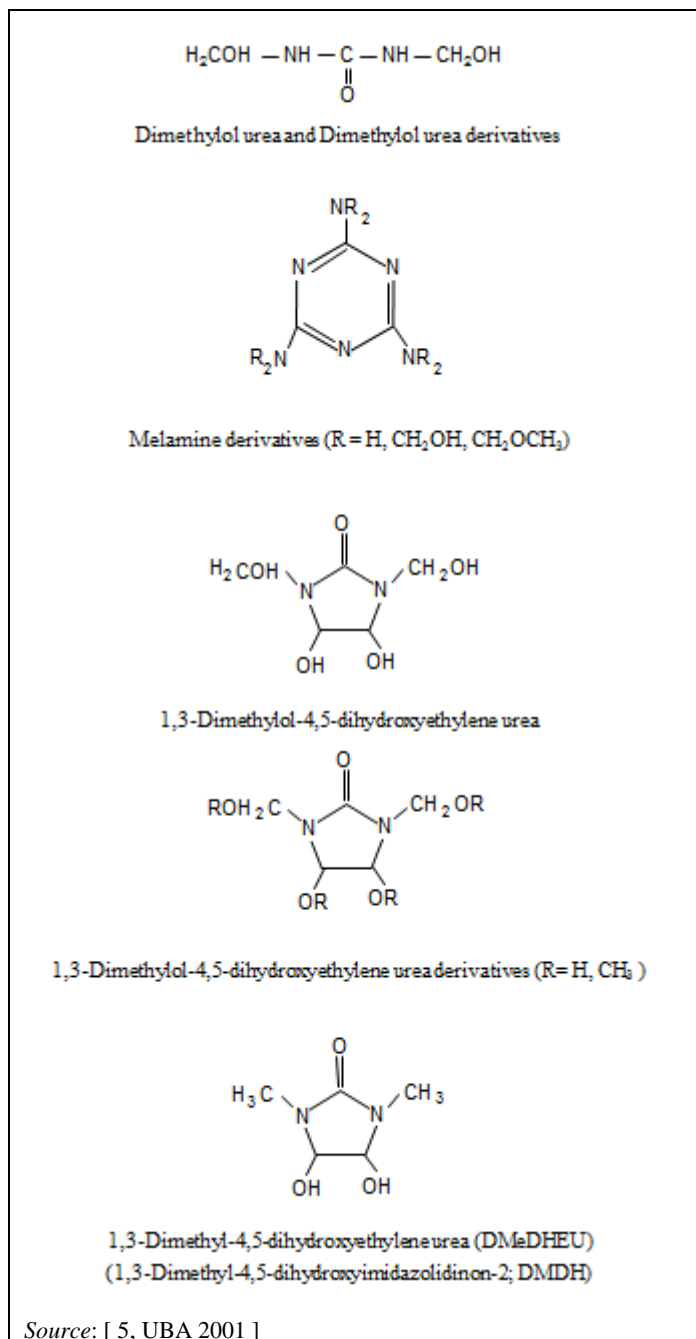
#### **Description**

The cross-linking agents which are used in easy-care finishing have no or low potential for formaldehyde release.

**Technical description**

Easy-care finishing is mainly carried out on cellulosic fibres and/or blends of cellulosic and synthetic fibres in order to increase the crease recovery and/or dimensional stability of the fabrics (see Sections 2.9.2.1 and 8.1.8.1).

Easy-care finishing agents are mainly compounds synthesised from urea, melamine, cyclic urea derivatives, alcohols, glyoxal, and/or formaldehyde. Cross-linking agents (reactive groups) are composed of free or etherificated N-methylol groups (see Figure 4.51 below).



**Figure 4.51: Chemical structure of cross-linking agents**

Formaldehyde-based cross-linking agents may release formaldehyde. According to the harmonised classification, formaldehyde is classified as carcinogenic 1B and mutagenic 2 [289, EU 2008] and can be harmful to the workforce (formaldehyde can also be released, for example, during cutting operations). The presence of free formaldehyde or releasable

formaldehyde on the finished fabric also represents a potential risk for the final consumer. The European Ecolabel scheme for textile products [ 112, COM 2014 ] sets a threshold of 16 ppm for products that come into direct contact with the skin and for products for babies and children under 3 years old and 75 ppm for garments with limited skin contact and interior textiles.

Low-formaldehyde or even formaldehyde-free products are an alternative (see Table 4.85 below). Formaldehyde-free cross-linking agents are based on modified (methylated and glycolated derivatives of) dimethyloldihydroxyethylene urea (DMDHEU) (e.g. 1,3-dimethyl 4,5-dihydroxy 2-imidazolidinone (DHDMI)) or polycarboxylic acids (e.g. 1,2,3,4-butanetetracarboxylic acid (BTCA), citric acid or maleic acid) [ 290, Saxena et al. 2017 ], [ 291, Choudhury A.K.R 2017 ], [ 292, SUBSPORT 2013 ].

Low-formaldehyde DMDHEU-based cross-linking agents (with less than 0.1 % residual formaldehyde in the formulation) are also used for reducing formaldehyde emissions in easy-care treatment [ 293, Zietlow B. 2020 ].

**Table 4.85: Overview of the formaldehyde release potential of the most important cross-linking agents**

Type of cross-linking agent	Formaldehyde release potential
Dimethylol urea	High
Melamine formaldehyde condensation products	High
Dimethyloldihydroxyethylene urea (DMDHEU)	High
Dimethyloldihydroxyethylene urea (DMDHEU) derivatives (most commonly used)	Low
Modified dimethyloldihydroxyethylene urea	None

Source: [ 5, UBA 2001 ]

#### Achieved environmental benefits

Reduced emissions of formaldehyde to air.

#### Environmental performance and operational data

Table 4.86 below shows the emission factors related to the use of different cross-linking agents.

**Table 4.86: Potential emissions of formaldehyde and methanol caused by the use of different types of cross-linking agents in textile finishing**

Type of cross-linking agents	Formaldehyde		Methanol	
	Textile substrate-based emission factor (g/kg textile substrate)	Resulting concentration with regard to an air-to-textile ratio of 20 m <sup>3</sup> /kg (mg/Nm <sup>3</sup> )	Textile substrate-based emission factor (g/kg textile substrate)	Resulting concentration with regard to an air-to-textile ratio of 20 m <sup>3</sup> /kg (mg/Nm <sup>3</sup> )
DMDHEU low-methanol	0.15-0.24	8-12	0.14-0.24	7-12
DMDHEU high-methanol	0.10-0.38	5-19	1.77-2.10	89-105
DMDHEU high-methanol moist cross-linking agent	0.30-0.80	15-40	2.86 and 10.88 Drying and condensation	143 and 544
Melamine Type I	0.61-1.07	31-54	2.10-2.39	105-120
Melamine Type II	0.68-0.80	29-40	1.74-1.93	87-97

Source: [ 44, ÖKOPOL 2011 ]

With low-formaldehyde or formaldehyde-free products, a reduction of formaldehyde emissions in finishing is achieved. Formaldehyde residues on the textiles can be minimised (< 75 ppm in the textile products, or even lower than 16 ppm for low-formaldehyde-content consumer requirements). With optimised catalysts, the curing temperature and therefore the energy consumption can be reduced.

If directly heated stenters are inefficiently maintained, they may also emit formaldehyde in the exhaust air.

A typical recipe for low-formaldehyde finishing of cotton (woven fabric) is:

- 40-60 g/l cross-linking agent;
- 12-20 g/l catalyst;
- liquor pick-up: 70 %;
- drying and condensation (150 °C, 3 minutes).

A typical recipe for formaldehyde-free finishing of cotton is:

- 80-120 g/l cross-linking agent (integrated catalyst);
- liquor pick-up: 80 %;
- possible add-on of acetic acid;
- drying and condensation (170 °C, 45 seconds).

Cross-linking compounds are often applied in combination with wetting agents, softeners, products which increase rip-resistance, etc.

Low-formaldehyde or formaldehyde-free cross-linking agents can be applied to different products. The kind and amount of catalyst are adjusted accordingly, as are the curing time and temperature.

### **Cross-media effects**

Like conventional cross-linking agents, the formaldehyde-free alternative products mentioned above are poorly biodegradable. However, as a fundamental rule, the amount of concentrated liquor is kept to a minimum by small pad boxes, and residues are disposed of separately without draining them to the waste water.

Non-optimised formaldehyde-free products can be intensely odorous.

The required quantity of formaldehyde-free products is approximately twice as high as conventional products.

In addition, the use of low-formaldehyde or formaldehyde-free products extends the required curing time and temperature in the stenter, which in turn leads to higher energy consumption.

[ 44, ÖKOPOL 2011 ]

### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

### **Economics**

Prices for formaldehyde-free products are significantly higher than for low-formaldehyde products (20-300 % in relation to chemical consumption) [ 44, ÖKOPOL 2011 ].

### **Driving force for implementation**

- Health and safety regulations.
- Environmental regulations.
- Consumer standards.

**Example plants**

In total, 19 plants from the data collection apply this technique.

**Reference literature**

[ 5, UBA 2001 ], [ 44, ÖKOPOL 2011 ], [ 112, COM 2014 ], [ 243, OSPAR 1994 ], [ 289, EU 2008 ], [ 290, Saxena et al. 2017 ], [ 291, Choudhury A.K.R 2017 ], [ 292, SUBSPORT 2013 ], [ 293, Zietlow B. 2020 ]

**4.7.3 Softening****4.7.3.1 Low-volume application of softening agents****Description**

Softening agents are not added to the dyeing liquor but applied in a separate process step by padding, spraying or foaming.

**Technical description**

In batch processing, softening agents are often applied after the dyeing process directly in the dyeing machine (e.g. jet, overflow) using the exhaustion method.

Unfortunately, this limits the choice of softening agents to environmentally harmful cationic agents and gives rise to a 10-20 % loss of the whole volume of the warm softening bath [ 267, Danish EPA 1999 ].

Alternative techniques are the application of softeners by pad mangles or by spraying and foaming application systems (see Sections 2.9.1 and 2.9.3).

The advantages of these techniques are that the use of cationic softening agents can be avoided and any chemical loss can be reduced to a few per cent [ 267, Danish EPA 1999 ].

The amount of residual liquors is also reduced compared with the waste water volume produced by a batch process. In this respect, the best performances are achieved with application techniques such as spraying and foaming, which allow minimum system losses (residual liquor in the chassis, residual liquor in the pipes and leftovers in the batch storage containers). However, the concentration of the active substance is much higher, which makes these liquors unsuitable for treatment in a biological system.

Another advantage of applying the softeners in separate equipment after the batch dyeing process is that it is then possible to reuse the dyeing or rinse baths as there is no longer a problem with the presence of residual cationic softeners, which would otherwise limit the adsorption of the dye in the subsequent dyeing process.

**Achieved environmental benefits**

- Savings in water, energy and chemicals.
- Introduction of less environmentally harmful softening agents.

**Environmental performance and operational data**

No information provided.

**Cross-media effects**

When softening is done in separate equipment after the dyeing process, the volume of the residual liquor is reduced (limited to system losses), but the concentration of the active substance is higher.

**Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

### **Economics**

Economic benefits can be derived from savings in water, energy and chemical consumption.

The technique consists of an additional process step which results in higher operational costs.

[ 44, ÖKOPOL 2011 ]

### **Driving force for implementation**

Savings in water, energy and chemicals.

### **Example plants**

Plants from the data collection: IT059, IT064, IT065, IT068, IT070, IT073, IT074, IT077, IT078, IT079, IT094, PT108 and SE119.

### **Reference literature**

[ 44, ÖKOPOL 2011 ], [ 267, Danish EPA 1999 ]

## **4.7.3.2 Softening of cotton textile materials with enzymes**

### **Description**

Enzymes are used for softening, possibly in combination with washing or dyeing.

### **Technical description**

Cellulase enzymes are widely used in ‘polishing’ (sometimes called bioblasting) of cotton yarns or (knitted) fabric to remove loose fibres adhered to the fabric, thereby replacing the singeing process step. This is a bio-polishing (bioblasting) process which gives cotton a soft feel and reduces the pilling (fuzz, lint) of the cellulosic fibre.

The technique can be combined with after-bleach washing (bleach clean-up) and dyeing in one process [ 294, Nagaraju et al. 2013 ].

### **Achieved environmental benefits**

- No emissions to air (as singeing is obsolete).
- Reduced chemical consumption (for softening).

### **Environmental performance and operational data**

Bio-polishing may reduce fabric strength and weight but will improve the appearance of a garment through repeated home laundering cycles. Bio-polishing may require a separate bath; however, a carefully selected compatible enzyme can be included in the dye bath, saving additional water, time and energy.

### **Technical considerations relevant to applicability**

Generally applicable to cotton yarn and fabric.

### **Cross-media effects**

The organic load in the effluent may be increased, demanding an appropriate biological waste water treatment.

### **Economics**

General investment costs are less than USD 200 000 with a typical 2-year payback period [ 171, Cotton Incorporated 2018 ].

### **Driving force for implementation**

Economics.

**Example plants**

No information provided.

**Reference literature**

[ 171, Cotton Incorporated 2018 ], [ 294, Nagaraju et al. 2013 ]

**4.7.4 Finishing with flame retardants****4.7.4.1 Optimisation or substitution of the flame retardants used for finishing****Description**

Textiles that do not require finishing with flame retardants are used. If not possible, flame retardants are selected considering:

- the risks associated with the substances (see Section 4.1.6.1) in particular in terms of persistence and toxicity, including the potential for substitution (e.g. brominated flame retardants (see Section 4.1.6.1));
- the composition and form of the textile materials to be treated;
- the product specifications (e.g. combined flame retardance and oil-/water-/soil-repellence, wash durability).

**Technical description**

Due to the complexity and number of possible combinations of textile substrate, finishing treatment and desired product properties, there is no overarching (one-size-fits-all) solution for suitable flame retardants. There are options available for certain specific textile products, but they are typically not transferrable to other textile products where flame resistance is required [ 214, EIPPCB 2019 ]

Moreover, the potential hazardousness of the flame retardants as well as their regulatory status also needs to be taken into account, by using the ECHA search tool [ 138, ECHA 2019 ].

For example, some brominated flame retardants (see also Section 8.1.8.4) are now strictly regulated:

- decabromodiphenyl ether (deca-BDE) which is listed in Annex XVII to REACH and cannot be manufactured or placed on the market at concentrations above 0.1 % w/w (with some exemptions possible);
- hexabromocyclododecane (HBCD) which is banned by the POP Regulation [ 295, EU 2004 ] and is listed in Annex XIV to REACH and is therefore subject to authorisation [ 7, EU 2006 ].

Intensive technical screening on a case-by-case basis is therefore needed to find suitable flame retardants and a number of criteria and/or product specifications may be used to carry out this screening:

- the alternative chemical is halogen-free;
- it does not contain other toxic compounds (antimony, formaldehyde, etc.) that may be associated with adverse health effects in animals and humans (workers or end users);
- it does not bioaccumulate in animals and humans;
- it is easily removable from the waste water;
- it does not migrate to the surface of the substrate, via leaching or volatilisation (i.e. it is fixed on the matrix);



- in comparison with the original chemical, it reduces smoke formation and the smoke produced is less harmful;
- it is renewable and bio-based;
- it is recyclable.

[ 296, VITO 2019 ]

Additionally, in the case of using alternatives to halogenated flame retardants (e.g. brominated flame retardants) the important aspects to take into account are:

- higher loadings and more chemicals are needed to realise the same fire-resistant properties in the textile;
- they are more prone to hydrolysis;
- some flame retardants are coloured (e.g. red phosphor, graphite);
- they are more difficult to disperse in formulation;
- they have different fire-resistant mechanisms;
- they change the properties of the textile (e.g. hardness, plasticity);
- their compliance with the requirements for fire-resistant properties of top-quality applications (e.g. hotels, boats, aeroplanes, trains, cinemas, theatres).

[ 129, Centexbel 2019 ] [ 108, Derden et al. 2010 ]

The certification of chemicals under existing schemes can help ensure that some of these criteria are fulfilled.

Possible fire retardants are distinguished based on their permanence in permanent fire retardants, on the one hand, and in non-permanent fire retardants on the other hand:

- Permanent fire retardance can be achieved by:
  - chemically binding complex organophosphorus compounds to fibres by treatment with an ammoniac or a melamine derivate (see Section 4.7.4.2);
  - mixing a flame retardant in melt spinning or in polymer granulates;
  - mixing fibres with polymers or co-polymers that are fire-retardant (e.g. polyvinyl chloride, polyvinylidene chloride, acrylic-based polymer combinations with antimony trioxide, polyphosphonates;
  - treating wool with zirconium salts for example.
- Non-permanent (not wash-proof) fire retardants include:
  - ammonium salts from phosphate, bromide, chloride, sulphonate;
  - boracic acid, borax.

[ 108, Derden et al. 2010 ] [ 297, Lubrizol 2021 ] [ 298, FRX Polymers 2019 ]

Flame retardant preparations with less than 0.1 % formaldehyde in the formulation are used for reducing formaldehyde emissions from the flame-retardant treatments [ 293, Zietlow B. 2020 ].

### Organophosphorus compounds

Textiles can be made fire-resistant by including phosphorus (P)-containing compounds, which in case of fire, act to convert carbon in the textile to a layer of char which blocks the access of oxygen to the textile, isolates against heat and limits the release of flammable gases from the textile, so preventing or limiting the fire development [ 324, TWG 2020 ], [ 299, Swedish EPA 2020 ].

Organic phosphorus compounds are used on the front side of textiles, so particular textile properties are thereby lost (technical limitation). However, as opposed to chemically binding complex organophosphorus compounds, non-permanent organophosphorus compounds offer very little resistance against moisture (for example they are washed out when the textile is cleaned). Thus, there are some technical limitations to the use of organophosphorus compounds. In addition, it should be noted that some organophosphorus flame retardants are also

halogenated (mostly chlorinated) and that several organophosphorus compounds have a harmonised classification under CLP for their hazard profile.

Products based on a dispersion of phosphorus-containing compounds offer environmental and economic advantages for flame-retardant finishing for 100 % PES substrates: Condensation temperatures (150-170 °C) are lower compared to the conventional thermosol process (190-200 °C) and no emissions of formaldehyde are induced. Final cleaning is not necessary. The product meets the values of the international standards such as DIN 4102 B1/B2, BS 5867 Part 2 and NFP 92-504 (M1) [ 44, ÖKOPOL 2011 ].

#### Melamine

Products based on melamine are also possible alternative chemicals for making textiles fire-resistant. Melamine pyrophosphate is an example of a melamine product. In 2010, this product was tested as an alternative fire retardant but insufficient fire-resistant properties were discovered for some applications [ 108, Derden et al. 2010 ].

#### Zirconium salts

Zirconium salts are a technically feasible alternative fire retardant for wool. According to [ 108, Derden et al. 2010 ], zirconium salts have already been in use in the textile sector for decades, for making wool fire-resistant. In this case, the yarn itself is made fireproof. In an additional step (e.g. if wool is incorporated into a carpet), an extra fireproof coating can be added (e.g. using latex). The latter activity is often carried out in job-processing companies, where decabDE is used as a fire retardant [ 108, Derden et al. 2010 ].

#### Aluminium trihydroxide

In the carpet industry, Al(OH)<sub>3</sub> has been used as fire retardant for the past 10-15 years. The formation of hydrates has a cooling effect [ 108, Derden et al. 2010 ]. Aluminium trihydroxide is also considered to be an alternative to SCCPs as flame retardant [ 300, SUBSPORT 2013 ].

#### Zinc borate

According to the sector, zinc borate is only used for specific applications (e.g. heavy-duty tents). This substance is also dangerous for the environment and public health (R-phrases, e.g. R-50, R-52) [ 108, Derden et al. 2010 ].

#### Intumescent systems

Intumescent systems, which can either be applied as coatings or can be reacted into the textile, act by generating a highly expansive foam char in fire, by a combination of an acid released in fire which reacts with carbon (either in the textile or in the intumescent system) to accelerate char formation and a 'blower' which releases gas to expand the char. Synergists can also be included to accentuate char production and improve the char barrier qualities, e.g. metals which ceramify the char [ 324, TWG 2020 ].

[ 301, SUBSPORT 2013 ] identified intumescent systems containing ammonium polyphosphate, pentaerythritol and melamine as possible alternatives for HBCD for textile coating.

#### **Achieved environmental benefits**

Reduction or prevention of emissions of hazardous substances to the environment and of waste.

#### **Environmental performance and operational data**

When replacing flame retardants, a point of consideration is that substitutes may have different characteristics (e.g. freezing point, water solubility) to the chemicals to be replaced and the use of alternatives may imply process-related modifications (e.g. keeping chemicals with a lower freezing point warm when in storage).

The flame retardants used also need to comply with the requirements (demanded test standards) and to be compatible with the substrate concerned. For example, the selection of flame

retardants is largely determined by the specific application (e.g. the fire-retarding mechanism that is used and the required fire-retarding properties).

Consequently, the selection of flame retardants may be more technically difficult for job-processing companies due to the higher variety of activities and requirements of clients, the smaller batches that are produced, the higher number of suppliers, etc.

### **Cross-media effects** [ 108, Derden et al. 2010 ]

In some cases, alternative substances have an equally negative (or even worse) impact on the environment and no, or very little, research has been found regarding its environmental effects and health risks.

Full-scale data for a Flemish case study indicate that a substantial part of the organic phosphorus, present in the waste water from the textile plant, originating from the application of DMPPA or THPC (tetrakis(hydroxymethyl)phosphonium chloride) as an active flame-retardant substance, is currently removed by the municipal sewage treatment plants (plants with indirect discharge). Biological degradation and adsorption to the sludge are considered the mechanisms responsible for this removal. However, using biological pretreatment (on site) removes organophosphorus compounds, but makes the effluent unsuitable for municipal sewer discharge (e.g. due to its COD/BOD and BOD/P ratio it is not considered compatible with household waste water ). On the other hand, to comply with the standards for direct discharge (2 mg/l), biological treatment would need to be followed by sand filtration or activated carbon (GAC) adsorption. Investment and operating costs for such biological and additional tertiary treatment are substantial [ 302, EURATEX 2020 ].

Physico-chemical phosphorus removal is based on the principle of (co-)precipitation of phosphates. However, organic phosphorus compounds are not removed from waste water when this waste water treatment technique is implemented [ 303, Derden et al. 2008 ]. There is therefore a possible displacement of the environmental problem and there may be difficulties to comply with the permit limit values for emissions of phosphorus to water.

The US EPA has assessed 31 hazard profiles of flame retardants, in terms of human health effects, aquatic toxicity and environmental fate. This helps in the selection of a flame retardant by pointing out the possible trade-offs (see Table 4.87) [ 304, US EPA 2014 ].

Table 4.87: Hazard profiles of some flame retardants

Chemical	CAS Number	Human health effects										Aquatic toxicity <sup>(1)</sup>		Environmental fate		
		Acute toxicity	Carcinogenicity	Genotoxicity	Reproductive	Developmental	Neurological	Repeated dose	Skin sensitisation	Respiratory sensitisation	Eye irritation	Dermal irritation	Acute	Chronic	Persistence	Bioaccumulation
<b>Halogenated flame retardants</b>																
<b>Discrete halogenated flame retardants</b>																
Bis(hexachlorocyclopentadieno) cyclooctane	13560-89-9	L	M <sup>(2)</sup>	M <sup>(2)</sup>	VL	VL	L	M	L	NI	VL	L	L	L	VH	H
Brominated poly(phenylether)	Confidential	L	L <sup>(3)</sup>	L	VL <sup>(3)</sup>	M <sup>(3)</sup>	L <sup>(3)</sup>	L <sup>(3)</sup>	L	NI	L	VL	L	L <sup>(3)</sup>	VH <sup>(4)</sup>	H <sup>(4)</sup>
Decabromodiphenyl ethane	84852-53-9	L	M <sup>(2)</sup>	L	L	H <sup>(2)</sup>	L	L	L	NI	VL	VL	L	L	VH	H
Ethylene bis-tetrabromophthalimide	32588-76-4	L	M	L	L	M <sup>(2)</sup>	L	L	L	NI	VL	VL	L	L	VH	H
Tetrabromobisphenol A bis (2,3-dibromopropyl) ether	21850-44-2	L	M	M	M	M	L	M	L	NI	L	L	L	L	VH	H
Tris(tribromoneopentyl) phosphate	19186-97-1	M	M	L	M	M	H	L	L	NI	L	L	L	L	H	M
Tris(tribromophenoxy) triazine	25713-60-4	L	L	L	L	L	L	L	L	NI	L	VL	L	L	VH	H
<b>Polymeric halogenated flame retardants <sup>(7)</sup></b>																
Brominated epoxy polymers	68928-70-1	L	L <sup>(5)</sup>	L	L <sup>(5)</sup>	L <sup>(5)</sup>	L	L <sup>(5)(6)</sup>	L	<sup>(5)</sup>	L	L	L <sup>(5)</sup>	L <sup>(5)</sup>	VH	L <sup>(5)</sup>
Brominated epoxy polymer(s)	Confidential	L	L <sup>(5)</sup>	L <sup>(5)</sup>	L <sup>(5)</sup>	L <sup>(5)</sup>	L	L <sup>(5)(6)</sup>	L <sup>(5)</sup>	<sup>(5)</sup>	L	L	L <sup>(5)</sup>	L <sup>(5)</sup>	VH	L <sup>(5)</sup>
Mixture of brominated epoxy polymer(s) and bromobenzyl acrylate	Confidential	L	L <sup>(5)</sup>	L <sup>(5)</sup>	L <sup>(5)</sup>	L <sup>(5)</sup>	L	L <sup>(5)(6)</sup>	L <sup>(5)</sup>	<sup>(5)</sup>	L	L	L <sup>(5)</sup>	L <sup>(5)</sup>	VH	L <sup>(5)</sup>
Brominated epoxy resin end-capped with tribromophenol	135229-48-0	L	L	L	L	L	L	L <sup>(6)</sup>	L	NI	L	VL	L	L	VH	L
Brominated polyacrylate	59447-57-3	L	L	L	L	L	L	L <sup>(6)</sup>	L	NI	L	L	L	L	VH	L
Brominated polystyrene	88497-56-7	L	L	L	L	L	L	L <sup>(6)</sup>	L	NI	L	L	L	L	VH	L
<b>Organic phosphorus or nitrogen flame retardants (PFR or NFR)</b>																
<b>Discrete PFR, NFR and P/NFR</b>																
Substituted amine phosphate mixture <sup>(10)</sup>	Confidential	H	M	M	M	M	L	M	L	M <sup>(2)</sup>	M	VL	M	L	H	L
Triphenyl phosphate	115-86-6	L	M	L	L	L	L	H	L	NI	L	VL	VH	VH	L	M
<b>Polymeric PFR and NFR</b>																
Bisphenol A bis-(diphenyl phosphate); BAPP	181028-79-5	L	M	L	L	L <sup>(2)</sup>	L <sup>(2)</sup>	L	L	NI	L	L	L	L	H	H <sup>(8)</sup>
Melamine cyanurate <sup>(10)</sup>	37640-57-6	L	M	M	M <sup>(2)</sup>	M <sup>(2)</sup>	L	H	L	NI	L	L	L	L	VH	L
Melamine polyphosphate <sup>(10)</sup>	<sup>(15)</sup>	L	M	M	H	M	M	M	L	NI	L	VL	L	L	H	L
N-alkoxy hindered amine reaction	191680-81-6	L	M	L	H	H	L	H	L	NI	L	VL	H	H	H	H <sup>(9)</sup>

products																
Phosphonate oligomer <sup>(11)</sup>	68664-06-2	L	M	L <sup>(2)</sup>	L <sup>(11)</sup>	L <sup>(11)</sup>	M <sup>(9)</sup>	L <sup>(2)(11)</sup>	L <sup>(2)(11)</sup>	NI	M <sup>(9)(11)</sup>	M <sup>(9)</sup>	L <sup>(11)</sup>	H <sup>(9)</sup>	VH	H <sup>(9)</sup>
Polyphosphonate	68664-06-2	L	L	L	L	L	L	L <sup>(6)</sup>	L	NI	L	L	L	L	VH	L
Phosphoric acid, mixed esters with [1,1'-bisphenyl-4,4'-diol] and phenol; BPBP	1003300-73-9	L	M	L	L <sup>(2)</sup>	L <sup>(2)</sup>	L	L	L	NI	VL	VL	H <sup>(2)</sup>	H <sup>(2)</sup>	H	M <sup>(9)</sup>
Poly[phosphonate-co-carbonate]	77226-90-5	L	L	L	L	L	L	L <sup>(6)</sup>	L	NI	L	L	L	L	VH	L
Resorcinol bis-diphenylphosphate; RDP	125997-21-9	L	M <sup>(2)</sup>	L	L	M	M	M	L	NI	L	VL	VH	VH	M	H <sup>(9)</sup>
<b>Inorganic flame retardants</b>																
Aluminium diethylphosphinate	225789-38-8	L	L <sup>(2)</sup>	L	-L	M <sup>(2)</sup>	M <sup>(2)</sup>	M <sup>(2)</sup>	L	NI	L	VL	M	M	H <sup>(14)</sup>	L
Aluminium hydroxide	21645-51-2	L	L <sup>(2)</sup>	L	L <sup>(2)</sup>	L	M	M <sup>(2)</sup>	L	NI	VL	VL	-L	-L	H <sup>(14)</sup>	L
Ammonium polyphosphate	68333-79-9	L	L	L	L	L	L	L <sup>(6)</sup>	L	NI	VL	L	L	L	VH	L
Antimony trioxide <sup>(12)</sup>	1309-64-4	L	M <sup>(13)</sup>	M	M	L	L	H	L	NI	L	M	H	M	H <sup>(14)</sup>	L
Magnesium hydroxide	1309-42-8	L	L	L	L	L	L	L	L	NI	M	L	L	L	H <sup>(14)</sup>	L
Red phosphorus	7723-14-0	L	L	M	L	L	L	L	L	NI	M	M	L	L	H	L
Zinc borate	1332-07-6	L	L	H	M	M	H	L	L	NI	L	L	H	H	H <sup>(14)</sup>	L

NB: VL: Very Low hazard, L: Low hazard, M: Moderate hazard, H: High hazard, VH: Very High hazard.

Endpoints in coloured cells (VL, L, M, H, and VH) were assigned based on empirical data.

Endpoints in italics (VL, L, M, H, and VH) were assigned using values from predictive models and/or professional judgment.

NI: No information.

<sup>(1)</sup> EPA/Department for Energy criteria are based in large part upon water column exposures which may not be adequate for poorly soluble substances such as many flame retardants that may partition to sediment and particulates.

<sup>(2)</sup> Based on analogy to experimental data for a structurally similar compound.

<sup>(3)</sup> This alternative may contain impurities. These impurities have hazard designations that differ from the flame-retardant alternative, brominated poly(phenylether), as follows, based on experimental data: HIGH for human health, HIGH for aquatic toxicity, and VERY HIGH for bioaccumulation.

<sup>(4)</sup> This chemical is subject to testing in an EPA consent order for this endpoint.

<sup>(5)</sup> Different formulations of the commercial product are available. One of these many formulations has an average molecular weight of ~1 600 and contains significant amounts of lower molecular weight components. These lower molecular weight components have hazard designations different than the polymeric flame retardant, as follows: HIGH (estimated) for bioaccumulation; HIGH (experimental) for acute aquatic toxicity; HIGH estimated for chronic aquatic toxicity; MODERATE (experimental) for developmental; and MODERATE (estimated) for carcinogenicity, genotoxicity, repeated dose, reproductive, and skin and respiratory sensitization toxicity.

<sup>(6)</sup> This hazard designation would be assigned MODERATE if > 5 % of the particles are in the respirable range as a result of dust-forming operations.

<sup>(7)</sup> The range of polymer molecular weight can be broad. The polymers listed here have low toxicity for human health and aquatic endpoints. Not all polymers will have this low toxicity; hazards will vary with physico-chemical properties.

<sup>(8)</sup> The highest hazard designation of a representative component of the oligomeric mixture with molecular weights < 1 000.

<sup>(9)</sup> The highest hazard designation of any of the oligomers with molecular weight < 1 000.

<sup>(10)</sup> Hazard designations are based upon the component of the salt with the highest hazard designation, including the corresponding free acid or base.

<sup>(11)</sup> Phosphonate oligomer, with a molecular weight range of 1 000 to 5 000, may contain significant amounts of an impurity, depending on the final product preparation. This impurity has hazard designations that differ from the polymeric flame retardant, as follows: MODERATE (experimental) for carcinogenicity, reproductive and repeated dose toxicity, skin sensitisation, eye and dermal irritation; and HIGH (experimental) for developmental toxicity and acute and chronic aquatic toxicity.

<sup>(12)</sup> This compound is included in the ongoing EPA Work Plan evaluation for antimony trioxide.

<sup>(13)</sup> Ongoing studies may result in a change in this endpoint.

<sup>(14)</sup> Recalcitrant: Substance is comprised of metallic species that will not degrade, but may change oxidation state or undergo complexation processes under environmental conditions.

<sup>(15)</sup> Some of the melamine polyphosphates:

- CAS 20208-95-1 1,3,5-triazine-2,4,6-triamine monophosphate
- CAS 15541-60-3 diphosphoric acid, compound with(...)
- CAS 218768-84-4 Melapur M 200
- CAS 209216-23-9 2-amino-1,9-dihydro-9-[(1S,3R,4S)-4-hydroxy-3-(...)]

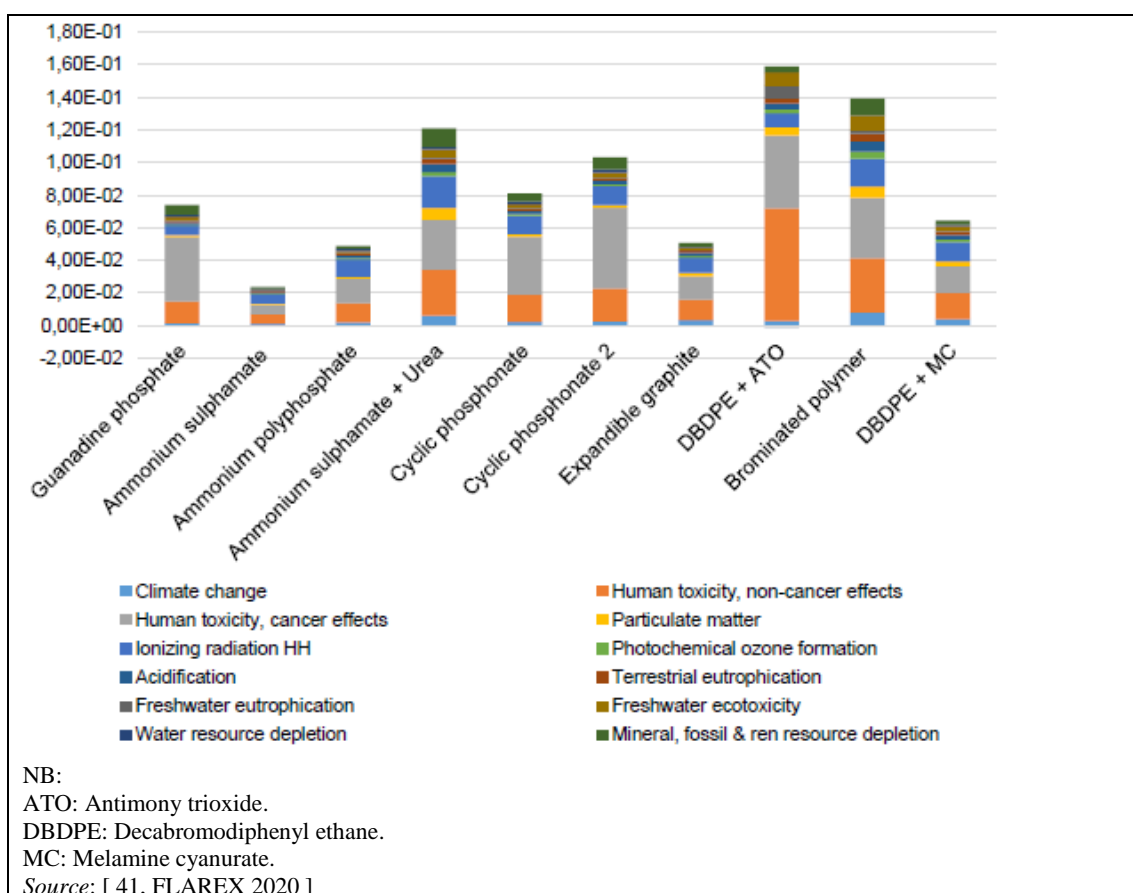
Source: based on [ 304, US EPA 2014 ] [ 305, US EPA 2015 ]

Other sources of information are Annex VI to the CLP Regulation, the REACH registration dossiers, the CoRAP evaluations, literature, etc.

In particular, the LIFE project FLAREX [41, FLAREX 2020] carried out an evaluation of the following alternatives:

- Guanidine phosphate (CAS number 5423-22-3).
- Ammonium polyphosphate (CAS number: 68333-79-9).
- Ammonium sulphamate (CAS number: 7773-06-0).
- Cyclic phosphonate, made of two components: (5-ethyl-2-methyl-1,3,2-dioxaphosphorin-5-yl) methyl dimethyl phosphonate P-oxide (CAS number: 41203-81-0) and Bis [5-ethyl-2-methyl-1,3,2-dioxaphosphorin-5-yl) methyl] methyl phosphonate P,P'-dioxide (CAS number: 42595-45-9).
- Expandable graphite (CAS number: 7782-42-5). Expandable graphite is granular graphite in which sulphuric acid has been introduced between the layers of the graphite structure with some oxidation of the carbon. The acid is tightly held and does not leach out. Grades are available with an acidic or neutral character. During a fire, the graphite expands very quickly to over 100 times its original volume, resulting in a heat and mass transfer barrier. This effect is visible in almost any thermoplastic, and is sometimes used in combination with other flame retardants like ammonium polyphosphate (APP).

Figure 4.52 below compares the results of the life-cycle assessment of alternative and conventional flame retardants. The results have been normalised to show the magnitude of the different impact categories. The normalised values represent the annual environmental impact or resource consumption that an average person contributes worldwide, expressing the results in person equivalent. The best environmental solutions are the ammonium–sulphamate-, ammonium–polyphosphate-, and expandable-graphite-based flame retardants.



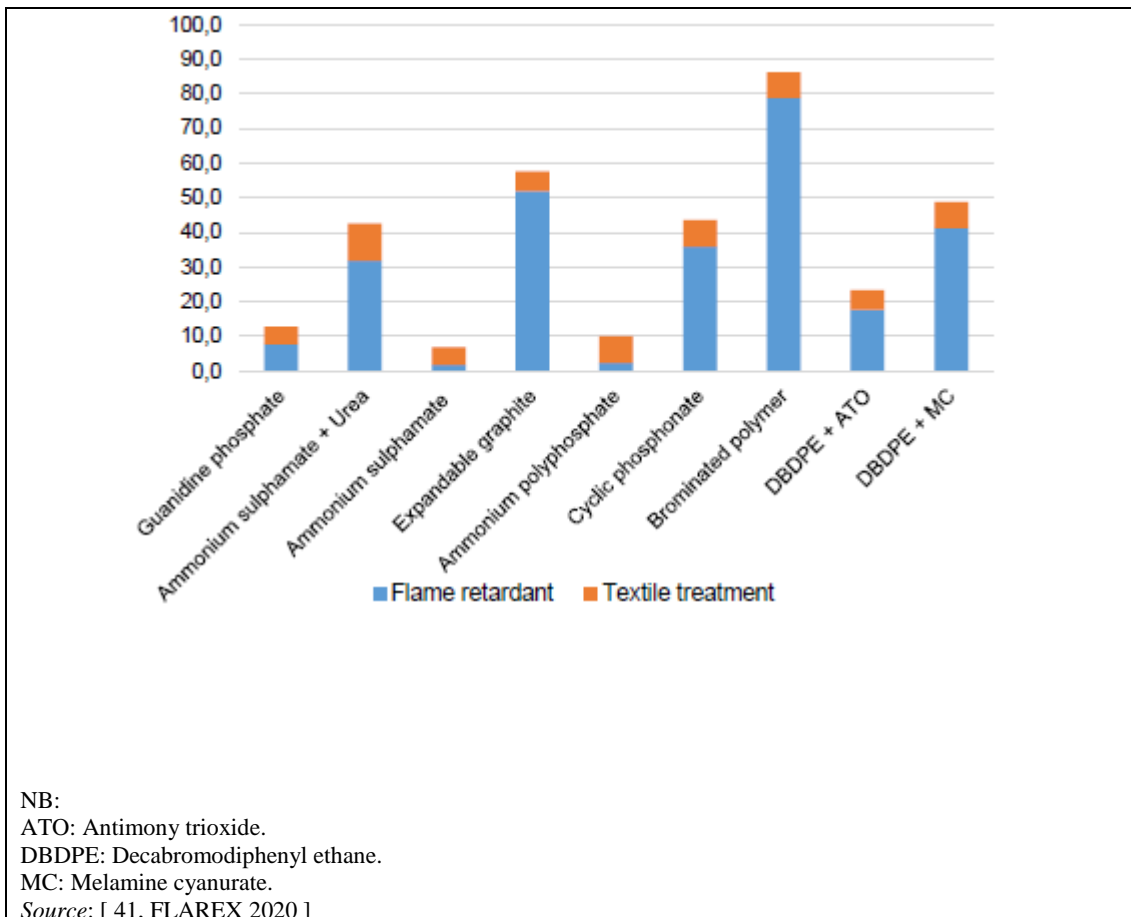
**Figure 4.52: Environmental impact of various flame retardants over their life cycles (expressed in person equivalent)**

**Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique. For many applications, alternative flame retardants are not readily available but have to be evaluated and tested case by case [129, Centexbel 2019].

**Economics**

The LIFE project FLAREX [41, FLAREX 2020] provides some information about the direct costs of some alternative and conventional flame retardants and the cost associated with the treatment of the textile products, as shown in Figure 4.53 below. The products with the best economical performance are ammonium sulphamate and ammonium polyphosphate.



**Figure 4.53: Direct costs of various flame retardants (expressed in euros per 100 m² of textiles finished with flame retardants)**

**Driving force for implementation**

- Chemical and environmental legislation (e.g. REACH).
- Compliance with certification schemes requested by clients.

**Example plants**

Concerning the plants from the data collection, 14 plants out of 28 carrying out finishing treatment for flame retardance do not use brominated flame retardants. In particular:

- Plant BE010 uses ammonium sulphamate;
- Plant BE011 uses aluminium trihydroxide;
- Plant SE118 uses phosphonate.

**Reference literature**

[ 41, FLAREX 2020 ], [ 44, ÖKOPOL 2011 ], [ 108, Derden et al. 2010 ], [ 214, EIPPCB 2019 ], [ 293, Zietlow B. 2020 ], [ 296, VITO 2019 ], [ 297, Lubrizol 2021 ], [ 298, FRX Polymers 2019 ], [ 299, Swedish EPA 2020 ], [ 300, SUBSPORT 2013 ], [ 301, SUBSPORT 2013 ], [ 303, Derden et al. 2008 ], [ 304, US EPA 2014 ], [ 305, US EPA 2015 ], [ 306, UMass Lowell 2005 ], [ 324, TWG 2020 ]

**4.7.4.2 Ammonia-cured flame retardants****Description**

Cotton textile is impregnated with phosphorus compounds and subsequently cured with ammonia.

**Technical description**

[ 307, UK, EURATEX 2019 ] [ 308, Cotton Incorporated 2003 ]

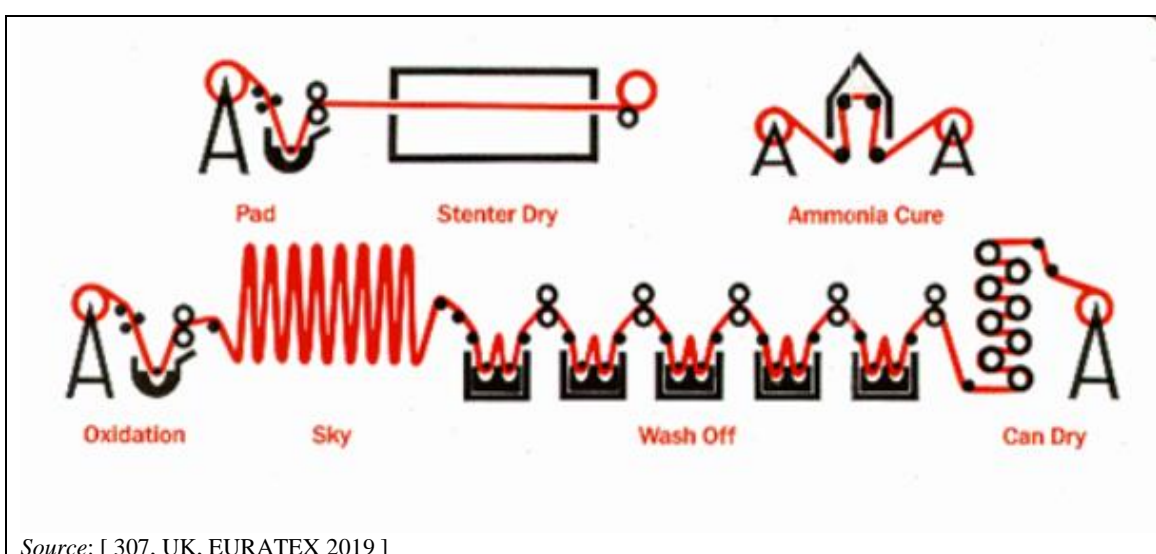
Flame-retardant finishing of natural fibres is required for applications such as technical textiles or personal protective equipment (PPE). This process often requires the application of organo-halogenated compounds for textiles with the strictest requirements in terms of flame retardance, especially if the textiles are washed frequently during their cycle of use (e.g. in the case of PPE). The aim of this technique is to replace these halogenated substances with less persistent substances.

The typical processes using ammonia-cured flame retardants are the 'Proban process' or the 'Pyrovatex process' [ 324, TWG 2020 ].

In the first step, the textile is impregnated by padding with a phosphorus compound (e.g. THPC - tetrakis(hydroxymethyl)phosphonium chloride) and dried, e.g. in a stenter frame. The textile is then chemically cured with ammonia in a closed chamber in order for the nitrogen-phosphorus complex to be fixed to the textile and to reach a high degree of fastness.

The full flame-retardant effect is achieved by oxidation of the phosphorus compound with  $H_2O_2$  and exposure of the treated textile to air for a short time (so-called sky time). Finally, excess chemicals are washed off and the textile is dried.

The process is summarised in Figure 4.54.



Source: [ 307, UK, EURATEX 2019 ]

**Figure 4.54: Flame-retardant finishing with ammonia curing**



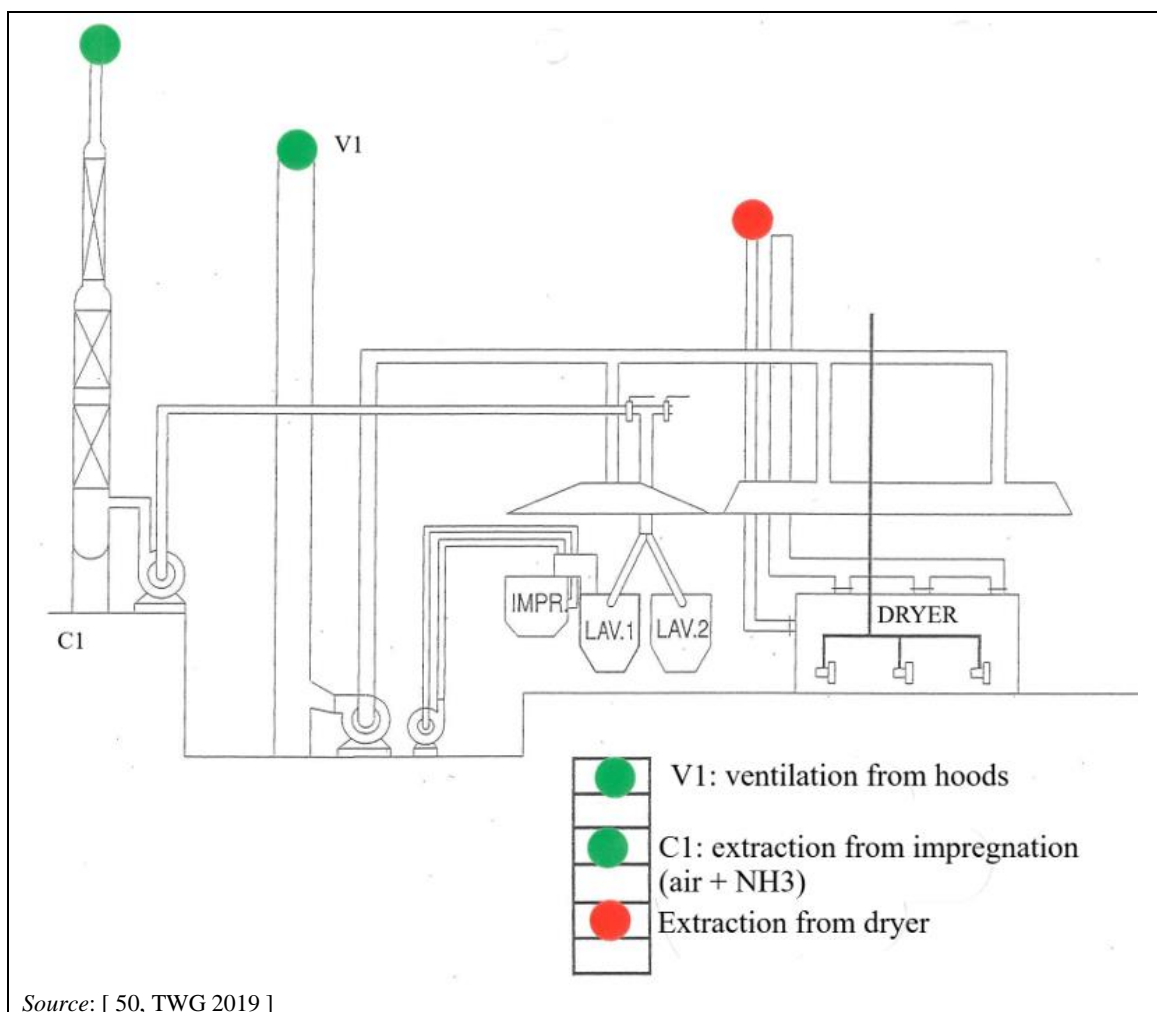
**Achieved environmental benefit**

Reduction of emissions of hazardous substances to the environment.

**Environmental performance and operational data**

The curing with ammonia is a continuous process. The textile is guided at the inlet and outlet of the fumigation chamber through a water lock, so that no gaseous ammonia from the chamber can escape to atmosphere.

The air extraction system of Plant BE013 is described in Figure 4.55. Air extracted from the impregnation stage is treated by water scrubbing and there are reported to be no  $\text{NH}_3$  emissions to air. Air extracted from the hoods is not treated and annual averages of  $\text{NH}_3$  emissions to air are between  $6 \text{ mg/Nm}^3$  and  $10.7 \text{ mg/Nm}^3$  (with short-term maximum values up to  $56.2 \text{ mg/Nm}^3$ ).



**Figure 4.55: Example of air extraction from flame-retardant finishing with ammonia curing**

Concerning emissions to water, the nitrogen-phosphorus compounds used are difficult to biodegrade and, depending on the capacity of the downstream waste water treatment plant, the retained residues may have to be recycled or disposed of as waste.

Residual ammonia on fabric as it exits the unit is usually minor and should permit handling with only normal ventilation facilities in that area [ 308, Cotton Incorporated 2003 ].

**Cross-media effects**

Emissions of  $\text{NH}_3$  to air and of nitrogen to water.

**Technical considerations relevant to applicability**

This technique is applicable to cotton fibres.

**Economics**

The technique described is significantly more expensive due to the additional process steps compared to the standard flame-resistant application equipment, e.g. in a stenter frame [ 307, UK, EURATEX 2019 ].

**Driving force for implementation**

Environmental and chemicals legislation.

**Example plants**

Plant from the data collection: BE013.

**Reference literature**

[ 50, TWG 2019 ], [ 307, UK, EURATEX 2019 ], [ 308, Cotton Incorporated 2003 ]

**4.7.5 Finishing with oil, water and soil repellents****4.7.5.1 Oil, water and soil repellents with improved environmental performance****Description**

Oil, water and soil repellents are selected considering:

- the risks associated with the substances (see Section 4.1.6.1) in particular in terms of persistence and toxicity, including the potential for substitution (e.g. PFAS, see Section 4.1.6.1);
- the composition and form of the textile materials to be treated;
- the product specifications (e.g. combined oil, water, soil repellence and flame retardance).

**Technical description**

As mentioned in Section 2.9.2.2, PFOA and its salts are listed in Annex XVII to REACH and PFOS are priority hazardous substances and prohibited by the POP Regulation.

An optimised water- and oil-repellent finish is designed for a specific fabric based on its fibre type and fabric construction. The finish forms an array of microscopic polymer domains on the fabric surface (not a film or coating) with the fluorinated chains perpendicular to the fabric surface and close enough to one another to act like a continuous surface, thus preventing water and oils from reaching the fabric [ 309, Danish EPA 2015 ].

For textiles requiring only a water-repellent finish without any soil- and oil-repellent effects, fluorine-free water-repellent agents with a different chemical basis are used depending on the specified finish requirements, e.g. paraffin formulations, polysiloxanes, modified melamine resins or polyurethanes or highly branched fluorine-free polymers [ 44, ÖKOPOL 2011 ].

Preparations with less than 0.1 % formaldehyde in the formulation are used for reducing formaldehyde emissions from the water- and oil-repellent treatments [ 293, Zietlow B. 2020 ].

Table 4.88 shows major categories of non-fluorine alternatives available on the market.

Table 4.88: Overview of non-fluorine alternatives

Major category	Example compounds	Application	Oil repellency	Water repellency	Market capacity
Hydrocarbons	Paraffin-based. Melamine-based. Acrylic copolymers. Waxes.	T.U.A.	None.	Yes (all subgroups).	Already in use, should have reasonable capacity.
Silicones	Aminofunctional PDMS. Sodium methylsiliconate water. Isobutyltrimethoxysilane. Octylsilane.	T.A.L.	None.	Yes (all subgroups).	Already in use, should have reasonable capacity. Note possible issues with D4, D5, D6 impurities.
Dendrimers	Hydrophobic, hyperbranched polymers. Hyperbranched polymers in hydrocarbon matrix.	T.A.	None.	Yes (all subgroups).	Only 2 manufacturers identified, may be more limited.
Polyurethane	Polyurethane emulsions. Polyurethane dispersions.	T.A.	Possibly. Evidence is unclear.	Yes (all subgroups).	Already in use, should have reasonable capacity
Nanomaterials	Hexamethyldisiloxane applied by plasma-based nano-coating. Molecularly attached hydrophobic 'whiskers' attached to individual fibres. Uses a hydrocarbon polymer.	T.A.	None.	Yes (all subgroups).	Three manufacturers identified with one product each.
Alternative technologies	Alternative weaving and fibre control.	T	Possibly. Evidence is unclear.	Yes.	Still subject to R&D.

NB: T: textiles, U: upholstery, L: leather, A: apparel, C: carpets  
Source: [ 310, COM 2020 ]

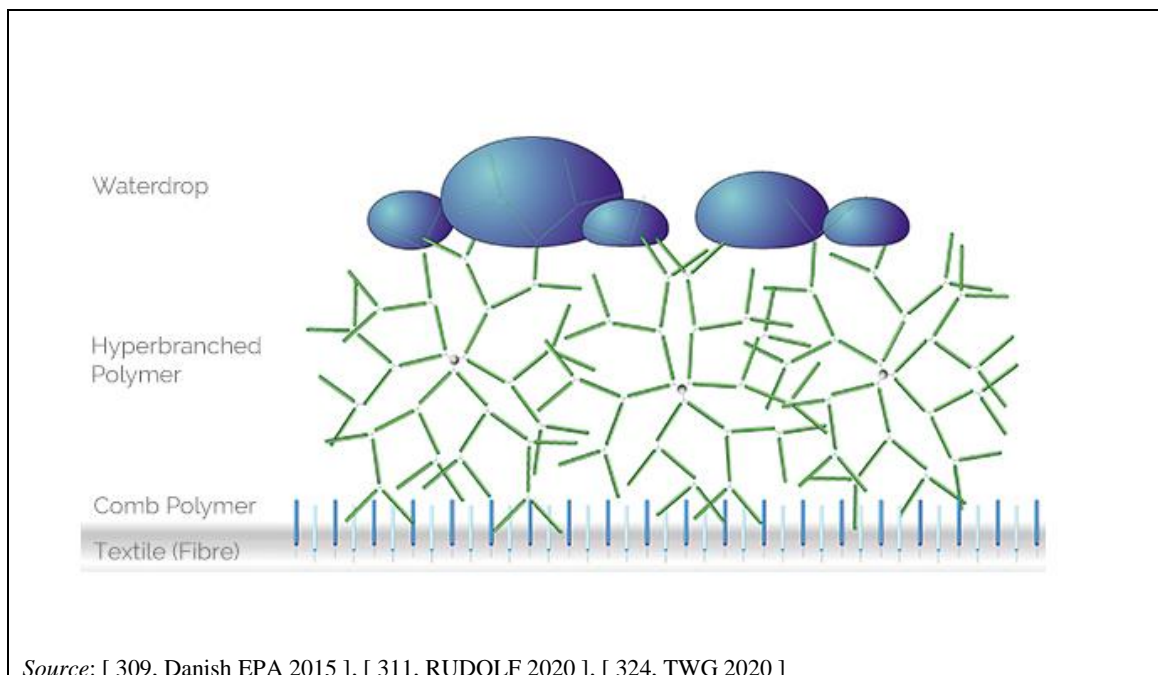
#### Dendrimers and hyperbranched polymers

The hyperbranched polymers group includes dendrimers, dendrons, dendrigraft polymers and branched polymers. They are all cascade polymers of different side- or branch extensions.

The oil- and soil-repellent dendrimer finishes include a fluorocarbon resin in their structure, while the fluorocarbon-free dendrimers only provide water repellency. Compared to other PFAS-based repellents, the fluorine content of the oleophobic dendrimer finishes is reduced. The fluorocarbon-free dendrimers provide water repellency through closely packed surface groups, i.e. methyl groups.

Commonly, these finishes are applied as two-component systems consisting of an emulsion containing the dendrimers and a solution containing a cross-linking substance providing the fixation to the fibre. Fluorocarbon-free dendrimers are based on hydrocarbon or polyurethane chemistry. Cross-linking is commonly achieved by chemical binding of the dendrimers with isocyanates to the fibre. Glycols are added as solvents and cationic surfactants in small amounts act as emulsifiers [ 309, Danish EPA 2015 ].

An example of a marketed product consists of polyurethane-dendrimer (hyperbranched polymers) with hydrophobic end groups connected to patented comb polymers (linear), which are fixed to the fibre surface (see Figure 4.56 below).



Source: [ 309, Danish EPA 2015 ], [ 311, RUDOLF 2020 ], [ 324, TWG 2020 ]

**Figure 4.56: Principle of a marketed dendrimer**

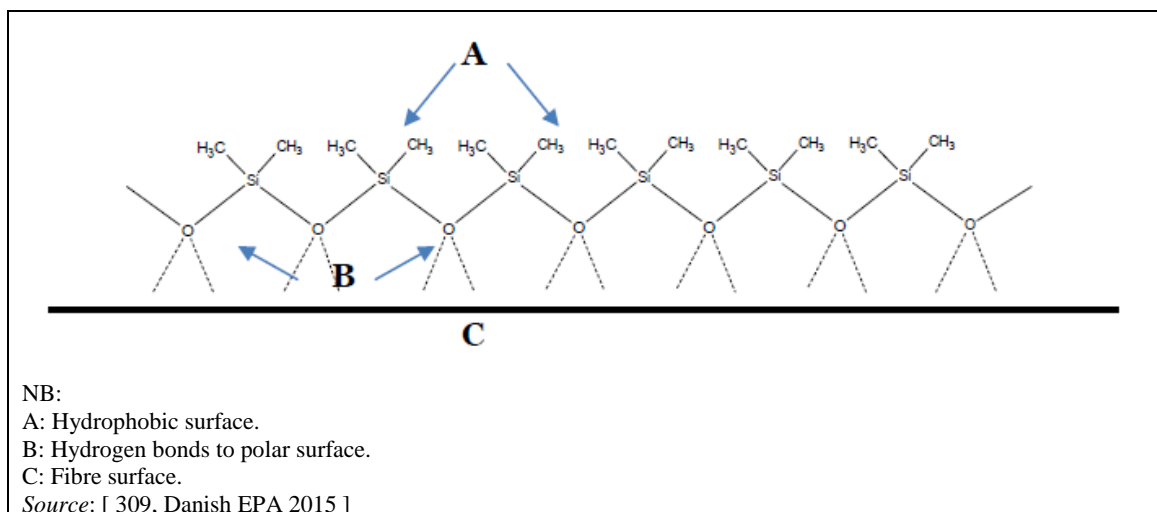
In the case of knitted polyester, this technology has provided very good results for water repellence, achieving the same water repellence grade and washing fastness as that obtained for the PFC C8 and C6 products.

In the case of wool, the product does not meet either water or oil repellence requirements after washing. Indeed, the water repellence achieved is similar to PFC C6, but the washing fastness is lower, because this product is not resistant to dry cleaning.

The dendrimers technically have some advantages in providing soft textiles and excellent low-temperature curing [ 309, Danish EPA 2015 ].

#### Silicone-based repellents

Silicone repellents are also commonly used in the textile industry to give water repellence to fabrics. These finishing agents are generally made of elastomeric polydimethylsiloxanes (PMDS) which can coat the fabric surface after curing. The structure obtained after finishing by padding of the fabric surface is a three-dimensional, flexible and hydrophobic layer bonded to the fabric's fibres (see Figure 4.57). It should be noted that silicone repellents' finishing agents have moderate washing fastness due to the hydrolysis of the siloxane during laundry.



**Figure 4.57: Principle of polydimethylsiloxanes on a fibre surface**

Various types of silicone polymers based on PDMS have been shown to contain residual levels of cyclic volatile methyl siloxanes due to residues from manufacturing processes, e.g. octamethylcyclotetrasiloxane (D4) and decamethylcyclopentasiloxane (D5).

Studies on related PDMS polymers showed a relatively fast depolymerisation process by hydrolytic degradation in soil. Thereby silanols of lower molecular weight are formed and further hydrolysis predominantly proceeds to yield dimethylsilanediol (DMSD) and trimethylsilanol (TMS) [ 312, Holmquist et al. 2016 ].

The silicone-based repellents have been tested on a non-woven polyester fabric (automotive), obtaining a high level of water repellence

#### Achieved environmental benefit

Reduction or prevention of emissions of hazardous substances to the environment and of waste.

#### Environmental performance and operational data

The alternative water and oil repellents do not need particular conditions; they can be applied by padding like conventional finishes or by spraying directly onto fabric surfaces. Chemicals with strong affinities for the surface of fibres can be applied by exhaustion in dyeing machines, usually after completing the dyeing process.

Recipes can be prepared and dosed by an automatised system.

Table 4.89 compares the energy, water and resource consumption of different types of water repellents (the dendrimer and silicone-based repellents versus the long-chain PFC C8).

**Table 4.89: Consumption of energy, water and resources for treating 90 m<sup>2</sup> of textile**

	PFC C8-based	Dendrimer	Silicone-based
<b>Padding process</b>			
Material	PFC C8-based 3.5 kg	Dendrimer 7.5 kg	Silicone-based 13.5 kg
	Water for padding 150 kg	Wetting agent 0.75 kg	Catalyst 6.75 kg
		Water for padding 150 kg	Acetic acid 80 % 52.5 g
Electricity	3.5 kWh	3.5 kWh	3.5 kWh
Waste water	0.15 m <sup>3</sup>	0.15 m <sup>3</sup>	0.3 m <sup>3</sup>

<b>Drying and curing</b>			
Thermal energy	800 MJ	800 MJ	800 MJ
Electricity	23.1 kWh	23.1 kWh	23.1 kWh
<i>Source: [ 37, Manich et al. 2018 ]</i>			

A research project ([ 313, SUPFES 2018 ]) reviewed the hazards and environmental impacts of different groups of alternative water repellents: side-chain fluorinated polymers, silicones, hydrocarbons and other chemistries (including dendrimer and inorganic nanoparticles). The results are summarised in Table 4.90 below. There is still a lack of information on the hazards associated with these alternative water repellents, in particular for the dendrimer and inorganic nanoparticles [ 312, Holmquist et al. 2016 ].

**Table 4.90: Hazard profiles of water repellents**

Substance	Human health								Ecotoxicity		Environmental Fate	
	Carcinogenicity	Mutagenicity	Reproductive toxicity	Development toxicity	Endocrine activity	Acute toxicity	Repeated dose toxicity	Neurotoxicity	Acute aquatic toxicity	Chronic aquatic toxicity	Persistence	Bioaccumulation
Benchmark												
PFOA (C8) # $\alpha$	<b>H</b>	<b>L</b>	<i>H</i>	<b>H</b>	PEA	<b>M</b>	<b>H</b>	DG	<b>L</b>	<i>L</i>	<b>VH</b>	<b>H</b>
Side-chain fluorinated polymers												
Perfluorohexanoic acid (PFHxA) (C6) # $\alpha$	<i>L</i>	<b>L</b>	<i>M</i>	<i>M</i>	PEA	<b>L</b>	<i>M</i>	DG	<i>L</i>	<i>L</i>	<b>VH</b>	<i>L</i>
Perfluorobutane sulphonic acid (PFBS) (C4) # $\alpha$	DG	<b>L</b>	<i>L</i>	<b>L</b>	PEA	<b>L</b>	<i>L</i>	DG	<i>L</i>	<i>L</i>	<b>VH</b>	<i>L</i>
Silicones												
Short-chain silanols #	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG
DMSD #	DG	DG	DG	DG	DG	DG	DG	DG	<i>M</i>	DG	<i>VH</i>	<i>L</i> *
TMS #	DG	<i>L</i>	DG	<i>L</i>	DG	<b>M</b>	<i>M</i>	DG	<b>L</b>	DG	DG	<i>L</i> *
D4 $\alpha$	<b>L</b>	<i>L</i>	<i>L</i>	<b>L</b>	PEA	<b>L</b>	<b>H</b>	DG	<i>L</i>	<b>VH</b>	<b>VH</b>	<i>VH</i>
D5 $\alpha$	<b>L</b>	<b>L</b>	<b>L</b>	<b>L</b>	PEA	<i>H</i>	<b>H</b>	DG	<b>L</b>	<i>L</i>	<b>VH</b>	<i>VH</i>
Hydrocarbons												
Paraffin wax #	<b>L</b>	<b>L</b>	<i>VL</i> *	<i>VL</i> *	DG	<b>L</b>	<i>M</i>	DG	<i>L</i> *	<i>L</i> *	<b>L</b>	<i>L</i> *
Other chemistries (dendrimers, inorganic nanoparticles)												
Unkown	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG
NB: VL: Very Low hazard, L: Low hazard, M: Moderate hazard, H: High hazard, VH: Very High hazard, PEA: Potentially Endocrine Active, DG: Data Gap. Degradation products are denoted by # and impurities are denoted by $\alpha$ . Classifications in italics are of low confidence and in bold of high confidence. Classifications based on estimated data are marked with an asterisk (*). <i>Source: based on [ 313, SUPFES 2018 ], [ 312, Holmquist et al. 2016 ]</i>												

### Cross-media effects

None identified.

**Technical considerations relevant to applicability**

Provided that oil and soil repellence is not demanded at the same time and the corresponding specification of requirements for the finish allows their use, fluorine-free water-repellent agents are available.

If, however, the specified requirements include:

- combined soil, oil and water repellence;
- high effect level in tumbler, or line drying;
- suitability for lamination,

then these requirements can only be achieved at this point in time by using fluorocarbon resins or combinations of these with extenders, e.g. based on polyisocyanates blocked with 2-butanone oxime.

[ 44, ÖKOPOL 2011 ] [ 175, Benninger et al. 2016 ] [ 314, LEITAT 2018 ]

Fluorine-free water-repellent agents provide durable water repellency, but no repellency against oil, oil-based dirt and alcohol [ 309, Danish EPA 2015 ].

Hyperbranched polymers are applicable for knitted polyester and silicone-based repellents for non-woven polyester.

Table 4.91 shows whether fluorine-free water-repellent agents provide a similar level of performance and function to PFAS-based agents for the same application.

**Table 4.91: Evaluation of fluorine-free water-repellent agents by use category**

Textile consumer apparel	Home textiles	Textile professional apparel	Technical textiles	Leather
Yes, as oil repellency is regarded to be not critical for consumer apparel (mainly sports, outdoor textiles).	Partly, as oil repellency also includes stain repellency (when stain is based on oil). It was also indicated that durability is lower.	No, the alternatives do not provide resistance against oil, chemicals, blood, etc.	No, the alternatives do not provide resistance against oil, chemicals, blood, etc. Also, physical durability of the treated material needs to be increased.	Yes, when only water repellency is needed. In cases where oil and stain repellency is critical then no (this could apply to professional sports and footwear).
Source: [ 310, COM 2020 ]				

Fluorine-free water-repellent agents can be applied in the same way as PFAS substances. However, it was noted that the fluorine-free water-repellent are less stable (temperature, sun light), so other storage conditions might apply [ 310, COM 2020 ].

A technical problem encountered when using possible substitutes for PFOS and/or PFOA (e.g. PFBS) is managing to retain a combination of particular properties in the textile (oil, water and dirt resistance combined with flame retardance) [ 108, Derden et al. 2010 ].

Different projects/reports have been developed to find a proper substitution of BFR or PFAS offering both flame retardance and water, oil or soil repellence. However, it has been concluded that it is not always possible to use chlorine- or fluorine-free alternative substances, as the requirements for fire-resistant properties of top-quality applications (e.g. complying with ISO 15025 Protective clothing - Protection against flame - Method of test for limited flame spread) may not be achievable. Selection of an appropriate finishing agent requires complex and comprehensive research and testing [ 129, Centexbel 2019 ], [ 310, COM 2020 ], [ 309, Danish EPA 2015 ].

**Economics**

No specific investment is needed. In general, the price of fluorine-free alternatives is lower than that of fluorinated treatments.

**Dendrimer**

The purchasing cost of dendrimer is lower than fluorinated treatments: 27 % cost decrease compared to PFC C8-based product and 49 % cost decrease compared to PFC C6-based product.

The treatment cost of textiles with dendrimer is higher (21 %) than with PFC C8-based product and slightly higher (8 %) than with PFC C6-based product due to a higher dosage of the chemicals.

**Silicone-based**

The purchasing cost of silicone-based product is lower than fluorinated treatments (e.g. PFC C8- or C6-based product): 32 % cost decrease compared to PFC C8-based product and 53 % cost decrease compared to PFC C6-based product. The treatment cost of textiles with silicone-based products is lower (44 %) than PFC C6-based product due to the higher purchasing cost of the PFC C6 product. Similar chemical dosages are applied for both treatments.

**Driving force for implementation**

Environmental legislation.

**Example plants****Dendrimer**

- HIDROCOLOR s.l. (Llinars del Vallès, Barcelona, Spain).
- BIELLA MANIFATTURE TESSILI s.r.l. (Mongrando, Biella, Italy).

**Silicone**

- Inotex (Czech Republic).

Out of 45 plants from the data collection carrying out finishing treatment for water, oil and soil repellence, 12 plants use polysiloxane compounds and one plant (SE119) uses dendrimers.

**Reference literature**

[ 37, Manich et al. 2018 ], [ 44, ÖKOPOL 2011 ], [ 175, Benninger et al. 2016 ], [ 293, Zietlow B. 2020 ], [ 309, Danish EPA 2015 ], [ 310, COM 2020 ], [ 311, RUDOLF 2020 ], [ 314, LEITAT 2018 ], [ 324, TWG 2020 ]

**4.7.6 Shrink-proof finishing of wool****4.7.6.1 Chemical low-chlorine anti-felting****Description**

Inorganic salts of peroxymonosulphuric acid (e.g. potassium peroxymonosulphate,  $\text{KHSO}_5$ ) are used as oxidising agents for shrink-proof finishing of wool.

**Technical description**

The alternative Hercosett process is continuous, with the oxidising step comprised of the following phases:

- applying a solution containing oxidising agents based on peroxymonosulphuric acid and a surfactant to the wool;
- washing the reaction products out of the wool;
- treating the wool with a reducing agent; and
- rewashing.



The second step, coating with the resin/polymer, is the same as for the conventional (using chlorine oxidising agents) Hercosett process. See Section 2.9.2.9.

An overview of the process is given in Figure 4.58.

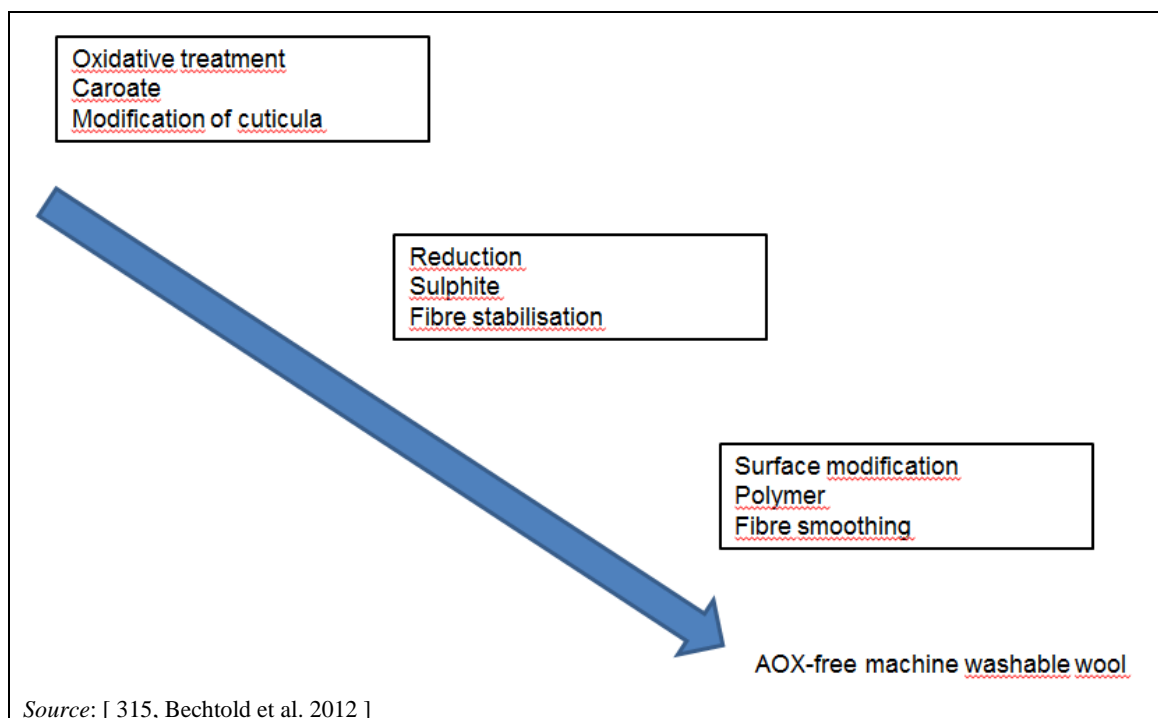


Figure 4.58: Low-chlorine anti-felting process steps

When the use of inorganic salts of peroxymonosulphuric acid as oxidising agents is limited due to product specifications (see the ‘Technical considerations relevant to applicability’) and the conventional Hercosett process using chlorine-containing chemicals as oxidising agents is applied, the following techniques are used to minimise emissions of AOX to water:

- closed-loop system for water reuse and recycling;
- evaporation of the residual waste water stream and handling of the remaining concentrated liquid as waste.

**Achieved environmental benefit**

No AOX emissions to water from the oxidising step.

**Environmental performance and operational data**

Table 4.92 below compares the mechanical properties of wool treated with the conventional chlorine-based Hercosett process and with the alternative Hercosett process using a chlorine-free oxidising agent.

Table 4.92: Mechanical properties of treated wool

Treatment	Diameter (µm)	Fineness (dtex)	Strength (cN/dtex)	Elongation (%)
Chlorine-Hercosett	22	5.17 ± 1.10	11.30 ± 2.12	41.52 ± 7.63
Low-chlorine anti-felting	21	4.58 ± 1.15	10.91 ± 1.88	43.00 ± 11.23

Source: [ 315, Bechtold et al. 2012 ]

The mechanical properties are comparable between the two processes. However, some evidence suggests that the shrinkage degree of washed wool for wool treated with the chlorine-free anti-felting process is much higher (up to 10 times for two or five washing cycles) than the maximum value of the Woolmark quality standard (Woolmark TM 31) [ 316, Blahutova M. 2021 ].

Alternative resins (low-chlorine or chlorine-free resins), as well as a shrink-proof finishing process totally avoiding chlorine have been investigated at laboratory scale [ 43, Johnson et al 2009 ].

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

The applicability may be restricted by product specifications (e.g. shrinkage).

#### **Economics**

The costs are comparable to the traditional chlorine-based Hercosett process.

#### **Driving force for implementation**

Environmental legislation.

#### **Example plants**

Plants from the data collection: AT005, CZ016, IT087 and IT097.

#### **Reference literature**

[ 43, Johnson et al 2009 ], [ 175, Benninger et al. 2016 ], [ 315, Bechtold et al. 2012 ], [ 316, Blahutova M. 2021 ], [ 317, Austrian EPA 2018 ]

## **4.7.7 Mothproofing**

### **4.7.7.1 Handling of mothproofing agents**

#### **Description**

Techniques to minimise spillage of mothproofing agents during dispensing and transport within the dyehouse.

#### **Technical description**

The majority of commercial formulations are supplied as self-emulsifying concentrates, referred to as concentrates.

For handling and transfer of concentrates to dyeing machines, the following measures are applied:

- concentrates are not pre-dissolved in the colour kitchen but are transferred from the colour storage to the point of addition to the process in sealed shockproof containers;
- concentrates are added directly to the process liquor only when the dyeing is under way and the dye bath volume is stable (prevents displacement spillage).

See also Sections 4.1.6.5.1 and 4.1.6.8.

For handling concentrates in relation to semi-continuous application, the following measures are applied:

- concentrates are stored in the original containers, within a bund and protected from accidental impact;

- concentrates are dispensed directly into the process liquor – stock solutions are not used;
- dispensing is not done manually but dosing pumps are used instead.

When using permethrin (CAS: 52645-53-1) as the mothproofing agent, specific measures concerning the waste water discharge (e.g. controlled water discharge, use of alkaline chemical oxidation pretreatment) should be implemented due to its hazardous properties (H410 very toxic to aquatic life with long-lasting effects) [ 318, bluesign 2012 ]. See also Section 4.1.6.1 and Section 4.1.7.3.4.1.

### **Achieved environmental benefits**

Reduction of emissions of mothproofing agents to soil, groundwater and surface water.

### **Environmental performance and operational data**

The impact of the material handling regime described above on overall plant effluent residues is difficult to quantify, but measurements on individual dyeing machines suggest that between 10 % and 20 % of the total emissions can arise from liquor spillage.

### **Cross-media effects**

None identified.

### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

### **Economics**

Many of the above measures regarding material handling have low or no cost. Accurate metering and dispensing systems for use in the colour store and as part of a continuous application system are estimated to cost in the range of EUR 8 000-16 000.

### **Driving force for implementation**

Environmental legislation.

### **Example plants**

Plants from the data collection: IT073, SE119, UK124 and UK127.

### **Reference literature**

[ 184, ENco 2001 ], [ 243, OSPAR 1994 ], [ 318, bluesign 2012 ], [ 319, OSPAR 1997 ]

## **4.7.7.2 Selection of dyeing auxiliaries**

### **Description**

When mothproofing agents are added directly in the dyeing liquor, dyeing auxiliaries (e.g. levelling agents) that do not hinder the uptake of mothproofing agents are selected.

### **Technical description**

Some dyeing auxiliaries are known to exert a retarding action on the uptake (exhaustion) of mothproofing agents in all dyeing processes. The choice of, for example, levelling agent and polyamide blocking agent can significantly affect the final dye bath and rinse residues. These effects are known to depend on both the dye liquor pH and the auxiliary concentration. Dyeing auxiliaries are therefore screened for retarding action. Products with a significant retarding action are substituted, if possible.

These dyeing auxiliaries are also selected considering the adverse impacts they may have on the environment (see Section 4.1.6.3).

**Achieved environmental benefits**

A targeted selection of the dyeing auxiliaries allows a reduction of the concentration of mothproofing agent in spent dye bath liquors.

**Environmental performance and operational data**

No information provided.

**Cross-media effects**

The chosen dyeing auxiliaries may have adverse impacts on the environment.

**Technical considerations relevant to applicability**

The above technique is applicable to all installations.

**Economics**

No information provided.

**Driving force for implementation**

Environnemental legislation.

**Example plants**

Plants from the data collection: IT073, UK124 and UK127.

**Reference literature**

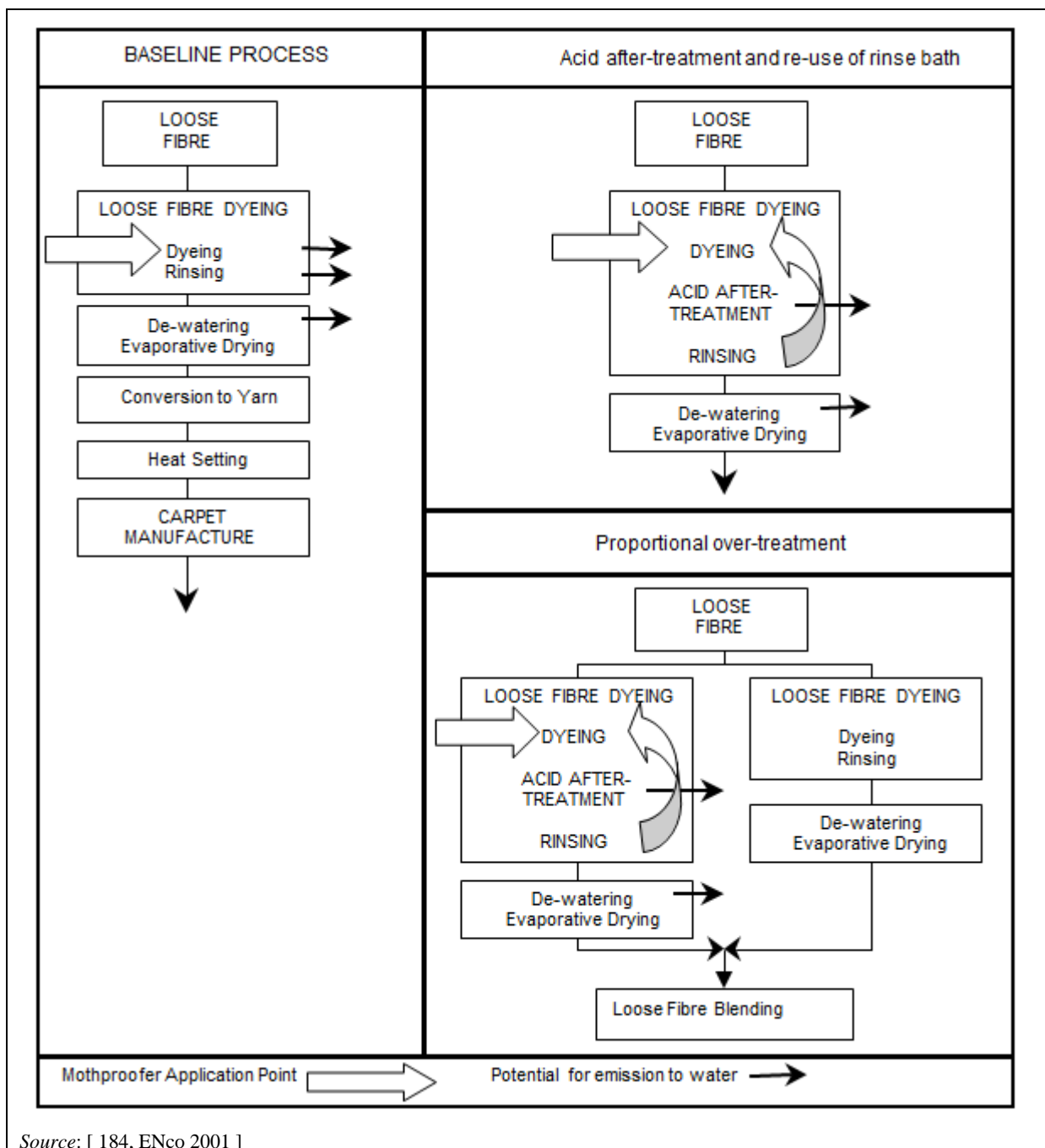
[ 184, ENCo 2001 ], [ 243, OSPAR 1994 ], [ 319, OSPAR 1997 ]

**4.7.7.3 Minimisation of emissions of mothproofing agents from yarn production when using the 'dry spinning route'**

Figure 4.59 below illustrates the baseline process used for the application of mothproofing agents to 'dry spun' yarn during wet processing of the fibre (see also Section 2.13.5.1). Mothproofing agent is applied in loose fibre dyeing by addition to the dye bath at the commencement of the dyeing. In the baseline process, the dye bath and the rinse liquor are discharged to the drain and may carry residual agent not taken up by the fibre. Dewatering the dyed fibre using either a centrifuge or with squeeze rollers also generates an additional potential source of residues.

Process modifications with the potential to reduce emissions of mothproofing agents in loose fibre dyeing include:

- acid after-treatment and reuse of the rinse bath (see Section 4.7.7.3.1);
- proportional overtreatment of loose fibre (see Section 4.7.7.3.2).



Source: [184, ENco 2001]

**Figure 4.59: Traditional and alternative processes for mothproofing in the dry spinning route**

#### 4.7.7.3.1 Acid after-treatment and reuse of the rinse bath

##### Description

An acidification step is added at the end of the dyeing cycle to increase the uptake of mothproofing agents and the rinse bath is reused for the next dyeing cycle.

##### Technical description

The technique illustrated in Figure 4.59 combines the following:

- Acid after-treatment which consists of lowering the dye liquor pH ( $< 4.0$ ) at the end of the dyeing cycle. This increases the uptake of mothproofing agents at the end of the cycle and reduces overall residues.
- Reuse of the rinse bath which can eliminate residues from the rinse bath.

**Achieved environmental benefits**

Reduction of residues and emissions to water from the dyeing process.

**Environmental performance and operational data**

Emissions of mothproofing agents are reduced by approximately 90 % when compared with the baseline process.

The example given in Table 4.93 below illustrates the effectiveness of acid after-treatment.

**Table 4.93: Indicative emissions from loose fibre dyeing**

Waste water source	Approximate waste water volume (l/kg)	Residual permethrin (mg/kg fibre)		Achieved reduction in residues
		Baseline process	Modified process after-treatment with formic acid	
Dye bath	10	1.5	0.17	88.7 %
Rinse bath	9	0.38	0.02	94.7 %
Hydroextractor liquor	0.5	0.6	0.04	93.3 %
Process total	19.5	2.48	0.23	90.7 %
NB: Indicative results from a single dyeing carried out with premetallised dyes. Permethrin application rate: 60 mg/kg. Source: based on [ 184, ENco 2001 ]				

**Cross-media effects**

Increased energy consumption to maintain the dye bath at an elevated temperature for longer.

**Technical considerations relevant to applicability**

This approach is only feasible if the machine can be unloaded without emptying the dye vessel or if the machine is equipped with an external liquor storage tank to which the liquor can be transferred between unloading and loading.

It is reported that this mothproofing technique may affect the quality of the product after dyeing [ 22, TWG 2002 ].

**Economics**

The after-treatment process requires additional time to complete, adding an average 30 minutes to a dyeing cycle. Productivity is reduced accordingly.

**Driving force for implementation**

Environmental legislation.

**Example plants**

Acid after-treatment is reported to be used extensively in the UK. A number of installations apply this technique in combination with rinse liquor recycling.

**Reference literature**

[ 22, TWG 2002 ], [ 184, ENco 2001 ]

### 4.7.7.3.2 Blending of treated and untreated loose fibres

#### **Description**

A fraction of the fibres (e.g. 5-20 % of the total blend weight) is treated with an excess amount of mothproofing agents and subsequently blended with untreated fibres.

#### **Technical description**

This technique utilises the fact that a intimate blend of treated and untreated fibres will be resistant to insect attack providing that the overall blend treatment level is maintained. In practice only a proportion of the fibre is treated, by adding mothproofing agents at an increased rate to one or more dyeings. The remaining fibre receives no treatment. Mixing of the two fibre types is achieved during mechanical blending.

The technique can be used for the preparation of both solid shades and yarns with mixed colour effects. The ratio of treated fibre can vary between 5 % and 20 % of the total blend weight.

#### **Achieved environmental benefits**

Reduction of emissions to water.

#### **Environmental performance and operational data**

Using a dedicated installation and treating only 5 % of the total fibre blend with mothproofing agents is an efficient way of providing protection to a large volume of finished fibre. Estimates of the waste water emissions from such an installation show values of less than 0.2 mg active substance/kg of fibre, which at a 5 % blending ratio is equivalent to 0.01 mg active substance/kg of spun yarn.

#### **Cross-media effects**

Fewer dyeings are carried out in the presence of mothproofing agents, but the higher application rates required would under normal circumstances result in higher emissions from those dyeings, which may exceed the emissions arising from the normal production sequence. In practice, it has been found that plants using this technique for more than a very small proportion of their production install some form of dedicated dye liquor reuse system to manage waste water concentrations.

#### **Technical considerations relevant to applicability**

The technique can only be adopted on a significant scale by using specially constructed equipment: both the spent dye liquor and the rinse liquor may need to be reused, which implies the construction of dedicated machinery, a revised drainage system and the installation of liquor storage tanks. A revision of the dyeing methods and dyestuff and auxiliary selection may be required to minimise colour contamination.

#### **Economics**

The cost of constructing a dedicated installation was reported to be in excess of EUR 130 000.

#### **Driving force for implementation**

Environmental legislation.

#### **Example plants**

One installation is known to exist in the UK. No design or operational details are available.

#### **Reference literature**

[ 184, ENco 2001 ]

#### 4.7.7.4 Minimisation of emissions of mothproofing agents from yarn production when using the 'loose stock dyeing route'

##### Technical description

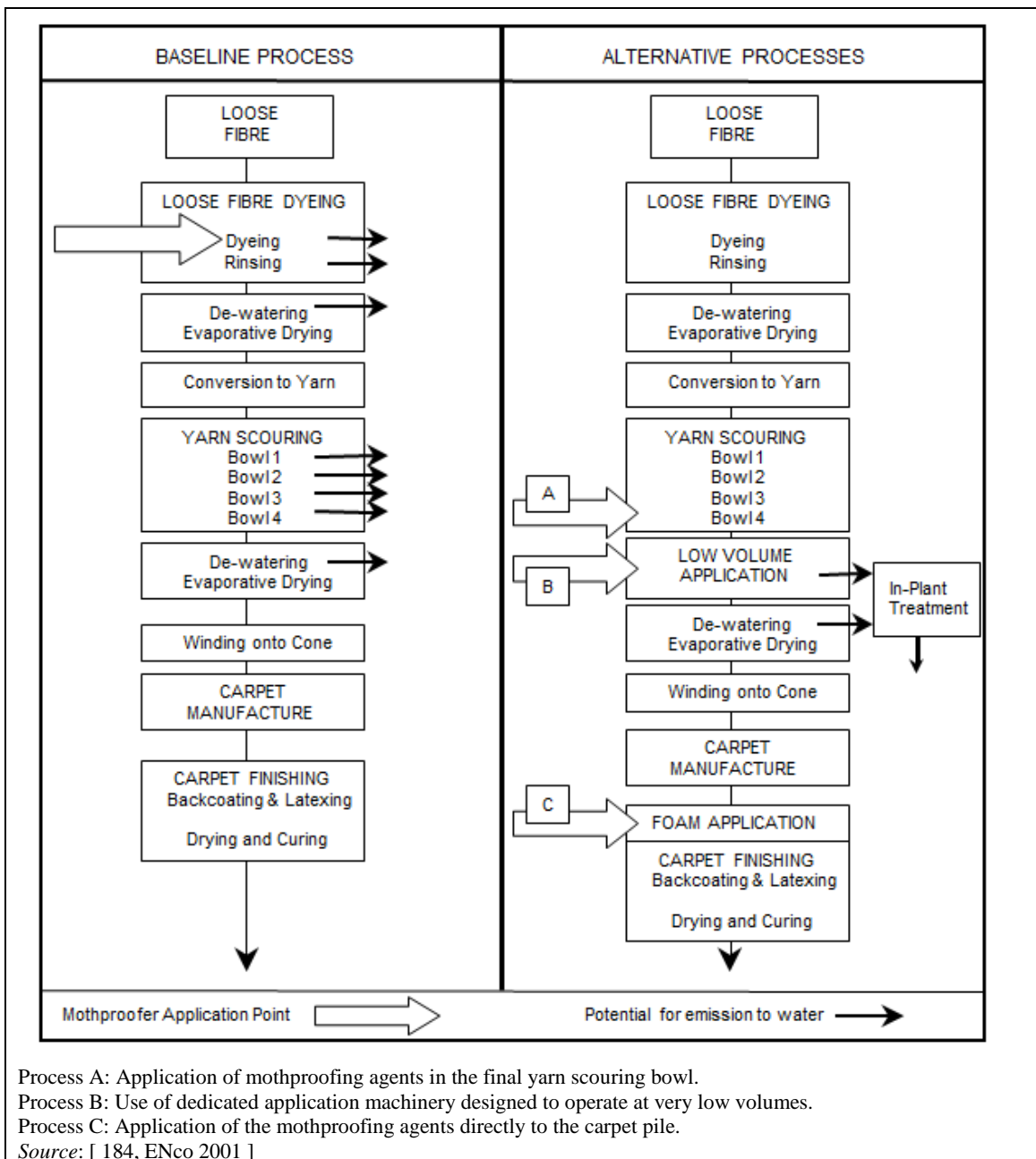
Figure 4.60 below illustrates the baseline process used for the application of mothproofing agents to yarn produced using the loose fibre dyeing and yarn scouring route ('loose stock dyeing route', see also Section 2.13.5.1). In the baseline process, mothproofing agents are applied during loose fibre dyeing. The fibre is then converted to yarn and scoured to remove mill dirt and spinning lubricant.

Emissions of mothproofing agents arise from the dyeing and rinsing operations and from the yarn scouring operation, as mothproofing agents are removed from the spun yarn during this operation and concentrate in the scouring liquor.

Figure 4.60 indicates that there are three possible alternative processes to the baseline process that may be applied to reduce mothproofing agent emissions:

- Application of mothproofing agent in the final bowl of the yarn scouring. It uses conventional existing equipment and eliminates emissions at the dyeing stage. This technique is not considered to be a best available technique for application of mothproofing agents in conjunction with yarn scouring and is therefore not further described in this document.
- Use of dedicated application machinery designed to operate at very low volumes (see Section 4.7.7.4.1). It eliminates emissions from the dyeing process and fugitive emissions from the conventional scouring bowl application.
- Application of the mothproofing agent directly to the carpet pile using dedicated foam application machinery (see Section 4.7.7.4.2). The equipment is enclosed and can be operated without emissions to water.





**Figure 4.60: Traditional and alternative processes for mothproofing in the loose stock dyeing route**

#### 4.7.7.4.1 Application using dedicated low-volume equipment

##### Description

Use of low-volume bowls to apply mothproofing agents.

##### Technical description

Minimal operating volume both limits liquor contamination and permits recycling of the liquor with intermediate cleaning to remove contaminants. Electronic measurement and process control are used to eliminate fugitive emissions and control mothproofing agent application levels and acidification conditions. Machines of this design are variously referred to as mini-bowl, low-volume bowl or EnviroProof installations.

A machine of the type described above is capable of operation in two modes:

- liquor storage between yarn batches and discharge to drain when liquor is contaminated;
- liquor storage between batches with adsorptive renovation of liquor to eliminate discharge.

Further developments of the low-volume application system have taken place in which residual liquor from the hydroextractor is treated with alkali at high temperature. This procedure is applicable to all mothproofing agent formulations based on synthetic pyrethroids, which undergo rapid hydrolysis at elevated temperatures. The degradation products from this reaction are several orders of magnitude less toxic to invertebrates than the parent molecule and can thus be safely discharged to drain with other waste water streams [ 320, Hill I.R. 1989 ].

The above technique has also been adapted to treat the spent bowl liquor in cases where heavy contamination cannot be managed with the adsorptive filter system.

A further variant of the system deals with the hydroextractor liquor by segregation from other effluents, followed by addition to a dye bath. Dark shades are usually chosen to accommodate any slight shade change due to contaminants in the hydroextractor liquor and only 10-20 % of the dye bath volume is made up using hydroextractor liquor. The active ingredient present in the hydroextractor liquor behaves in a similar manner to that present in the original formulation and is adsorbed by the fibre under the hot acidic dyeing conditions. Overall residues from this process are of a similar magnitude to those encountered when mothproofing agent is applied in the dye bath.

##### Achieved environmental benefits

Dedicated application machinery eliminates emissions from the dyeing process and fugitive emissions from the conventional scouring bowl application.

##### Environmental performance and operational data

Permethrin releases from installations processing respectively 22 tonnes and 92 tonnes of carpet yarn were quantified. Both operating modes mentioned above were assessed (i.e. discharge to the drain when liquor is contaminated and adsorptive renovation of liquor to eliminate discharge).

Permethrin released from the installation amounted to 0.97 mg/kg in the case of simple multiple batch processing without clean-up and 0.23 mg/kg for the system running with full clean-up and recycling of the process liquor. In both cases, a significant proportion of the emissions arose when the treated yarn was hydroextracted prior to evaporative drying.

[ 321, Allanach et al. 1995 ]

##### Cross-media effects

None identified.

### **Technical considerations relevant to applicability**

Installations of this type may be retrofitted to any continuous yarn scouring machine. Versions of the technology have been adapted for both hank and continuous end-to-end yarn processing machines.

### **Economics**

Both commercial and self-built versions of the low-volume application system described above are known. A commercial installation retrofitted to an existing scouring line normally includes all the control features associated with chemical dosing and liquor management, together with refurbishment of the final squeeze press of the existing scouring line. Installation costs are in the region of EUR 185 000. The chemical dosing system fitted to these installations is capable of closely regulating application levels in proportion to the yarn throughput. As a result, the nominal treatment level can normally be reduced without compromising the insect resistance of the treated yarn. The magnitude of these savings can vary from site to site, but a 50 % reduction is not uncommon, equivalent to a saving of approximately EUR 7.0/tonne of treated yarn.

Equipment for the control and in-plant treatment of hydroextractor residues and highly contaminated liquors using the alkali hydrolysis technique is often assembled on a self-built basis to suit local site conditions and space. Depending on the complexity of the installation, costs are estimated to be upwards of EUR 7 000. Treatment costs, excluding energy, are in the region of EUR 1.4/m<sup>3</sup>.

### **Driving force for implementation**

Environmental legislation.

### **Example plants**

A significant number of plants in the UK use variations of the low-volume application techniques described above and their associated spent liquor management systems for the mothproofing of yarn in both hank and single end form. Other installations operating similar systems are known to be in operation in Europe and New Zealand.

### **Reference literature**

[ 184, ENco 2001 ], [ 320, Hill I.R. 1989 ], [ 321, Allanach et al. 1995 ]

#### 4.7.7.4.2 Application of mothproofing agents to the carpet pile

##### Description

Application of mothproofing agents directly to the pile of the carpet by using foam.

##### Technical description

Specialised equipment has been developed in which a high-density foam incorporating the mothproofing agents is generated on site and applied to the carpet using a specially profiled application head. This is a continuous process and can be carried out simultaneously with backing/latexing. The use of foam minimises moisture addition. The foam is generated within a contained area on demand and any rinsing water is recycled and used to prepare the next batch of foam.

##### Achieved environmental benefits

When operated with a rinse liquor reuse system, the process is effluent-free and eliminates the emission of the mothproofing agent active substance to the aquatic environment.

##### Environmental performance and operational data

There are no emissions to the installation waste water stream. For the treatment to be fully effective, the active ingredient must penetrate to the base of the carpet pile structure. The density of the pile structure, the foam density and foam blow ratio control penetration.

[ 322, Allanach et al. 1995 ]

In comparison to yarn application techniques, a somewhat higher overall application rate is required to ensure that the base of the pile is adequately protected against insect damage. The foam adds moisture to the carpet which must be removed by evaporation and additional drying capacity may be required, which implies increased energy consumption.

##### Cross-media effects

- Increased energy consumption.
- Increased amount of chemicals needed.

##### Technical considerations relevant to applicability

The technique relies on application of the mothproofing finish directly to the pile of the carpet and is, therefore, applicable only on sites where the final carpet manufacturing processes are carried out. Commission dyers and sales yarn spinners are unable to make use of this technique.

Practical experience indicates that penetration of the foam to the base of the pile may be difficult to achieve with some densely tufted and woven pile structures. The application of a foam to the surface of some pile structures is also known to cause unacceptable changes in the surface appearance of the finished carpet and these effects have to be determined on a case-by-case basis.

##### Economics

Dedicated equipment designed specifically to achieve the level application of foam at a low moisture add-on is required. The equipment can be retrofitted to an existing carpet finishing line if space allows, at a cost of approximately EUR 160 000. Depending on the construction of the carpet, additional drying capacity may need to be installed, or alternatively the finishing line may need to be run at a slower speed. Due to the higher required application rate, chemical costs are approximately twice those incurred when a mothproofing finish is applied during yarn wet processing.

##### Example plants

The technique is employed by a number of UK and European carpet manufacturers.

##### Reference literature

[ 184, ENco 2001 ], [ 322, Allanach et al. 1995 ]

#### 4.7.7.5 Minimisation of emissions of mothproofing agents from yarn production when using the 'yarn dyeing route'

##### Technical description

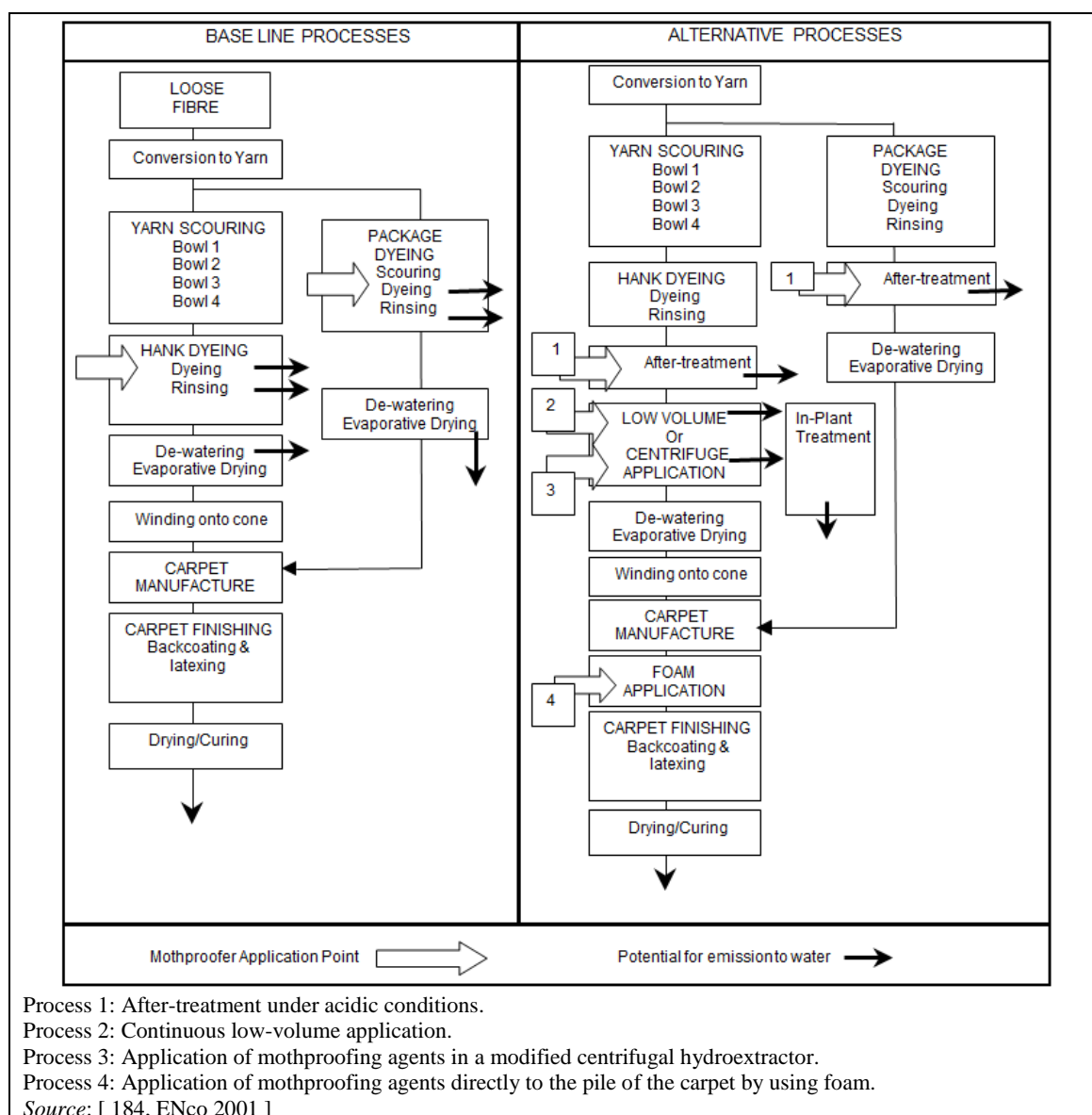
Figure 4.61 below illustrates the baseline process for the mothproofing of carpet yarn produced via the yarn dyeing route. In this process, mothproofing is carried out simultaneously with colouration, the required quantity of mothproofing agent being added to the dye vessel at the commencement of dyeing.

The active substance is adsorbed by the fibre as the temperature of the dye liquor increases. This adsorptive process reaches equilibrium at the boiling point, with more than 98 % of the active substance partitioning towards the fibre. The spent dye liquor contains residual active substance in a concentration that depends on the dyeing conditions. Acidic dyeing conditions ( $\text{pH} < 4$ ) yield the lowest residues. Dyeing carried out under more neutral conditions, for example in the case of dyeing with pre-metallised dyestuffs, generally results in higher residues in liquors.

The dyeing may be followed by a rinsing cycle, which may also contain residual active substance. In the conventional process both these spent liquors are discharged to the installation's waste water equalisation tank. The liquor extracted during hydroextraction of the dyed yarn may also contain the active substance at trace levels.

Emissions from the baseline process depend on a large number of interrelated variables as each dyeing is virtually unique. For practical purposes, the pH of the dye liquor can be considered to have the single most important effect.

As shown in Figure 4.61, there are four alternative processes (numbered 1 to 4) which are capable of minimising the emission of mothproofing agents when compared with the baseline process. Two of these alternatives, continuous low-volume application (Process 2) and foam application (Process 4) have been described above in Sections 4.7.7.4.1 and 4.7.7.4.2 respectively. Process 1 and Process 3 are described in Sections 4.7.7.5.1 and 4.7.7.5.2 below.



**Figure 4.61: Traditional and alternative processes for mothproofing in the yarn dyeing route**

#### 4.7.7.5.1 After-treatment under acidic conditions

##### Description

Mothproofing is carried out in a separate bath to dyeing as an after-treatment, following rinsing. The after-treatment bath is acidified to provide optimum conditions for mothproofing agent uptake.

##### Technical description

See above.

##### Achieved environmental benefits

Reduced generation of waste water.

##### Environmental performance and operational data

Treatment is carried out in the absence of any retarding chemicals and at a pH optimal for mothproofing agent adsorption. Residual active substance loads are typically between 0.1 mg/kg and 0.4 mg/kg.

In many dyehouses, wool and wool blend dyeing is carried out using a variety of dyeing conditions, depending on the particular dyestuffs selected to meet end-product requirements. This process is used for the mothproofing of yarn when yarn is dyed under conditions which are not optimised for mothproofing agent uptake. In practice, the technique is used to mothproof yarn when the dyeing conditions specify a liquor pH greater than approximately 5.

### **Cross-media effects**

- Increased water consumption.
- Increased energy consumption to maintain the dye bath at an elevated temperature for longer.

### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

### **Economics**

The process requires the use of an additional after-treatment bath, equal in volume to the original dye bath. Depending on machine design and yarn load, water consumption will lie between 15 m<sup>3</sup>/tonne and 25 m<sup>3</sup>/tonne. Additional energy is required to raise the after-treatment bath to the dyeing temperature, together with additional time to complete the lengthened process.

### **Example plants**

This technique is used in UK dyehouses.

### **Reference literature**

[ 184, ENco 2001 ]

#### **4.7.7.5.2 Application of mothproofing agent in a modified centrifugal hydroextractor**

### **Description**

Centrifugal force is used to transport treatment liquor sprayed into the centrifugal hydroextractor from a centrally located spray head through the yarn load as it rotates.

Liquor expelled from the centrifuge is either collected and recycled, or separated from other waste water streams and treated to remove residual active substance.

### **Technical description**

The technique is fully described in [ 323, Allanach 1990 ].

The technique requires modification of the centrifuge, the centrifuge drainage system and the provision of spent liquor treatment techniques. These may consist of either alkali hydrolysis or a physical separation technique.

### **Achieved environmental benefit**

A reduction in mothproofing agents discharged to waste water.

### **Environmental performance and operational data**

Batch to batch reuse of the liquor can be difficult to implement because of the risk of colour change.

### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

**Economics**

There are no commercially available solutions. Modification of an existing centrifugal hydroextractor on a self-built basis and the provision of ancillary equipment is estimated at approximately EUR 30 000.

**Driving force for implementation**

Environmental legislation.

**Example plants**

One plant in the UK is known to operate a variant of the process described above, but no details are available.

**Reference literature**

[ 184, ENco 2001 ], [ 323, Allanach 1990 ]



## 4.8 Laminating and coating

### 4.8.1 Hot-melt lamination

[ 44, ÖKOPOL 2011 ]

#### Description

Hot-melt lamination is used instead of flame lamination.

#### Technical description

In hot-melt lamination, melted solvent-free polymers are applied to textile fabrics by appropriate aggregates (see Section 2.10.1).

Compared to flame lamination where the substrates to be stuck together are exposed directly to a flame burner leading to emissions of crack products of the polyurethane foams used, in hot-melt lamination the operating temperature is too low to generate crack products. For this reason no air emission abatement techniques are necessary. Thus no additional environmental impacts like energy and water consumption, as well as the resulting waste water and operating expenses, will occur.

#### Achieved environmental benefits

Reduction of emissions of organic compounds to air.

#### Environmental performance and operational data

Only a very small amount of isocyanate emissions can be expected when using PU aggregates (e.g. reactive or non-cross-linking polyurethanes). They depend on the amount of non-bonded isocyanate monomers. The monomer content of the polyurethanes used can be up to 2 %. The content in monomer-poor products is less than 0.1 %. They will be captured by an exhaust device and discharged to the atmosphere, because they react immediately with humidity to form non-hazardous substances. Workplace measurements show concentrations of MDI (methylene diphenyl diisocyanate) of  $< 0.05 \text{ mg/m}^3$  ( $< 0.005 \text{ ml/m}^3$ ) [ 44, ÖKOPOL 2011 ]

Hot-melt lamination provides high production velocities. Theoretically, in slot die coating the rate rises up to more than 500 m/min. Limits of velocity are defined by the substrate: 30-60 m/min for fine knitted fabrics and 150-200 m/min for tight woven fabrics and non-wovens. In the textile sector the velocity of roller systems is in the range of 40-50 m/min. Due to short exposure times, the thermal stress for the substrates is low.

The energy consumption of the extruder is approximately 0.3-0.5 kW/kg of adhesive, and 0.4-0.6 kW/kg of adhesive for the melting tank [ 44, ÖKOPOL 2011 ]

Normally, the power input of slot die coating systems is lower compared to roller systems (due to the lower mass ratio between slot dies and rollers). The power input also depends on the process parameters (operating temperature, applied quantity, capacity, etc.)

Adhesive consumption is between  $1 \text{ g/m}^2$  and  $50 \text{ g/m}^2$  or even higher depending on the type of substrates to be laminated and the laminate performance requirements.

#### Cross-media effects

None identified.

#### Technical considerations relevant to applicability

Hot-melt lamination may not be applicable to thin textiles and may be restricted by the strength of the bond between the laminate and textile material.

Compared to flame lamination, hot-melt lamination causes an irregular surface on thin fabrics ('orange-peel skin' effect). Additionally, there is the problem of adhesive penetration in thin fabrics.

Hot-melt lamination can be performed with a lot of different substrates and foams. Adhesive characteristics and fogging behaviour conform to all requirements of the automotive industry [ 44, ÖKOPOL 2011 ]

### **Economics**

Investment costs for hot-melt lamination are higher compared to flame lamination equipment, especially with regard to the purchase cost of an extruder for thermoplastics.

Equipment for hot-melt triplex-laminates used for seats in vehicles is more expensive than equipment for hot-melt duplex-laminates.

Generally, investing in equipment for hot-melt lamination will be profitable considering the absence of 'burnt' foam and the lack of a need for exhaustion equipment. According to the data of an operator, the break-even point for flame lamination for conventional foams compared to hot-melt lamination is achieved for a foam density of 55 kg/m<sup>3</sup>, e.g. used for the ceiling in vehicles. For a foam density of approximately 38 kg/m<sup>3</sup> (used for seats in vehicles), the cost advantage is approximately 7 % for flame lamination.

### **Driving force for implementation**

- Improved environmental performance (emissions to air).
- Economics.

### **Example plants**

C.H. Müller GmbH, DE-08468 Heinsdorfergrund.

Plants from the data collection: CZ015, DE026 and FR131. DE026 reported the use of diphenylmethane 4,4'-diisocyanate as an adhesive.

### **Reference literature**

[ 44, ÖKOPOL 2011 ], [ 45, Weydts et al. 2019 ]



## 5 BEST AVAILABLE TECHNIQUES (BAT) CONCLUSIONS FOR THE TEXTILES INDUSTRY

### 5.1 Scope

These BAT conclusions concern the following activities specified in Annex I to Directive 2010/75/EU:

- 6.2 Pre-treatment (operations such as washing, bleaching, mercerisation) or dyeing of textile fibres or textiles where the treatment capacity exceeds 10 tonnes per day.
- 6.11. Independently operated treatment of waste water not covered by Directive 91/271/EEC, provided that the main pollutant load originates from activities covered by these BAT conclusions.

These BAT conclusions also cover the following:

- The following activities when they are directly associated with activities specified in point 6.2 of Annex I to Directive 2010/75/EU:
  - coating;
  - dry cleaning;
  - fabric production;
  - finishing;
  - lamination;
  - printing;
  - singeing;
  - wool carbonising;
  - wool fulling;
  - spinning of fibres (other than man-made fibres);
  - washing or rinsing associated with dyeing, printing or finishing.
- The combined treatment of waste water from different origins, provided that the main pollutant load originates from activities covered by these BAT conclusions and that the waste water treatment is not covered by Directive 91/271/EEC.
- On-site combustion plants that are directly associated with the activities covered by these BAT conclusions, provided that the gaseous products of combustion are put into direct contact with the textile fibres or textiles (such as direct heating, drying, heat-setting) or when radiant and/or conductive heat is transferred through a solid wall (indirect heating) without using an intermediary heat transfer fluid.

These BAT conclusions do not cover the following:

- Coating and lamination with an organic solvent consumption capacity of more than 150 kg per hour or more than 200 tonnes per year. These are covered by the BAT conclusions on surface treatment using organic solvents including preservation of wood and wood products with chemicals (STS).
- Production of man-made fibres and yarns. This may be covered by the BAT conclusions covering the sector of polymers production.
- Unhairing of hides and skins. This may be covered by the BAT conclusions for the tanning of hides and skins (TAN).

Other BAT conclusions and reference documents which could be relevant for the activities covered by these BAT conclusions include the following:

- Surface Treatment Using Organic Solvents including Preservation of Wood and Wood Products with Chemicals (STS);
- Waste Incineration (WI);
- Waste Treatment (WT);

- Emissions from Storage (EFS);
- Energy Efficiency (ENE);
- Industrial Cooling Systems (ICS);
- Monitoring of Emissions to Air and Water from IED Installations (ROM);
- Economics and Cross-Media Effects (ECM).

These BAT conclusions apply without prejudice to other relevant legislation, e.g. on the registration, evaluation, authorisation and restriction of chemicals (REACH), on the classification, labelling and packaging of substances and mixtures (CLP), on biocidal products (BPR) or on energy efficiency (energy efficiency first principle).

## 5.2 Definitions

For the purposes of these BAT conclusions, the following **definitions** apply:

<b>General terms</b>	
<b>Term used</b>	<b>Definition</b>
Air-to-textile ratio	The ratio of the total exhaust gas volume flow (expressed in Nm <sup>3</sup> /h) from the emission point of a textile treatment unit (e.g. stenter) to the corresponding throughput of the textile to be treated (dry textile, expressed in kg/h).
Cellulosic materials	Cellulosic materials include cotton and viscose.
Channelled emissions	Emissions of pollutants to air through any kind of duct, pipe, stack, etc.
Continuous measurement	Measurement using an automated measuring system permanently installed on site.
Desizing	Pre-treatment of textile materials to remove sizing chemicals from woven fabric.
Diffuse emissions	Non-channelled emissions to air.
Direct discharge	Discharge to a receiving water body without further downstream waste water treatment.
Dry cleaning	Cleaning of textile materials with an organic solvent.
Existing plant	A plant that is not a new plant.
Fabric production	Production of fabric, e.g. by weaving or knitting.
Finishing	Physical and/or chemical treatment aiming at giving the textile materials end-use properties such as visual effects, handle characteristics, waterproofness or non-flammability.
Flame lamination	Bonding of fabrics using a thermoplastic foam sheet, exposed to a flame located before the laminating rolls.
Hazardous substance	Hazardous substance as defined in point 18 of Article 3 of Directive 2010/75/EU.
Hazardous waste	Hazardous waste as defined in point 2 of Article 3 of Directive 2008/98/EC of the European Parliament and of the Council <sup>(1)</sup> .
Indirect discharge	Discharge that is not a direct discharge.
Liquor ratio	For a batch process, weight ratio between the dry textile materials and the process liquor used.
n-Octanol/water partition coefficient	The ratio of the equilibrium concentrations of a dissolved substance in a two-phase system consisting of the largely immiscible solvents n-octanol and water.
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.
Mass flow	The mass of a given substance or parameter which is emitted over a defined period of time.
New plant	A plant first permitted at 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.
Organic solvent	Organic solvent as defined in Article 3(46) of Directive 2010/75/EU.
Periodic measurement	Measurement at specified time intervals using manual or automated methods.
Pick-up	For a continuous process, weight ratio between the liquid taken up by the textile materials and the dry textile materials.
Process chemicals	Substances and/or mixtures as defined in Article 3 of Regulation (EC) No 1907/2006 <sup>(2)</sup> that are used in the process(es), including sizing chemicals, bleaching chemicals, dyes, printing pastes and finishing chemicals. Process chemicals may contain hazardous substances and/or substances of very high concern.
Process liquor	Solution and/or suspension containing process chemicals.
Residual pick-up	The remaining capacity of wet textile materials to take up additional liquid (after the initial pick-up).
Scouring	Pre-treatment of textile materials which consists of washing the incoming textile material.
Singeing	Removal of the fibres at the surface of the fabric by passing the fabric through a flame or heated plates.
Sizing	Impregnation of yarn with process chemicals aiming to protect the yarn and

	provide lubrication during weaving.
Substances of very high concern	Substances meeting the criteria mentioned in Article 57 and included in the Candidate List of Substances of Very High Concern, according to the REACH Regulation ((EC) No. 1907/2006).
Synthetic materials	Synthetic materials include polyester, polyamide and acrylic.
Textile materials	Textile fibres and/or textiles.
Thermal treatment	Thermal treatment of textile materials includes thermofixation, heat-setting or a process step (e.g. drying, curing) of the activities covered by these BAT conclusions (e.g. coating, dyeing, pre-treatment, finishing, printing, lamination).
<p>(<sup>1</sup>) Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (OJ L 312, 22.11.2008, p. 3).</p> <p>(<sup>2</sup>) 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).</p>	

Pollutants and parameters	
Term used	Definition
Antimony	Antimony, expressed as Sb, includes all inorganic and organic antimony compounds, dissolved or bound to particles.
AOX	Adsorbable organically bound halogens, expressed as Cl, include adsorbable organically bound chlorine, bromine and iodine.
BOD <sub>n</sub>	Biochemical oxygen demand. Amount of oxygen needed for the biochemical oxidation of the organic matter to carbon dioxide in <i>n</i> days ( <i>n</i> is typically 5 or 7). BOD <sub>n</sub> is an indicator for the mass concentration of biodegradable organic compounds.
Chromium	Chromium, expressed as Cr, includes all inorganic and organic chromium compounds, dissolved or bound to particles.
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.
Copper	Copper, expressed as Cu, includes all inorganic and organic copper compounds, dissolved or bound to particles.
CMR	Carcinogenic, mutagenic or toxic for reproduction. This includes CMR substances of categories 1A, 1B and 2, as defined in Regulation (EC) No 1272/2008 of the European Parliament and of the Council <sup>(1)</sup> and amended, i.e. with hazard statement codes: H340, H341, H350, H351, H360 and H361.
Dust	Total particulate matter (in air).
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).
NH <sub>3</sub>	Ammonia.
Nickel	Nickel, expressed as Ni, includes all inorganic and organic nickel compounds, dissolved or bound to particles.
NO <sub>x</sub>	The sum of nitrogen monoxide (NO) and nitrogen dioxide (NO <sub>2</sub> ), expressed as NO <sub>2</sub> .
SO <sub>x</sub>	The sum of sulphur dioxide (SO <sub>2</sub> ), sulphur trioxide (SO <sub>3</sub> ), and sulphuric acid aerosols, expressed as SO <sub>2</sub> .
Sulphide, easily released	The sum of dissolved sulphides and of those undissolved sulphides that are easily released upon acidification, expressed as S <sup>2-</sup> .
TOC	Total organic carbon, expressed as C (in water), includes all organic compounds.
TN	Total nitrogen, expressed as N, includes free ammonia and ammonium nitrogen (NH <sub>4</sub> -N), nitrite nitrogen (NO <sub>2</sub> -N), nitrate nitrogen (NO <sub>3</sub> -N) and organically bound nitrogen.
TP	Total phosphorus, expressed as P, includes all inorganic and organic phosphorus compounds, dissolved or bound to particles.
TSS	Total suspended solids. Mass concentration of all suspended solids (in water), measured via filtration through glass fibre filters and gravimetry.
TVOC	Total volatile organic carbon, expressed as C (in air).
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.

<sup>(1)</sup> 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 (OJ L 353, 31.12.2008, p. 1).

For the purposes of these BAT conclusions, the following **acronyms** apply:

Acronym	Definition
CMS	Chemicals management system
DTPA	Diethylenetriaminepentaacetic acid
EDTA	Ethylenediaminetetraacetic acid
EMS	Environmental management system



ESP	Electrostatic precipitator
IED	Industrial Emissions Directive (2010/75/EU)
OTNOC	Other than normal operating conditions
PFAS	Per- and polyfluoroalkyl substances

## 5.3 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, the BAT conclusions are generally applicable.

### Emission levels associated with the best available techniques (BAT-AELs) for emissions to air

The BAT-AELs for emissions to air given in these BAT conclusions refer to concentrations (mass of emitted substances 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<sup>3</sup>.

For averaging periods of BAT-AELs for emissions to air, the following **definition** applies.

Type of measurement	Averaging period	Definition
Periodic	Average over the sampling period	Average value of three consecutive samplings/measurements of at least 30 minutes each. ( <sup>1</sup> )
( <sup>1</sup> ) 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 samplings/measurements is inappropriate, a more representative sampling/measurement procedure may be employed.		

For the purpose of calculating the mass flows in relation to BAT 9, BAT 26, BAT 27 and Table 5.5 and Table 5.6, where waste gases from one type of source (e.g. stenter) discharged through two or more separate emission points could, in the judgement of the competent authority, be discharged through a common emission point, these emission points shall be considered as a single emission point (see also BAT 23). Mass flows at the plant/installation level can be used as an alternative.

### Emission levels associated with the best available techniques (BAT-AELs) for emissions to water

The BAT-AELs for emissions to water given in these BAT conclusions refer to concentrations (mass of emitted substances 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, or, provided that the effluent is appropriately mixed and homogeneous, a spot sample taken before discharge.

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.

In the case of total organic carbon (TOC) and chemical oxygen demand (COD), the calculation of the average abatement efficiency referred to in these BAT conclusions (see Table 5.3) is based on the influent and effluent load of the waste water treatment plant.

The BAT-AELs apply at the point where the emission leaves the installation.

### Other environmental performance levels

#### Indicative levels for specific energy consumption

The indicative environmental performance levels related to specific energy consumption refer to yearly averages calculated using the following equation:

$$\text{specific energy consumption} = \frac{\text{energy consumption rate}}{\text{activity rate}}$$

where:

energy consumption rate: total annual amount of heat and electricity consumed by the thermal treatment, minus the heat recovered from the thermal treatment, expressed in MWh/year;

activity rate: total annual amount of textile materials treated in the thermal treatment, expressed in t/year.

#### Indicative levels for specific water consumption

The indicative environmental performance levels related to specific water consumption refer to yearly averages calculated using the following equation:

$$\text{specific water consumption} = \frac{\text{water consumption rate}}{\text{activity rate}}$$

where:

water consumption rate: total annual amount of water consumed by a given process (e.g. bleaching) including water used for washing and rinsing the textile materials and for cleaning the equipment, minus the water reused and/or recycled to the process, expressed in m<sup>3</sup>/year;

activity rate: total annual amount of textile materials treated in a given process (e.g. bleaching), expressed in t/year.

#### Specific wool grease recovery level associated with the best available techniques

The environmental performance level related to specific wool grease recovery refers to a yearly average calculated using the following equation:

$$\text{specific wool grease recovery} = \frac{\text{rate of wool grease recovered}}{\text{activity rate}}$$

where:

rate of wool grease recovered: total annual amount of wool grease recovered from the pre-treatment of raw wool fibres by scouring, expressed in kg/year;

activity rate: total annual amount of raw wool fibres pre-treated by scouring, expressed in t/year.

### Caustic soda recovery level associated with the best available techniques

The environmental performance level related to caustic soda recovery refers to a yearly average calculated using the following equation:

$$\text{caustic soda recovery} = \frac{\text{rate of caustic soda recovered}}{\text{rate of caustic soda before recovery}}$$

where:

rate of caustic soda recovered: total annual amount of caustic soda recovered from spent mercerisation rinsing water, expressed in kg/year;

rate of caustic soda before recovery: total annual amount of caustic soda in the spent mercerisation rinsing water, expressed in kg/year.

## 5.4 General BAT conclusions

### 5.4.1 Overall environmental performance

**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 the textile industry, BAT is also to incorporate the following features in the EMS:

- xxi. an inventory of inputs and outputs (see BAT 2);
- xxii. an OTNOC management plan (see BAT 3);
- xxiii. a water management plan (see BAT 10);
- xxiv. an energy efficiency plan (see BAT 11);
- xxv. a chemicals management system (see BAT 14);
- xxvi. a waste management plan (see BAT 29).

### **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.

**BAT 2. In order to improve the overall environmental performance, BAT is to establish, maintain and regularly review (including when a significant change occurs) an inventory of inputs and outputs, as part of the environmental management system (see BAT 1), that incorporates all of the following features:**

- I.information about the production process(es), including:
  - a. simplified process flow sheets that show the origin of the emissions;
  - b. descriptions of process-integrated techniques and waste water/waste gas treatment techniques to prevent or reduce emissions, including their performance (e.g. abatement efficiency);
- II.information about the quantity and characteristics of materials used, including textile materials (see BAT 5 (a)) and process chemicals (see BAT 15);
- III.information about water consumption and usage (e.g. flow diagrams and water mass balances);
- IV.information about energy consumption and usage;
- V.information about the quantity and characteristics of the waste water streams, such as:
  - a. average values and variability of flow, pH, temperature and conductivity;
  - b. average concentration and mass flow values of relevant substances/parameters (e.g. COD/TOC, nitrogen species, phosphorus, metals, priority substances, microplastics) as well as their variability;
  - c. data on toxicity, bioeliminability and biodegradability (e.g. BOD<sub>n</sub>, BOD<sub>n</sub> to COD ratio, results of Zahn-Wellens test, biological inhibition potential (e.g. inhibition of activated sludge));
- VI.information about the characteristics of the waste gas streams, such as:
  - a. average values and variability of flow and temperature;
  - b. average concentration and mass flow values of relevant substances/parameters (e.g. dust, organic compounds) as well as their variability; emission factors may be used to assess the variability of emissions to air (see Section 5.12.1);
  - c. flammability, lower and higher explosive limits, reactivity, hazardous properties;
  - d. presence of other substances that may affect the waste gas treatment system or installation safety (e.g. water vapour, dust);
- VII.information about the quantity and characteristics of waste generated.

### **Applicability**

The scope (e.g. level of detail) and nature of the inventory will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

**BAT 3.** In order to reduce the frequency of the occurrence of OTNOC and to reduce emissions during OTNOC, BAT is to set up and implement a risk-based OTNOC management plan as part of the EMS (see BAT 1) that includes all of the following elements:

- i. identification of potential OTNOC (e.g. failure of equipment critical to the protection of the environment ('critical equipment')), of their root causes and of their potential consequences, and regular review and update of the list of identified OTNOC following the periodic assessment below;
- ii. appropriate design of critical equipment (e.g. waste water treatment, waste gas abatement techniques);
- iii. set-up and implementation of an inspection and preventive maintenance plan for critical equipment (see BAT 1 xii);
- iv. monitoring (i.e. estimating or, where possible, measuring) and recording of emissions during OTNOC and of associated circumstances;
- v. periodic assessment of the emissions occurring during OTNOC (e.g. frequency of events, duration, amount of pollutants emitted) and implementation of corrective actions if necessary;
- vi. regular review and update of the list of identified OTNOC under point i. following the periodic assessment of point v.;
- vii. regular testing of back-up systems.

#### Applicability

The level of detail and degree of formalisation of the OTNOC management plan will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

**BAT 4.** In order to improve the overall environmental performance, BAT is to use advanced process monitoring and control systems.

#### Description

The monitoring and control of processes is carried out with on-line automated systems equipped with sensors and controllers using feedback connections to rapidly analyse and adapt key process parameters to reach optimal process conditions (e.g. optimal uptake of process chemicals).

Key process parameters include:

- volume, pH and temperature of the process liquor;
- amount of textile materials treated;
- dosage of process chemicals;
- drying parameters (see also BAT 13 (d)).

**BAT 5.** In order to improve the overall environmental performance, BAT is to use both of the techniques given below.

Technique	Description	Applicability
a. Use of textile materials containing a minimised content of contaminants	Criteria for the selection of incoming textile materials (including recycled textile materials) are defined to minimise the content of contaminants including hazardous substances, poorly biodegradable substances and substances of very high concern. These criteria may be based on certification schemes or standards.  Regular controls are carried out to verify that	Generally applicable.

		<p>incoming textile materials fulfil the predefined criteria. These controls may consist of measurements and/or verification of information provided by suppliers and/or producers of textile materials. These controls may address the content of:</p> <ul style="list-style-type: none"> <li>• ectoparasiticides (veterinary drugs) and biocides in the incoming raw (or semi-processed) wool fibres;</li> <li>• biocides in the incoming cotton fibres;</li> <li>• manufacturing residues in the incoming synthetic fibres (e.g. monomers, side products of polymer synthesis, catalysts, solvents);</li> <li>• mineral oils (e.g. used for coning, spooling, spinning or knitting) in the incoming textile materials;</li> <li>• sizing chemicals in the incoming textile materials.</li> </ul>	
b.	Use of textile materials with reduced processing needs	<p>Use of textile materials with inherent characteristics that reduce the need for processing. These materials include:</p> <ul style="list-style-type: none"> <li>• spin-dyed man-made fibres;</li> <li>• fibres with inherent flame retardance properties;</li> <li>• elastane fibres or blends of elastane fibres with other polymer fibres that contain reduced amounts of silicone oils and residual solvents;</li> <li>• blends of synthetic fibres with thermoplastic elastomers;</li> <li>• polyester fibres dyeable without carriers.</li> </ul>	The applicability may be restricted by product specifications.

## 5.4.2 Monitoring

### BAT 6. BAT is to monitor at least once every year:

- the annual consumption of water, energy and materials used, including textile materials and process chemicals;
- the annual amount of waste water generated;
- the annual amount of materials recovered or reused;
- the annual amount of each type of waste generated and sent for disposal.

#### Description

Monitoring preferentially includes direct measurements. Calculations or recording, e.g. using suitable meters or invoices, can also be used. The monitoring is broken down, as much as possible, to process level and considers any significant changes in the processes.

**BAT 7. For waste water streams identified by the inventory of inputs and outputs (see BAT 2), BAT is to monitor key parameters (e.g. continuous monitoring of waste water flow, pH and temperature) at key locations (e.g. at the inlet and/or outlet of the waste water pre-treatment, at the inlet to the final waste water treatment, at the point where the emission leaves the installation).**



**Description**

When bioeliminability/biodegradability and inhibitory effects are key parameters (e.g. see BAT 19), monitoring is carried out before the biological treatment for:

- bioeliminability/biodegradability using standards EN ISO 9888 or EN ISO 7827, and
- inhibitory effects on biological treatment using standards EN ISO 9509 or EN ISO 8192,

with a minimum monitoring frequency to be decided after effluent characterisation.

The effluent characterisation is carried out before starting operation of the plant or before a permit for the plant is updated for the first time after the publication of these BAT conclusions, and after each change (e.g. change of ‘recipe’) in the plant that may increase the pollutant load.

**BAT 8. 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(s)/parameter		Standard(s)	Activities / processes	Minimum monitoring frequency	Monitoring associated with
Adsorbable organically bound halogens (AOX) <sup>(1)</sup>		EN ISO 9562	All activities / processes	Once every month <sup>(2)</sup>	BAT 20
Biochemical oxygen demand (BOD <sub>n</sub> ) <sup>(3)</sup>		Various EN standards available (e.g. EN 1899-1, EN ISO 5815-1)		Once every month	
Brominated flame retardants <sup>(1)</sup>		EN standard available for some polybrominated diphenyl ethers (i.e. EN 16694)	Finishing with flame retardants	Once every 3 months	
Chemical oxygen demand (COD) <sup>(4)</sup>		No EN standard available	All activities / processes	Once every day <sup>(5)</sup> <sup>(6)</sup>	
Colour		EN ISO 7887	Dyeing	Once every month <sup>(2)</sup>	
Hydrocarbon oil index (HOI) <sup>(1)</sup>		EN ISO 9377-2	All activities / processes	Once every 3 months <sup>(7)</sup>	
Metals / metalloids	Antimony (Sb)	Various EN standards available (e.g. EN ISO 11885, EN ISO 17294-2, EN ISO 15586)	Pre-treatment and/or dyeing of polyester textile materials	Once every month <sup>(2)</sup>	
	Chromium (Cr)		Finishing with flame retardants using antimony trioxide		
			Dyeing with chromium mordant or chromium-containing dyes (e.g. metal-complex dyes)		
			Copper (Cu)		Dyeing
Nickel (Ni)	Printing with				

			dyes		
	Zinc (Zn) <sup>(1)</sup>		All activities / processes		
	Hexavalent chromium (Cr(VI))	Various EN standards available (e.g. EN ISO 10304-3, EN ISO 23913)	Dyeing with chromium mordant	Once every month	
Pesticides <sup>(1)</sup>		EN standards available for some pesticides (e.g. EN 12918, EN 16693, EN ISO 27108)	Pre-treatment of raw wool fibres by scouring	To be decided, after effluent characterisation <sup>(8)</sup>	
Per- and polyfluoroalkyl substances (PFAS) <sup>(1)</sup>		No EN standard available	All activities / processes	Once every 3 months	
Sulphide, easily released (S <sup>2-</sup> )		No EN standard available	Dyeing with sulphur dyes	Once every week or once every month <sup>(2)</sup>	
Surfactants	Alkylphenols and alkylphenol ethoxylates <sup>(1)</sup>	EN standards available for some non-ionic surfactants, e.g. alkylphenols and alkylphenol ethoxylates (i.e. EN ISO 18857-1 and EN ISO 18857-2)	All activities / processes	Once every 3 months	
	Other surfactants	EN 903 for anionic surfactants		Once every 3 months <sup>(7)</sup>	
No EN standard available for cationic surfactants					
Total nitrogen (TN)		Various EN standards available (e.g. EN 12260, EN ISO 11905-1)		Once every day <sup>(5) (6)</sup>	
Total organic carbon (TOC) <sup>(4)</sup>		EN 1484		Once every day <sup>(5) (6)</sup>	
Total phosphorus (TP)		Various EN standards available (e.g. EN ISO 6878, EN ISO 15681-1, EN ISO 15681-2, EN ISO 11885)		Once every day <sup>(5) (6)</sup>	
Total suspended solids (TSS)		EN 872		Once every day <sup>(5) (6)</sup>	
Toxicity <sup>(9)</sup>	Fish eggs ( <i>Danio rerio</i> )	EN ISO 15088		To be decided based on a risk assessment, after effluent characterisation <sup>(8)</sup>	
	Daphnia ( <i>Daphnia magna Straus</i> )	EN ISO 6341			
	Luminescent bacteria ( <i>Vibrio fischeri</i> )	Various EN standards available (e.g. EN ISO 11348-1, EN ISO 11348-2, EN ISO 11348-3)			
	Duckweed ( <i>Lemna minor</i> )	Various EN standards available (e.g. EN ISO 20079, EN ISO 20227)			
	Algae	Various EN standards			

		available (e.g. EN ISO 8692, EN ISO 10253, EN ISO 10710)			
<p>(<sup>1</sup>) The monitoring only applies when the substance(s)/parameter(s) (including groups of substances or individual substances in a group of substances) concerned is identified as relevant in the waste water stream based on the inventory of inputs and outputs mentioned in BAT 2.</p> <p>(<sup>2</sup>) In the case of an indirect discharge, the monitoring frequency may be reduced to once every 3 months if the downstream waste water treatment plant is designed and equipped appropriately to abate the pollutants concerned.</p> <p>(<sup>3</sup>) The monitoring only applies in the case of a direct discharge.</p> <p>(<sup>4</sup>) 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.</p> <p>(<sup>5</sup>) In the case of an indirect discharge, the monitoring frequency may be reduced to once every month if the downstream waste water treatment plant is designed and equipped appropriately to abate the pollutants concerned.</p> <p>(<sup>6</sup>) If the emission levels are proven to be sufficiently stable, a lower monitoring frequency of once every month can be adopted.</p> <p>(<sup>7</sup>) In the case of an indirect discharge, the monitoring frequency may be reduced to once every 6 months if the downstream waste water treatment plant is designed and equipped appropriately to abate the pollutants concerned.</p> <p>(<sup>8</sup>) The effluent characterisation is carried out before starting operation of the plant or before a permit for the plant is updated for the first time after the publication of these BAT conclusions, and after each change (e.g. change of 'recipe') in the plant that may increase the pollutant load.</p> <p>(<sup>9</sup>) Either the most sensitive toxicity parameter or an appropriate combination of the toxicity parameters can be used.</p>					

**BAT 9. BAT is to monitor channelled emissions to air 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	Standard(s)	Activities / processes	Minimum monitoring frequency ( <sup>1</sup> )	Monitoring associated with
CO	EN 15058	Singeing	Once every 3 years	—
		Combustion		
		Flame lamination		
Dust	EN 13284-1	Singeing	Once every year ( <sup>2</sup> )	BAT 27
		Combustion		
		Thermal treatments associated with pre-treatment, dyeing, printing and finishing		
CMR (other than formaldehyde) ( <sup>3</sup> )	No standards available	Coating ( <sup>4</sup> )	Once every year	—
		Flame lamination ( <sup>4</sup> )		
		Finishing ( <sup>4</sup> )		
		Thermal treatments associated with coating, lamination and finishing ( <sup>4</sup> )		
Formaldehyde ( <sup>3</sup> )	EN standard under development	Coating ( <sup>4</sup> )	Once every year	BAT 26
		Flame lamination		
		Printing ( <sup>4</sup> )		
		Singeing		
		Finishing ( <sup>4</sup> )		
		Thermal treatment ( <sup>4</sup> )		
NH <sub>3</sub> ( <sup>3</sup> )	EN ISO 21877	Coating ( <sup>4</sup> )	Once every year	BAT 28
		Printing ( <sup>5</sup> )		
		Finishing ( <sup>4</sup> )		
		Thermal treatments associated with coating, printing and finishing ( <sup>4</sup> )		

NO <sub>x</sub>	EN 14792	Singeing	Once every 3 years	—
		Combustion		
SO <sub>2</sub> <sup>(5)</sup>	EN 14791	Combustion	Once every 3 years	—
TVOC <sup>(3)</sup>	EN 12619	Coating	Once every year <sup>(6)</sup>	BAT 26
		Dyeing		
		Finishing		
		Lamination		
		Printing		
		Singeing		
		Thermofixation or heat-setting		
		Thermal treatments associated with coating, dyeing, lamination, printing and finishing		
<p>(<sup>1</sup>) To the extent possible, the measurements are carried out at the highest expected emission state under normal operating conditions.</p> <p>(<sup>2</sup>) In the case of a dust mass flow of less than 50 g/h, the minimum monitoring frequency may be reduced to once every 3 years.</p> <p>(<sup>3</sup>) Monitoring results are reported together with the corresponding air-to-textile ratio.</p> <p>(<sup>4</sup>) The monitoring only applies when the substance concerned is identified as relevant in the waste gas stream based on the inventory of inputs and outputs mentioned in BAT 2.</p> <p>(<sup>5</sup>) The monitoring does not apply if natural gas only, or liquefied petroleum gas only, is used as fuel.</p> <p>(<sup>6</sup>) In the case of a TVOC mass flow of less than 200 g/h, the minimum monitoring frequency may be reduced to once every 3 years.</p>				

### 5.4.3 Water consumption and waste water generation

**BAT 10.** In order to reduce water consumption and waste water generation, BAT is to use techniques (a), (b) and (c), and an appropriate combination of the techniques (d) to (j) given below.

Technique	Description	Applicability
<i>Management techniques</i>		
a.	<p>Water management plan and water audits</p> <p>A water management plan and water audits are part of the EMS (see BAT 1) and include:</p> <ul style="list-style-type: none"> <li>flow diagrams and water mass balances of the plant and processes as part of the inventory of inputs and outputs mentioned in BAT 2;</li> <li>establishment of water efficiency objectives;</li> <li>implementation of water optimisation techniques (e.g. control of water usage, reuse/recycling, detection and repair of leaks).</li> </ul> <p>Water audits are carried out at least once every year to ensure that the objectives of the water management plan are met and the water audits recommendations are followed up and implemented.</p> <p>The water management plan and the water audits may be integrated in the overall water management plan of a larger industrial site.</p>	<p>The level of detail of the water management plan and water audits will generally be related to the nature, scale and complexity of the plant.</p>
b.	<p>Production optimisation</p> <p>This includes:</p> <ul style="list-style-type: none"> <li>optimised combination of processes (e.g. pre-treatment processes are combined, bleaching of textile materials is avoided before dyeing in dark shades);</li> </ul>	<p>Generally applicable.</p>

		<ul style="list-style-type: none"> <li>optimised scheduling of batch processes (e.g. dyeing of the textile materials in dark shades is carried out after dyeing in light shades in the same dyeing equipment).</li> </ul>	
<b>Design and operation techniques</b>			
c.	Segregation of polluted and unpolluted water streams	Water streams are collected separately, based on the pollutant content and on the required treatment techniques. Polluted water streams (e.g. spent process liquors) and unpolluted water streams (e.g. cooling waters) that can be reused without treatment are segregated from waste water streams that require treatment.	Applicability to existing plants may be restricted by the layout of the water collection system and the lack of space for temporary storage tanks.
d.	Processes using little or no water	Processes include plasma or laser treatment, and processes using low amounts of water such as ozone treatment.	The applicability may be restricted by the characteristics of the textile materials and/or product specifications.
e.	Optimisation of the amount of process liquor used	Batch processes are carried out with low-liquor-ratio systems (see Section 5.12.4). Continuous processes are carried out with low-volume application systems, such as spraying (see Section 5.12.4).	Generally applicable.
f.	Optimised cleaning of the equipment	This includes: <ul style="list-style-type: none"> <li>water-free cleaning (e.g. by wiping or brushing the tanks' inner surfaces, mechanical pre-cleaning of squeegees, rotary screens and drums containing printing pastes (see BAT 44));</li> <li>multiple cleaning steps with low amounts of water; the water of the last cleaning step may be reused to clean another part of the equipment.</li> </ul>	The applicability of water-free cleaning in existing plants may be restricted by accessibility to the equipment (e.g. closed and semi-closed systems).
g.	Optimised batch processing, washing and rinsing of textile materials	This includes: <ul style="list-style-type: none"> <li>use of auxiliary tanks for temporary storage of: <ul style="list-style-type: none"> <li>spent washing or rinsing water;</li> <li>fresh or spent process liquor.</li> </ul> </li> <li>multiple drain and fill steps for rinsing and washing with low amounts of water.</li> </ul>	The use of auxiliary tanks in existing plants may be restricted by a lack of space.
h.	Optimised continuous processing, washing and rinsing of textile materials	This includes: <ul style="list-style-type: none"> <li>timely process liquor preparation based on online pick-up measurements;</li> <li>automatic closure of the washing water inflow when the washing machine stops;</li> <li>countercurrent rinsing and washing;</li> <li>intermediary mechanical dewatering of textile materials (see BAT 13 (a)) to reduce the carry-over of process chemicals.</li> </ul>	Generally applicable.
<b>Reuse and recycling techniques</b>			
i.	Water reuse and/or recycling	Water streams may be segregated (see BAT 10 (c)) and/or pre-treated (e.g. membrane filtration, evaporation) before reuse and/or recycling, e.g. for cleaning, rinsing, cooling or in the processing of textile materials. The degree of water reuse/ recycling is limited by the content of impurities in the water streams. Reuse and/or recycling of water originating from several plants operating on the same site may be	Generally applicable.

		integrated in the overall site water management of a larger industrial site (e.g. using common waste water treatment).	
j.	Reuse of process liquor	Process liquor, including the process liquor extracted from textile materials by mechanical dewatering (see BAT 13 (a)), is reused after analysis and make-up if needed. The degree of reuse of the process liquor is limited by the modification of its chemical composition, or by its content of impurities and perishability.	Generally applicable.

**Table 5.1: Indicative environmental performance levels for specific water consumption**

Specific process(es)		Indicative levels (Yearly average) (m <sup>3</sup> /t)
Bleaching	Batch	10–32 <sup>(1)</sup>
	Continuous	3–8
Scouring of cellulosic materials	Batch	5–15 <sup>(1)</sup>
	Continuous	5–12 <sup>(1)</sup>
Desizing of cellulosic materials		5–12 <sup>(1)</sup>
Combined bleaching, scouring and desizing of cellulosic materials		9–20 <sup>(1)</sup>
Mercerisation		2–13 <sup>(1)</sup>
Washing of synthetic material		5–20 <sup>(1)</sup>
Batch dyeing	Fabric	10–150 <sup>(1)</sup>
	Yarn	3–140 <sup>(1)</sup> <sup>(2)</sup>
	Loose fibre	13–60
Continuous dyeing		2–16 <sup>(1)</sup> <sup>(3)</sup>
<sup>(1)</sup> The lower end of the range may be achieved with a high level of water recycling (e.g. sites with integrated water management for several plants). <sup>(2)</sup> The range also applies to combined yarn and loose fibre batch dyeing. <sup>(3)</sup> The higher end of the range may be higher and up to 100 m <sup>3</sup> /t for plants using a combination of continuous and batch processes.		

The associated monitoring is given in BAT 6.

## 5.4.4 Energy efficiency

**BAT 11.** In order to use energy efficiently, BAT is to use techniques (a), (b) (c) and (d), and an appropriate combination of the techniques (e) to (k) given below.

Technique	Description	Applicability
<b>Management techniques</b>		
a.	Energy efficiency plan and audits  An energy efficiency plan and audits are part of the EMS (see BAT 1) and include: <ul style="list-style-type: none"> <li>energy flow diagrams of the plants and processes as part of the inventory of inputs and outputs (see BAT 2);</li> <li>setting objectives in terms of energy efficiency (e.g. MWh/t of textile materials processed);</li> <li>implementing actions to achieve these objectives.</li> </ul> Audits are carried out at least once every year to ensure that the objectives of the energy efficiency plan are met and the energy audits' recommendations are followed up and implemented.	The level of detail of the energy efficiency plan and audits will generally be related to the nature, scale and complexity of the plant.
b.	Production optimisation  Optimised scheduling of fabric batches to undergo thermal treatment in order to minimise the idling time of the equipment.	Generally applicable.
<b>Process and equipment selection and optimisation</b>		
c.	Use of general energy-saving techniques  This includes: <ul style="list-style-type: none"> <li>burner maintenance and control;</li> <li>energy-efficient motors;</li> <li>energy-efficient lighting;</li> <li>optimising steam distribution systems, e.g. by using point-of-use boilers;</li> <li>regular inspection and maintenance of the steam distribution systems to prevent or reduce steam leaks;</li> <li>process control systems;</li> <li>variable speed drives;</li> <li>optimising air conditioning and building heating.</li> </ul>	Generally applicable.
d.	Optimisation of heating demand  This includes: <ul style="list-style-type: none"> <li>reducing heat losses by insulating equipment components and by covering tanks or bowls containing warm process liquor;</li> <li>optimising the temperature of the rinsing water;</li> <li>avoiding overheating of the process liquors.</li> </ul>	Generally applicable.
e.	Wet-on-wet dyeing or finishing of fabric  Dyeing or finishing liquors are applied directly to the wet fabric, thus avoiding an intermediate drying step. Appropriate scheduling of production steps and dosing of chemicals need to be considered.	May not be applicable when chemicals cannot be taken up by the fabric due to insufficient residual pick-up.

f.	Cogeneration	Cogeneration of heat and electricity where the heat (mainly from the steam that leaves the turbine) is used for producing hot water/steam to be used in industrial processes/activities or in a district heating/cooling network.	Applicability in existing plants may be restricted by the plant layout and/or lack of space.
<b>Heat recovery techniques</b>			
g.	Recycling of warm cooling water	See BAT 10 (i). This avoids the need for heating cold water.	Generally applicable.
h.	Reuse of warm process liquor	See BAT 10 (j). This avoids the need for heating cold process liquor.	
i.	Heat recovery from waste water	Heat from waste water is recovered by heat exchangers, e.g. to warm up process liquor.	
j.	Heat recovery from waste gases	Heat from waste gases (e.g. from thermal treatment of textile materials, steam boilers) is recovered by heat exchangers and used (e.g. to warm up process water or to preheat combustion air).	
k.	Heat recovery from steam use	Heat, e.g. from hot condensate and boiler blowdown, is recovered.	

**BAT 12.** In order to increase energy efficiency when using compressed air, BAT is to use a combination of the techniques given below.

Technique		Description	Applicability
a.	Optimal design of the compressed air system	Several compressed air units supply air with different pressure levels. This avoids the unnecessary production of high-pressure air.	Only applicable to new plants or major plant upgrades.
b.	Optimal use of the compressed air system	Compressed air production is stopped during long shutdown or idling times of equipment, and single areas can be isolated (e.g. by valves) from the rest of the system, in particular if they are associated with infrequent use.	Generally applicable.
c.	Control of leakages in the compressed air system	The most common sources of air leakages are regularly inspected and maintained (e.g. couplings, hoses, tubes, fittings, pressure regulators).	
d.	Reuse and/or recycling of warm cooling water or warm cooling air from air compressors	Warm cooling air (e.g. from air-cooled air compressors) is reused and/or recycled (e.g. for drying of coils and hanks if needed). For reuse and/or recycling of warm cooling water, see BAT 11 (g).	

**BAT 13.** In order to increase the energy efficiency of thermal treatment, BAT is to use all of the techniques given below.

Technique		Description	Applicability
<b>Techniques for reducing the use of heating</b>			
a.	Mechanical dewatering of textile materials	The water content of textile materials is reduced by mechanical techniques (e.g. centrifugal extraction, squeezing and/or vacuum extraction).	Generally applicable.
b.	Avoiding overdrying of textile materials	The textile materials are not dried below their natural moisture level.	
<b>Design and operation techniques</b>			



c.	Optimising air circulation in stenters	<p>This includes:</p> <ul style="list-style-type: none"> <li>• adapting the number of air injection nozzles to the width of the fabric;</li> <li>• ensuring the distance between the nozzles and the fabric is as short as possible;</li> <li>• ensuring the pressure drop caused by the stenters' internal components is as small as possible.</li> </ul>	Only applicable to new plants or major plant upgrades.
d.	Advanced process monitoring and control of drying	<p>The drying parameters are monitored and controlled (see BAT 4). These parameters include:</p> <ul style="list-style-type: none"> <li>• humidity content and temperature of the inlet air;</li> <li>• temperature of textile materials and air within the dryer;</li> <li>• humidity content and temperature of the exhaust air; drying efficiency is optimised by an appropriate humidity content (e.g. above 0.1 kg water/kg dry air);</li> <li>• residual moisture content of the fabric.</li> </ul> <p>The exhaust airflow is adjusted to optimise drying efficiency and is reduced during idle periods of drying equipment.</p>	Generally applicable.
e.	Microwave or radio-frequency dryers	Drying of textile materials with high-efficiency microwave or radio frequency dryers.	Not applicable to textile materials containing metallic parts or fibres. Only applicable to new plants or major plant upgrades.
<b>Heat recovery techniques</b>			
f.	Heat recovery from waste gases	See BAT 11 (j).	Only applicable when the waste gas flow is sufficient.

**Table 5.2: Indicative environmental performance levels for specific energy consumption**

Process	Indicative level (Yearly average) (MWh/t)
Thermal treatment	0.5–4.4

The associated monitoring is given in BAT 6.

#### 5.4.5 Chemicals management, consumption and substitution

**BAT 14.** In order to improve the overall environmental performance, BAT is to elaborate and implement a chemicals management system (CMS), as part of the EMS (see BAT 1), that incorporates all of the following features:

- I. A policy to reduce the consumption and risks associated with process chemicals, including a procurement policy to select less harmful process chemicals and their suppliers with the aim of minimising the use and risks associated with hazardous substances and substances of very high concern as well as avoiding the procurement of an excess amount of process chemicals. The selection of process chemicals is based on:

- a) the comparative analysis of their bioeliminability/biodegradability, ecotoxicity and potential to be released into the environment (which in the case of emissions to air can be determined by using emission factors for example (see Section 5.12.1));
- b) the characterisation of the risks associated with the process chemicals, based on the chemicals' hazard classification, pathways through the plant, potential release and level of exposure;
- c) the potential for recovery and reuse (see BAT 16 (f) and (g) as well as BAT 39);
- d) the regular (e.g. annual) analysis of the potential for substitution with the aim to identify potentially new available and safer alternatives to the use of (groups of) hazardous substances and substances of very high concern, such as PFAS, phthalates, brominated flame retardants, chromium-(VI)-containing substances; this may be achieved by changing process(es) or using other process chemicals with no or lower environmental impacts;
- e) the anticipatory analysis of regulatory changes related to hazardous substances and substances of very high concern, and safeguarding compliance with applicable legal requirements.

The inventory of process chemicals (see BAT 15) may be used to provide and keep the information needed for the selection of process chemicals.

The criteria for selecting process chemicals and their suppliers may be based on certification schemes or standards. In that case, the compliance of the process chemicals and their suppliers with these schemes or standards is regularly verified.

- II. Goals and action plans to avoid or reduce the use of and risks associated with hazardous substances and substances of very high concern.
- III. Development and implementation of procedures for the procurement, handling, storage and use of process chemicals (see BAT 21), disposal of waste containing process chemicals and return of unused process chemicals (see BAT 29 (d)), to prevent or reduce emissions to the environment.

### **Applicability**

The level of detail of the CMS will generally be related to the nature, scale and complexity of the plant.

**BAT 15. In order to improve the overall environmental performance, BAT is to elaborate and implement a chemicals inventory as part of the CMS (see BAT 14).**

### **Description**

The chemicals inventory is computer-based and contains information about:

- the identity of the process chemicals;
- the quantities, location and perishability of the process chemicals procured, recovered (see BAT 16 (g)), stored, used and returned to suppliers;
- the composition and physico-chemical properties of process chemicals (e.g. solubility, vapour pressure, n-octanol/water partition coefficient), including properties with adverse effects on the environment and/or human health (e.g. ecotoxicity, bioeliminability/biodegradability).

Such information may be retrieved from Safety Data Sheets, Technical Data Sheets or other sources.

**BAT 16. In order to reduce the consumption of chemicals, BAT is to use all of the techniques given below.**

Technique		Description	Applicability
a.	Reduction of the need for process chemicals	This includes: <ul style="list-style-type: none"> <li>regularly reviewing and optimising the formulation of process chemicals and liquors;</li> <li>production optimisation (see BAT 10 (b)).</li> </ul>	Generally applicable.
b.	Reduction of the use of complexing agents	The use of soft/softened water reduces the amount of complexing agents used in the process liquors, e.g. for dyeing or bleaching (see BAT 38 (b)).	Not applicable to washing and rinsing.
c.	Treatment of textile materials with enzymes	Enzymes are selected (see BAT 14 I. (d)) and used to catalyse the reactions with textile materials to lower the consumption of process chemicals (e.g. in desizing, bleaching and/or washing).	The applicability may be restricted by the availability of suitable enzymes.
d.	Automatic systems for preparation and dosing of process chemicals and process liquors	Automatic systems for weighing, dosing, dissolving, measuring and dispensing which ensure precise delivery of process chemicals and process liquors to the production machines. See BAT 4.	The applicability to existing plants may be restricted by a lack of space, the distance between the preparation and the production machines or by frequent changes of process chemicals and process liquors.
e.	Optimisation of the quantity of process chemicals used	See BAT 10 (e).	Generally applicable.
f.	Reuse of process liquors	See BAT 10 (j).	Generally applicable.
g.	Recovery and use of leftover process chemicals	Residual process chemicals are recovered (e.g. by thoroughly purging pipes or completely emptying packaging) and used in the process. The degree of use may be limited by the content of impurities and the perishability of the process chemicals.	Generally applicable.

**BAT 17. In order to prevent or reduce emissions to water of poorly biodegradable substances, BAT is to use all of the techniques given below.**

Technique		Description	Applicability
a.	Substitution of alkylphenols and alkylphenol ethoxylates	Alkylphenols and alkylphenol ethoxylates are substituted by biodegradable surfactants, e.g. alcohol ethoxylates.	Generally applicable.

b.	Substitution of poorly biodegradable phosphorus- or nitrogen-containing complexing agents	<p>Complexing agents containing phosphorus (e.g. triphosphates) or nitrogen (e.g. amino polycarboxylic acids such as EDTA or DTPA) are substituted by biodegradable/bioeliminable substances, e.g.:</p> <ul style="list-style-type: none"> <li>• polycarboxylates (e.g. polyacrylates);</li> <li>• salts of hydroxy carboxylic acids (e.g. gluconates, citrates);</li> <li>• sugar-based acrylic acid copolymers;</li> <li>• methylglycinediacetic acid (MGDA), L-glutamic acid N,N-diacetic acid (GLDA) and iminodisuccinic acid (IDS);</li> <li>• phosphonates (e.g. aminotris methylene phosphonic acid (ATMP), diethylenetriamine pentamethylene phosphonic acid (DTPMP) and 1-hydroxyl ethylidene-1,1-diphosphonic acid (HEDP)).</li> </ul>	Generally applicable.
c.	Substitution of mineral-oil-based antifoaming agents	Mineral-oil-based antifoaming agents are substituted by biodegradable substances, e.g. antifoaming agents based on synthetic ester oil.	Generally applicable.

#### 5.4.6 Emissions to water

**BAT 18.** In order to reduce the waste water volume, to prevent or reduce the pollutant loads discharged to the waste water treatment plant and the emissions to water, BAT is to use an integrated strategy for waste water management and treatment that includes an appropriate combination of the techniques given below with the following order of priority:

- process-integrated techniques (see BAT 10 and BAT conclusions in Sections 5.5 to 5.10),
- techniques to recover and reuse process liquors (see BAT 10(j) and BAT 39), separate collection of waste water streams and pastes (e.g. printing and coating) containing high loads of pollutants that cannot be adequately treated by biological treatment; these waste water streams and pastes are either pretreated (see BAT 19) or handled as waste (see BAT 30),
- (final) waste water treatment techniques (see BAT 20).

##### Description

The integrated strategy for waste water management and treatment is based on the information provided by the inventory of inputs and outputs (see BAT 2).

**BAT 19.** In order to reduce emissions to water, BAT is to pretreat (separately collected) waste water streams and pastes (e.g. printing and coating) containing high loads of pollutants that cannot be treated adequately by biological treatment.

##### Description

Such waste water streams and pastes include:

- spent dyeing, coating or finishing padding liquors from continuous and/or semi-continuous treatments;
- desizing liquors;
- spent printing and coating pastes.

The pre-treatment is carried out as part of an integrated strategy for waste water management and treatment (see BAT 18) and is generally necessary to:

- protect the (downstream) biological waste water treatment against inhibitory or toxic compounds;
- remove compounds that are insufficiently abated during biological waste water treatment (e.g. toxic compounds, poorly biodegradable organic compounds, organic compounds that are present in high loads or metals);
- remove compounds that could otherwise be stripped to air from the collection system or during biological waste water treatment (e.g. sulphide);
- remove compounds that have other negative effects (e.g. corrosion of equipment; unwanted reaction with other substances; contamination of waste water sludge).

The above-mentioned compounds to be removed include organophosphorus and brominated flame retardants, PFAS, phthalates and chromium-(VI)-containing compounds.

The pre-treatment of these waste water streams is generally carried out as close as possible to the source in order to avoid dilution. The pre-treatment techniques used depend on the pollutants targeted and may include adsorption, filtration, precipitation, chemical oxidation or chemical reduction (see BAT 20).

The bioeliminability/biodegradability of the waste water streams and pastes before they are sent to the downstream biological treatment is at least:

- 80 % after 7 days (for adapted sludge), when determined according to standard EN ISO 9888, or
- 70 % after 28 days when determined according to standard EN ISO 7827.

The associated monitoring is given in BAT 7.

**BAT 20. In order to reduce emissions to water, BAT is to use an appropriate combination of the techniques given below.**

Technique <sup>(1)</sup>		Typical pollutants targeted	Applicability
<i>Pre-treatment of individual waste water streams, e.g.</i>			
a.	Adsorption	Adsorbable dissolved non-biodegradable or inhibitory pollutants (e.g. AOX in dyestuffs, organophosphorus flame retardants)	Generally applicable.
b.	Precipitation	Precipitable dissolved non-biodegradable or inhibitory pollutants (e.g. metals in dyestuffs)	
c.	Coagulation and flocculation	Suspended solids and particulate-bound non-biodegradable or inhibitory pollutants (e.g. metals in dyestuffs)	
d.	Chemical oxidation (e.g. oxidation with ozone, hydrogen peroxide or UV light)	Oxidisable dissolved non-biodegradable or inhibitory pollutants (e.g. optical brighteners and azo dyestuffs, sulphide)	
e.	Chemical reduction	Reducible dissolved non-biodegradable or inhibitory pollutants (e.g. hexavalent chromium (Cr(VI)))	
f.	Anaerobic pre-treatment	Biodegradable organic compounds (e.g. azo dyestuffs, printing pastes)	
g.	Filtration (e.g. nanofiltration)	Suspended solids and particulate-bound non-biodegradable or inhibitory pollutants	

<b>Pre-treatment of combined waste water streams, e.g.</b>			
h.	Physical separation (e.g. screens, sieves, grit separators, grease separators, oil-water separation, or primary settlement tanks)	Gross solids, suspended solids, oil/grease	Generally applicable.
i.	Equalisation	All pollutants	
j.	Neutralisation	Acids, alkalis	
<b>Primary treatment, e.g.</b>			
k.	Sedimentation	Suspended solids and particulate-bound metals or non-biodegradable or inhibitory pollutants	Generally applicable.
l.	Precipitation	Precipitable dissolved non-biodegradable or inhibitory pollutants (e.g. metals in dyestuffs)	
m.	Coagulation and flocculation	Suspended solids and particulate-bound non-biodegradable or inhibitory pollutants (e.g. metals in dyestuffs)	Generally applicable.
<b>Secondary treatment (biological treatment), e.g.</b>			
n.	Activated sludge process	Biodegradable organic compounds	Generally applicable.
o.	Membrane bioreactor		
p.	Nitrification/denitrification (when the treatment includes a biological treatment)	Total nitrogen, ammonium/ammonia	Nitrification may not be applicable in the case of high chloride concentrations (e.g. above 10 g/l). Nitrification may not be applicable when the temperature of the waste water is low (e.g. below 12 °C).
<b>Tertiary treatment, e.g.</b>			
q.	Coagulation and flocculation	Suspended solids and particulate-bound non-biodegradable or inhibitory pollutants (e.g. metals in dyestuffs)	Generally applicable.
r.	Precipitation	Precipitable dissolved non-biodegradable or inhibitory pollutants (e.g. metals in dyestuffs)	
s.	Adsorption	Adsorbable dissolved non-biodegradable or inhibitory pollutants (e.g. AOX in dyestuffs)	
t.	Chemical oxidation (e.g. oxidation with ozone, hydrogen peroxide or UV light)	Oxidisable dissolved non-biodegradable or inhibitory pollutants (e.g. optical brighteners and azo dyestuffs, sulphide)	
u.	Flotation	Suspended solids and particulate-bound non-biodegradable or inhibitory pollutants	
v.	Filtration (e.g. sand filtration)		
<b>Advanced treatment for recycling the waste water, e.g. (2)</b>			
w.	Filtration (e.g. sand filtration, or membrane filtration)	Suspended solids and particulate-bound non-biodegradable or inhibitory pollutants	Generally applicable.
x.	Evaporation	Soluble contaminants (e.g. salts)	

(1) The descriptions of the techniques are given in Section 5.12.3.

(2) Minimal waste water discharge (e.g. 'zero liquid discharge') may be achieved using a combination of techniques including advanced treatment techniques for recycling the waste water.

**Table 5.3: BAT-associated emission levels (BAT-AELs) for direct discharges**

Substance/Parameter		Activities / processes	BAT-AEL <sup>(1)</sup> (mg/l)
Adsorbable organically bound halogens (AOX) <sup>(2)</sup>		All activities / processes	0.1–0.4 <sup>(3)</sup>
Chemical oxygen demand (COD) <sup>(4)</sup>			40–100 <sup>(5)</sup> <sup>(6)</sup>
Hydrocarbon oil index (HOI) <sup>(2)</sup>			1–7
Metals / metalloids	Antimony (Sb)	Pre-treatment and/or dyeing of polyester textile materials	0.1–0.2 <sup>(7)</sup>
		Finishing with flame retardants using antimony trioxide	
	Chromium (Cr)	Dyeing with chromium mordant or chromium-containing dyes (e.g. metal-complex dyes)	0.01–0.1 <sup>(8)</sup>
	Copper (Cu)	Dyeing	0.03–0.4
	Nickel (Ni)	Printing with dyes	0.01–0.1 <sup>(9)</sup>
	Zinc (Zn) <sup>(2)</sup>	All activities / processes	0.04–0.5 <sup>(10)</sup>
Sulphide, easily released (S <sup>2-</sup> )		Dyeing with sulphur dyes	< 1
Total nitrogen (TN)		All activities / processes	5–15 <sup>(11)</sup>
Total organic carbon (TOC) <sup>(4)</sup>			13–30 <sup>(6)</sup> <sup>(12)</sup>
Total phosphorus (TP)			0.4–2
Total suspended solids (TSS)			5–30

<sup>(1)</sup> The averaging periods are defined in the general considerations.

<sup>(2)</sup> The BAT-AELs only apply when the substance/parameter concerned is identified as relevant in the waste water stream based on the inventory of inputs and outputs mentioned in BAT 2.

<sup>(3)</sup> The higher end of the BAT-AEL range may be higher and up to 0.8 mg/l when dyeing polyester and/or modacrylic fibres.

<sup>(4)</sup> Either the BAT-AEL for COD or the BAT-AEL for TOC applies. The BAT-AEL for TOC is the preferred option because TOC monitoring does not rely on the use of very toxic compounds.

<sup>(5)</sup> The higher end of the BAT-AEL range may be up to 150 mg/l:

- when the specific amount of waste water discharged is less than 25 m<sup>3</sup>/t of treated textile materials as a rolling yearly average; or
- when the abatement efficiency is ≥ 95 % as a rolling yearly average.

<sup>(6)</sup> No BAT-AEL applies for biochemical oxygen demand (BOD). As an indication, the yearly average BOD<sub>5</sub> level in the effluent from a biological waste water treatment plant will generally be ≤ 10 mg/l.

<sup>(7)</sup> The higher end of the BAT-AEL range may be higher and up to 1.2 mg/l when dyeing polyester and/or modacrylic fibres.

<sup>(8)</sup> The higher end of the BAT-AEL range may be higher and up to 0.3 mg/l when polyamide, wool or silk fibres are dyed using metal-complex dyes.

<sup>(9)</sup> The higher end of the BAT-AEL range may be higher and up to 0.2 mg/l when dyeing or printing with nickel-containing reactive dyes or pigments.

<sup>(10)</sup> The higher end of the BAT-AEL range may be higher and up to 0.8 mg/l when treating viscose fibres or when dyeing using zinc-containing cationic dyes.

<sup>(11)</sup> The BAT-AEL may not apply when the temperature of the waste water is low (e.g. below 12 °C) for prolonged periods.

<sup>(12)</sup> The higher end of the BAT-AEL range may be up to 50 mg/l:

- when the specific amount of waste water discharged is less than 25 m<sup>3</sup>/t of treated textile materials as a rolling yearly average; or
- when the abatement efficiency is ≥ 95 % as a rolling yearly average.

The associated monitoring is given in BAT 8.

**Table 5.4: BAT-associated emission levels (BAT-AELs) for indirect discharges**

Substance/Parameter		Activities / processes	BAT-AEL <sup>(1)</sup> <sup>(2)</sup> (mg/l)
Adsorbable organically bound halogens (AOX) <sup>(3)</sup>		All processes	0.1–0.4 <sup>(4)</sup>
Hydrocarbon oil index (HOI) <sup>(3)</sup>		All processes	1–7
Metals / metalloids	Antimony (Sb)	Pre-treatment and/or dyeing of polyester textile materials	0.1–0.2 <sup>(5)</sup>

		Finishing with flame retardants using antimony trioxide	
	Chromium (Cr)	Dyeing with chromium mordant or chromium-containing dyes (e.g. metal-complex dyes)	0.01–0.1 <sup>(6)</sup>
	Copper (Cu)	Dyeing Printing with dyes	0.03–0.4
	Nickel (Ni)	Dyeing Printing with dyes	0.01–0.1 <sup>(7)</sup>
	Zinc (Zn) <sup>(3)</sup>	All processes	0.04–0.5 <sup>(8)</sup>
Sulphide, easily released (S <sup>2-</sup> )		Dyeing with sulphur dyes	< 1
<p><sup>(1)</sup> The averaging periods are defined in the general considerations.</p> <p><sup>(2)</sup> 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.</p> <p><sup>(3)</sup> The BAT-AELs only apply when the substance/parameter concerned is identified as relevant in the waste water stream based on the inventory of inputs and outputs mentioned in BAT 2.</p> <p><sup>(4)</sup> The higher end of the BAT-AEL range may be higher and up to 0.8 mg/l when dyeing polyester and/or modacrylic fibres.</p> <p><sup>(5)</sup> The higher end of the BAT-AEL range may be higher and up to 1.2 mg/l when dyeing polyester and/or modacrylic fibres.</p> <p><sup>(6)</sup> The higher end of the BAT-AEL range may be higher and up to 0.3 mg/l when polyamide, wool or silk fibres are dyed using metal-complex dyes.</p> <p><sup>(7)</sup> The higher end of the BAT-AEL range may be higher and up to 0.2 mg/l when dyeing or printing with nickel-containing reactive dyes or pigments.</p> <p><sup>(8)</sup> The higher end of the BAT-AEL range may be higher and up to 0.8 mg/l when treating viscose fibres or when dyeing using zinc-containing cationic dyes.</p>			

The associated monitoring is given in BAT 8.

#### 5.4.7 Emissions to soil and groundwater

**BAT 21.** In order to prevent or reduce emissions to soil and groundwater and to improve the overall performance of the handling and storage of process chemicals, BAT is to use all of the techniques given below.



Technique		Description	Applicability
a.	Techniques to reduce the likelihood and environmental impact of overflows and failures of process and storage tanks	<p>This includes:</p> <ul style="list-style-type: none"> <li>slow immersion into and withdrawal of textile materials from the process liquor to avoid spillages;</li> <li>automatic level adjustment of process liquor (see BAT 4);</li> <li>avoiding direct injection of water to heat or cool the process liquor;</li> <li>overflow detectors;</li> <li>channelling overflows to another tank;</li> <li>locating tanks for liquids (process chemicals or liquid waste) in a suitable secondary containment; their volume is sized to accommodate at least the complete loss of the liquid of the largest tank that is within the secondary containment;</li> <li>isolation of tanks and secondary containment (e.g. by closing valves);</li> <li>ensuring that the surfaces of the process and storage areas are impermeable to the liquids concerned.</li> </ul>	Generally applicable.
b.	Regular inspection and maintenance of plant and equipment	The plant and the equipment are regularly inspected and maintained to ensure proper functioning; this includes in particular checking the integrity and/or leak-free status of valves, pumps, pipes, tanks and containments/bunds as well as the proper functioning of warning systems (e.g. overflow detectors).	
c.	Optimised storage location of process chemicals	The storage areas are located in such a way as to eliminate or minimise the unnecessary transport of process chemicals within the plant (e.g. the transport distances on site are minimised).	The applicability to existing plants may be restricted by a lack of space.
d.	Dedicated area for unloading process chemicals containing hazardous substances	Process chemicals containing hazardous substances are unloaded in a bunded area. Occasional spillages are collected and sent for treatment.	
e.	Segregated storage of process chemicals	Incompatible process chemicals are kept separated. This segregation relies on physical separation and on the chemicals inventory (see BAT 15).	Generally applicable.
f.	Handling and storage of packaging containing process chemicals	Packaging containing liquid process chemicals is completely emptied by gravity or by mechanical means (e.g. brushing, wiping) without the use of water. Packaging containing process chemicals in powder is emptied by gravity for small packaging and using suction for large packaging. Empty packaging is stored in a dedicated area.	

### 5.4.8 Emissions to air

**BAT 22.** In order to reduce diffuse emissions to air (e.g. VOCs from the use of organic solvents), BAT is to collect diffuse emissions and send the waste gases to treatment.

#### Applicability

In the case of existing plants, the applicability may be restricted by operational constraints or by the high volume of air to be extracted.

**BAT 23.** In order to facilitate the recovery of energy and the reduction of channelled emissions to air, BAT is to limit the number of emission points.

#### Description

The combined treatment of waste gases with similar characteristics ensures more effective and efficient treatment compared to the separate treatment of individual waste gas streams. The extent to which the number of emission points can be limited depends on technical (e.g. compatibility of the individual waste gas streams) and economic factors (e.g. distance between different emission points). Care is taken that limiting the number of emission points does not lead to the dilution of emissions.

**BAT 24.** In order to prevent emissions of organic compounds to air from dry cleaning and from scouring with organic solvent, BAT is to extract the air from these processes, to treat it using adsorption with activated carbon (see Section 5.12.2) and to fully recirculate it.

**BAT 25.** In order to reduce emissions of organic compounds to air from the pre-treatment of knitted synthetic textile materials, BAT is to wash them prior to thermofixation or heat-setting.

#### Applicability

Applicability may be limited by the fabric construction.

**BAT 26.** In order to prevent or reduce channelled emissions of organic compounds to air from singeing, thermal treatment, coating and lamination, BAT is to use one or a combination of the techniques given below.

Technique		Typical pollutants target	Description
<i>Prevention techniques</i>			
a.	Selection and use of mixtures of chemicals ('recipes') leading to low emissions of organic compounds	Organic compounds	Mixtures with low emissions of organic compounds are selected and used taking into consideration product specifications (see BAT 14, BAT 17, BAT 50, BAT 51). As an example, emission factors may be used for selection (see Section 5.12.1).
<i>Reduction techniques</i>			
b.	Condensation	Organic compounds excluding formaldehyde	See Section 5.12.2.
c.	Thermal oxidation	Organic compounds	
d.	Wet scrubbing	Organic compounds	
e.	Adsorption	Organic compounds excluding formaldehyde	

**Table 5.5: BAT-associated emission levels (BAT-AELs) for channelled emissions of organic compounds and formaldehyde to air**

Substance/Parameter	Activities / Processes (including associated thermal treatments)	BAT-AEL (Average over the sampling period) (mg/Nm <sup>3</sup> )
Formaldehyde	Coating <sup>(1)</sup>	1–5 <sup>(2)</sup> <sup>(3)</sup>
	Flame lamination	
	Printing <sup>(1)</sup>	
	Singeing	
	Finishing <sup>(1)</sup>	
TVOC	Coating	3–40 <sup>(2)</sup> <sup>(4)</sup> <sup>(5)</sup>
	Dyeing	
	Finishing	
	Lamination	
	Printing	
	Singeing	
Thermofixation or heat-setting		
<p><sup>(1)</sup> The BAT-AEL only applies when formaldehyde is identified as relevant in the waste gas stream based on the inventory of inputs and outputs mentioned in BAT 2.</p> <p><sup>(2)</sup> For activities listed under points 3 and 9, Part 1 of Annex VII to the IED, the BAT-AEL ranges only apply to the extent that they lead to lower emission levels than the emission limit values in Parts 2 and 4 of Annex VII to the IED.</p> <p><sup>(3)</sup> For finishing processes with easy-care agents, water-/oil-/soil-repellents and/or flame retardants, the higher end of the BAT-AEL range may be higher and up to 10 mg/Nm<sup>3</sup>.</p> <p><sup>(4)</sup> The lower end of the BAT-AEL range is typically achieved when using thermal oxidation.</p> <p><sup>(5)</sup> The BAT-AEL does not apply when the TVOC mass flow is below 200 g/h for emission point(s) where:</p> <ul style="list-style-type: none"> <li>- abatement techniques are not used, and</li> <li>- no CMR substances are identified as relevant in the waste gas stream based on the inventory of inputs and outputs mentioned in BAT 2.</li> </ul>		

The associated monitoring is given in BAT 9.

**BAT 27. In order to reduce channelled dust emissions to air from singeing and thermal treatments, excluding thermofixation and heat-setting, BAT is to use one or a combination of the techniques given below.**

Technique		Description
a.	Cyclone	See Section 5.12.2. Cyclones are mainly used as pretreatment before further dust abatement (e.g. for coarse dust).
b.	Electrostatic precipitator (ESP)	See Section 5.12.2.
c.	Wet scrubbing	

**Table 5.6: BAT-associated emission level (BAT-AEL) for channelled dust emissions to air from singeing and thermal treatments, excluding thermofixation and heat-setting**

Substance/Parameter	BAT-AEL (Average over the sampling period) (mg/Nm <sup>3</sup> )
Dust	< 2–10 <sup>(1)</sup>
<sup>(1)</sup> The BAT-AEL does not apply when the dust mass flow is below 50 g/h for emission point(s) where: <ul style="list-style-type: none"> <li>- abatement techniques are not used, and</li> <li>- no CMR substances are identified as relevant in the waste gas stream based on the inventory of inputs and outputs mentioned in BAT 2.</li> </ul>	

The associated monitoring is given in BAT 9.

**BAT 28. In order to prevent or reduce channelled ammonia emissions to air from coating, printing and finishing, including thermal treatments associated with these processes, BAT is to use one or a combination of the techniques given below.**

Technique		Description
<i>Prevention techniques</i>		
a.	Selection and use of mixtures of chemicals ('recipes') leading to low emissions of ammonia	Mixtures with low emissions of ammonia are selected and used taking into consideration product specifications (see BAT 14, BAT 17, BAT 46, BAT 47, BAT 50, BAT 51). As an example, emission factors may be used for selection (see Section 5.12.1).
<i>Reduction techniques</i>		
b.	Wet scrubbing	See Section 5.12.2.

**Table 5.7: BAT-associated emission level (BAT-AEL) for channelled ammonia emissions to air from coating, printing and finishing, including thermal treatments associated with these processes**

Substance/Parameter	BAT-AEL <sup>(1)</sup> (Average over the sampling period) (mg/Nm <sup>3</sup> )
NH <sub>3</sub>	3–10 <sup>(2)</sup>
<sup>(1)</sup> The BAT-AEL only applies when NH <sub>3</sub> is identified as relevant in the waste gas stream based on the inventory of inputs and outputs mentioned in BAT 2. <sup>(2)</sup> The higher end of the BAT-AEL range may be higher and up to 20 mg/Nm <sup>3</sup> when ammonium sulphamate is used as a flame retardant or ammonia is used for curing (see BAT 50).	

The associated monitoring is given in BAT 9.

## 5.4.9 Waste

**BAT 29.** In order to prevent or reduce the generation of waste and to reduce the quantity of waste sent for disposal, BAT is to use all of the techniques given below.

Technique		Description	Applicability
a.	Waste management plan	A waste management plan is part of the EMS (see BAT 1) and is a set of features aiming to: <ul style="list-style-type: none"> <li>• minimise the generation of waste,</li> <li>• optimise the reuse, regeneration, recycling and/or recovery of waste, and</li> <li>• ensure the proper disposal of waste.</li> </ul>	The level of detail of the waste management plan will generally be related to the nature, scale and complexity of the plant.
b.	Timely use of process chemicals	Criteria are clearly established associated for example with maximum storage time of process chemicals, and relevant parameters are monitored to avoid process chemicals perishing.	Generally applicable.
c.	Reuse/recycling of packaging	Process chemicals packaging is selected to facilitate its complete emptying (e.g. considering the size of the packaging aperture or the nature of the packaging material). After emptying (see BAT 21), the packaging is reused, returned to the supplier or sent for material recycling.	
d.	Return of unused process chemicals	Unused process chemicals (i.e. which remain in their original containers) are returned to their suppliers.	Generally applicable.

**BAT 30.** In order to improve the overall environmental performance of the handling of waste, especially to prevent or reduce emissions to the environment, BAT is to use the technique given below before waste is sent for disposal.

Technique	Description
Separate collection and storage of wastes contaminated with hazardous substances and/or substances of very high concern	Wastes contaminated with hazardous substances and/or substances of very high concern (e.g. finishing chemicals such as flame retardants, oil-, water- and soil-repellents) are collected and stored separately. These wastes may contain high loads of pollutants such as organophosphorus and brominated flame retardants, PFAS, phthalates and chromium-(VI)-containing compounds (see BAT 18) and include in particular: <ul style="list-style-type: none"> <li>• liquid waste (e.g. first rinsing water in flame retardance finishing), coating and printing pastes;</li> <li>• waste paper, cloths, absorbent material;</li> <li>• laboratory waste;</li> <li>• sludge from waste water treatment.</li> </ul>

## 5.5 BAT conclusions for the pre-treatment of raw wool fibres by scouring

The BAT conclusions in this section apply to the pre-treatment of raw wool fibres by scouring and apply in addition to the general BAT conclusions in Section 5.4.

**BAT 31. In order to use resources efficiently as well as to reduce water consumption and waste water generation, BAT is to recover wool grease and recycle waste water.**

### Description

Waste water from wool scouring is treated (e.g. by a combination of centrifugation and sedimentation) to separate grease, dirt and water. Grease is recovered, water is partially recycled to scouring and dirt is sent for further treatment.

**Table 5.8: BAT-associated environmental performance levels (BAT-AEPLs) for the recovery of wool grease from the pre-treatment of raw wool fibres by scouring**

Type of wool	Unit	BAT-AEPL (Yearly average)
Coarse wool (i.e. wool fibre diameter typically higher than 35 µm)	kg of recovered grease per tonne of raw wool fibres pretreated by scouring	10–15
Extra- and super-fine wool (i.e. wool fibre diameter typically lower than 20 µm)		50–60

The associated monitoring is given in BAT 6.

**BAT 32. In order to use energy efficiently, BAT is to use all of the techniques given below.**

Technique	Description	Applicability
a. Covered scouring bowls	Scouring bowls are fitted with covers to prevent heat losses by convection or evaporation (see BAT 11 (c)).	Only applicable to new plants or major plant upgrades.
b. Optimised temperature of the last scouring bowl	The temperature of the last scouring bowl is optimised to increase the efficiency of the subsequent mechanical wool dewatering (see BAT 13 (a)) and drying.	Generally applicable.
c. Direct heating	Scouring bowls and dryers are directly heated in order to avoid the heat losses which occur in the generation and distribution of steam.	Only applicable to new plants or major plant upgrades.

**BAT 33. In order to use resources efficiently and to reduce the amount of waste sent for disposal, BAT is to biologically treat organic residues from the pre-treatment of raw wool fibres by scouring (e.g. dirt, waste water treatment sludge).**

### Description

The organic residues are treated, for example by composting.

## 5.6 BAT conclusions for the spinning of fibres (other than man-made fibres) and the production of fabric

The BAT conclusions presented in this section apply to the spinning of fibres (other than man-made fibres) and the production of fabric and apply in addition to the general BAT conclusions in Section 5.4.

**BAT 34. In order to reduce emissions to water from the use of sizing chemicals, BAT is to use all of the techniques given below.**

Technique		Description	Applicability
a.	Selection of sizing chemicals	Sizing chemicals with improved environmental performance in terms of quantity needed, washability, recoverability and/or bioeliminability/biodegradability (e.g. modified starches, certain galactomannans and carboxymethyl cellulose) are selected (see BAT 14) and used.	Generally applicable.
b.	Pre-wetting of the cotton yarns	The cotton yarns are dipped into hot water prior to sizing. This allows a reduction of the amounts of sizing chemicals used.	The applicability may be restricted by product specifications (e.g. when high tension is required on the fibre during weaving).
c.	Compact spinning	The fibre strands are compressed by suction or by mechanical or magnetic compacting. This allows a reduction of the amounts of sizing chemicals used.	The applicability may be restricted by product specifications (e.g. level of hairiness or technical properties of the yarn).

**BAT 35. In order to improve the overall environmental performance of spinning and knitting, BAT is to avoid the use of mineral oils.**

### Description

Mineral oils are substituted by synthetic oils and/or ester oils, with improved environmental performance in terms of washability and bioeliminability/biodegradability.

**BAT 36.** In order to use energy efficiently, BAT is to use technique (a) and one or both of techniques (b) and (c) given below.

Technique		Description	Applicability
a.	Use of general energy-saving techniques for spinning and weaving	<p>This includes:</p> <ul style="list-style-type: none"> <li>reducing, as much as possible, the volume of the production area (e.g. by installing a suspended ceiling) to reduce the amount of energy needed for humidifying the ambient air;</li> <li>using advanced sensors that detect thread breaks to stop the spinning or weaving machines.</li> </ul>	Generally applicable.
b.	Use of energy-saving techniques for spinning	<p>This includes:</p> <ul style="list-style-type: none"> <li>using lighter spindles and bobbins in ring frames;</li> <li>using spindle oil with optimal viscosity;</li> <li>maintaining an optimal oiling level of the yarn;</li> <li>optimising the ring diameter with respect to the yarn diameter in ring frames;</li> <li>gradual start-up of the ring spinning machines;</li> <li>using vortex spinning;</li> <li>optimising the movement of empty bobbin conveyors in cone winding machines.</li> </ul>	Generally applicable.
c.	Use of energy-saving techniques for weaving	<p>This includes:</p> <ul style="list-style-type: none"> <li>avoiding excessive air pressure for air-jet weaving;</li> <li>using a double-width loom for large-volume batches.</li> </ul>	A double-width loom may only be applicable to new plants or major plant upgrades.



## 5.7 BAT conclusions for the pre-treatment of textile materials other than raw wool fibres

The BAT conclusions in this section apply to the pre-treatment of textile materials other than raw wool fibres and apply in addition to the general BAT conclusions in Section 5.4.

**BAT 37.** In order to use resources and energy efficiently as well as to reduce water consumption and waste water generation, BAT is to use both techniques (a) and (b), in combination with technique (c) or in combination with technique (d) given below.

Technique		Description	Applicability
a.	Combined pre-treatment of cotton textile	Various pre-treatment operations of cotton textiles (e.g. washing, desizing, scouring and bleaching) are carried out simultaneously.	Generally applicable.
b.	Cold pad-batch treatment of cotton textiles	Desizing and/or bleaching are carried out with the cold pad-batch technique (see Section 5.12.4).	Generally applicable.
c.	Single or limited number of desizing liquors	The number of desizing liquors for removing different types of sizing chemicals is limited. In some cases, e.g. for various cellulosic materials, a single oxidative desizing liquor may be used.	Generally applicable.
d.	Recovery and reuse of water-soluble sizing chemicals	When desizing is carried out by washing with hot water, water-soluble sizing chemicals (e.g. polyvinyl alcohol and carboxymethyl cellulose) are recovered from the washing water by ultrafiltration. The concentrate is reused for sizing, whereas the permeate is reused for washing.	Only applicable where sizing and desizing are carried out at the same plant. May not be applicable for synthetic sizing chemicals (e.g. containing polyester polyols, polyacrylates or polyvinyl acetate).

**BAT 38.** In order to prevent or reduce emissions to water of chlorine-containing compounds and complexing agents, BAT is to use one or both of the techniques given below.

Technique		Description	Applicability
a.	Chlorine-free bleaching	Bleaching is carried out with chlorine-free bleaching chemicals (e.g. hydrogen peroxide, peracetic acid or ozone), often combined with pre-treatment with enzymes (see BAT 16 (c)).	May not be applicable to the brightening of flax and other bast fibres.
b.	Optimised hydrogen peroxide bleaching	The use of complexing agents can be completely avoided or minimised by reducing the concentration of hydroxyl radicals during bleaching. This is achieved by: <ul style="list-style-type: none"> <li>• using soft/softened water;</li> <li>• prior removal of metal impurities from textile materials (e.g. by magnetic separation, chemical treatment or pre-washing);</li> <li>• controlling the pH and the hydrogen peroxide concentration during bleaching.</li> </ul>	Generally applicable.

**BAT 39.** In order to use resources efficiently and to reduce the amount of alkali discharged to waste water treatment, BAT is to recover caustic soda used for mercerisation.

**Description**

Caustic soda is recovered from the rinsing water by evaporation and further purified, if needed. Before evaporation, the impurities in the rinsing water are removed by using, for example, screens and/or microfiltration.

**Applicability**

Applicability may be restricted by a lack of suitable recovered heat and/or by a low amount of caustic soda.

**Table 5.9: BAT-associated environmental performance level (BAT-AEPL) for the recovery of caustic soda used for mercerisation**

<b>Unit</b>	<b>BAT-AEPL (Yearly average)</b>
% of caustic soda recovered	75–95

The associated monitoring is given in BAT 6.

## 5.8 BAT conclusions for dyeing

The BAT conclusions in this section apply to dyeing and apply in addition to the general BAT conclusions in Section 5.4.

**BAT 40.** In order to use resources efficiently and to reduce emissions to water from dyeing, BAT is to use one or a combination of the techniques given below.

Technique		Description
<b>Techniques for batch and continuous dyeing</b>		
a.	Selection of dyes	Dyes with dispersing agents that are biodegradable (e.g. based on fatty acid esters) are selected.
b.	Dyeing with levelling agents made from recycled vegetable oil	Levelling agents made from recycled vegetable oil are used in high-temperature dyeing of polyester and in dyeing of protein and polyamide fibres.
<b>Techniques for batch dyeing</b>		
c.	pH-controlled dyeing	For textile materials with zwitterionic characteristics, dyeing is carried out at constant temperature and controlled by gradually lowering the pH of the dyeing liquor below the isoelectric point of the textile materials.
d.	Optimised removal of unfixed dyestuff in reactive dyeing	Unfixed dyestuff is removed from the textile materials by using enzymes (e.g. laccase, lipase) (see BAT 16 (c)) and/or vinyl polymers. This reduces the number of rinsing steps needed.
<b>Techniques for batch dyeing</b>		
e.	Low-liquor-ratio systems	See Section 5.12.4.
<b>Techniques for continuous dyeing</b>		
f.	Low-volume application systems	See Section 5.12.4.

**BAT 41.** In order to use resources efficiently and to reduce emissions to water from the dyeing of cellulosic materials, BAT is to use one or a combination of the techniques given below.

Technique	Description	Applicability
<b>Technique for dyeing with sulphur and vat dyes</b>		
a.	Minimised use of sulphur-based reducing agents	Dyeing is carried out without sodium sulphide or hydrosulphite as reducing agents. Where this is not possible, partially chemically pre-reduced dyes (e.g. indigo dyes) are used so that less sodium sulphide or hydrosulphite is added for dyeing. The applicability may be restricted by product specifications (e.g. shade).
<b>Technique for continuous dyeing with vat dyes</b>		
b.	Selection of vat dyes	Vat dyes that are not prone to emissions during the use phase of the textile are selected. Auxiliaries (e.g. polyglycols) are used to enable dyeing with less or without subsequent steaming, oxidising and washing and to ensure appropriate colour fastness. May not be applicable to dyeing with dark shades.
<b>Techniques for dyeing with reactive dyes</b>		
c.	Use of poly-functional reactive dyes	Poly-functional reactive dyes with more than one reactive functional group are used to provide a high level of fixation in exhaust dyeing. Generally applicable.
d.	Cold pad-batch dyeing	Dyeing is carried out with the cold pad-batch technique (see Section 5.12.4). Generally applicable.
e.	Optimised rinsing	Rinsing after dyeing with reactive dyes is carried out at a high temperature (e.g. up to 95 °C) and without using detergents. The heat of the rinsing water is recovered (see BAT 11 (i)). Generally applicable.

<i>Techniques for continuous dyeing with reactive dyes</i>			
f.	Use of concentrated alkali solution	In cold pad-batch dyeing (see Section 5.12.4), concentrated aqueous alkali solutions without sodium silicate are used for the fixation of dyes.	May not be applicable to dyeing with dark shades.
g.	Steam fixation of reactive dyes	The reactive dyes are fixed with steam, which avoids the use of chemicals for fixation.	The applicability may be restricted by the characteristics of the textile materials and by product specifications (e.g. high-quality dyeing of polyester/cotton blends).

**BAT 42.** In order to reduce emissions to water from the dyeing of wool, BAT is to use one of the techniques given below in the following order of priority.

Technique		Description	Applicability
a.	Optimised reactive dyeing	Wool dyeing is carried out with reactive dyes without chromium mordant.	Generally applicable.
b.	Optimised metal-complex dyeing	Dyeing is carried out with metal-complex dyes under optimised conditions in terms of pH, auxiliaries and acid used, in order to increase the exhaustion of the dyeing liquor and the fixation of the dyes.	May not be applicable to dyeing with dark shades.
c.	Minimised use of chromates	When the use of sodium or potassium dichromate as mordant is authorised, dichromates are dosed as a function of the amount of dye taken up by the wool. Dyeing parameters (e.g. pH and temperature of the dyeing liquor) are optimised to ensure that the dyeing liquor is exhausted as much as possible.	Generally applicable.

**BAT 43.** In order to reduce emissions to water from the dyeing of polyester with disperse dyes, BAT is to use one or a combination of the techniques given below.

Technique		Description	Applicability
a.	Batch dyeing without dyestuff carriers	Batch dyeing of polyester and wool-free polyester blends is carried out at high temperature (e.g. 130 °C) without the use of dyestuff carriers.	Generally applicable.
b.	Use of environmentally friendly dyestuff carriers in batch dyeing	Batch dyeing of polyester-wool blends is carried out with chlorine-free and biodegradable dyestuff carriers.	
c.	Optimised desorption of unfixed dye in batch dyeing	<p>This includes:</p> <ul style="list-style-type: none"> <li>• using a desorption accelerator based on carboxylic acid derivatives;</li> <li>• using a reducing agent that can be used in the acidic conditions of the spent dyeing liquor;</li> <li>• using disperse dyes that can be desorbed in alkaline conditions by hydrolysis instead of reduction.</li> </ul>	The use of a reducing agent that can be used in acidic conditions may not be applicable to polyester-elastane blends. The use of dyes that are desorbable in alkaline conditions may be restricted by product specifications (e.g. colour fastness and shade).

## 5.9 BAT conclusions for printing

The BAT conclusions in this section apply to printing and apply in addition to the general BAT conclusions in Section 5.4.

**BAT 44. In order to reduce water consumption and waste water generation, BAT is to optimise the cleaning of the printing equipment.**

### Description

This includes:

- mechanical removal of the printing paste;
- automatic start and stop of the cleaning water supply;
- reuse and/or recycling of cleaning water (see BAT 10 (i)).

**BAT 45. In order to use resources efficiently, BAT is to use a combination of the techniques given below.**

Technique		Description	Applicability
<b>Selection of printing technology</b>			
a.	Digital jet printing	Computer-controlled injection of dye onto textile materials.	Only applicable to new plants or major plant upgrades.
b.	Transfer printing on synthetic textile materials	The design is first printed on an intermediate substrate (e.g. paper) using selected disperse dyes and is subsequently transferred to the fabric by applying high temperature and pressure.	
<b>Design and operation technique</b>			
c.	Optimised use of printing paste	<p>This includes:</p> <ul style="list-style-type: none"> <li>• minimisation of the volume of the printing paste supply system (e.g. minimising pipe lengths and diameters);</li> <li>• ensuring a uniform paste distribution over the whole width of the printing machine;</li> <li>• stopping the supply of printing paste shortly before the end of the printing;</li> <li>• manual addition of printing paste for small-scale usage.</li> </ul>	Generally applicable.
<b>Recovery and reuse of printing paste</b>			
d.	Recovery of residual printing paste in rotary screen printing	Residual printing paste in the supply system is pushed back to its original container.	Applicability in existing plants may be restricted by the equipment.
e.	Reuse of residual printing paste	The residual printing paste is collected, sorted by type, stored and reused. The degree of reuse of printing paste is limited by its perishability.	Generally applicable.

**BAT 46.** In order to prevent ammonia emissions to air and to prevent the generation of urea-containing waste water from printing with reactive dyes on cellulosic materials, BAT is to use one of the techniques given below.

Technique		Description
a.	Reduction of urea content in printing pastes	Printing is carried out with a reduced amount of urea in printing pastes and by controlling the moisture content of textile materials.
b.	Two-step printing	Printing is carried out without urea by two padding steps with intermediate drying and addition of fixation agents (e.g. sodium silicate).

**BAT 47.** In order to reduce emissions of organic compounds (e.g. formaldehyde) and ammonia to air from printing with pigments, BAT is to use printing chemicals with improved environmental performance.

#### Description

This includes:

- thickeners with no or low contents of volatile organic compounds;
- fixation agents with low potential for formaldehyde releases;
- binders with low contents of ammonia and low potential for formaldehyde releases.

## 5.10 BAT conclusions for finishing

The BAT conclusions in this section apply to finishing and apply in addition to the general BAT conclusions in Section 5.4.

### 5.10.1 Easy-care finishing

**BAT 48.** In order to reduce emissions of formaldehyde to air from easy-care finishing of textile materials made of cellulosic fibres and/or blends of cellulosic and synthetic fibres, BAT is to use cross-linking agents with no or low potential for formaldehyde releases.

### 5.10.2 Softening

**BAT 49.** In order to improve the overall environmental performance of softening, BAT is to use one of the techniques given below.

Technique		Description
a.	Low-volume application of softening agents	See Section 5.12.4. Softening agents are not added to the dyeing liquor but applied in a separate process step by padding, spraying or foaming.
b.	Softening of cotton textile materials with enzymes	See BAT 16 (c). Enzymes are used for softening, possibly in combination with washing or dyeing.

### 5.10.3 Flame retardance finishing

**BAT 50.** In order to improve the overall environmental performance, especially to prevent or reduce emissions to the environment and waste, of flame retardance finishing, BAT is to use one or both of the techniques given below, giving priority to technique (a).

Technique		Description	Applicability
a.	Use of textile materials with inherent flame retardance properties	Textiles that do not require finishing with flame retardants are used.	The applicability may be restricted by product specifications (e.g. flame retardance).
b.	Selection of flame retardants	Flame retardants are selected considering: <ul style="list-style-type: none"> <li>the risks associated with them, in particular in terms of persistence and toxicity, including the potential for substitution (e.g. brominated flame retardants, see BAT 14 point I.(d));</li> <li>the composition and form of the textile materials to be treated;</li> <li>the product specifications (e.g. combined flame retardance and oil-/water-/soil-repellence, wash durability).</li> </ul>	Generally applicable.

### 5.10.4 Oil-, water- and soil-repellence finishing

**BAT 51.** In order to improve the overall environmental performance, especially to prevent or reduce emissions to the environment and waste, of oil-, water- and soil-repellence finishing, BAT is to use oil-, water- and soil-repellents with improved environmental performance.

#### Description

Oil-, water- and soil-repellents are selected considering:

- the risks associated with them, in particular in terms of persistence and toxicity, including the potential for substitution (e.g. PFAS, see BAT 14 point I.(d));
- the composition and form of the textile materials to be treated;
- the product specifications (e.g. combined oil-, water-, soil-repellence and flame retardance).

### 5.10.5 Shrink-proof finishing of wool

**BAT 52.** In order to reduce emissions to water from shrink-proof finishing of wool, BAT is to use chlorine-free antifelting chemicals.

#### Description

Inorganic salts of peroxymonosulphuric acid are used for shrink-proof finishing of wool.

#### Applicability

The applicability may be restricted by product specifications (e.g. shrinkage).

### 5.10.6 Mothproofing

**BAT 53.** In order to reduce the consumption of mothproofing agents, BAT is to use one or a combination of the techniques given below.

Technique		Description	Applicability
a.	Selection of dyeing auxiliaries	When mothproofing agents are added directly in the dyeing liquor, dyeing auxiliaries (e.g. levelling agents) that do not hinder the uptake of mothproofing agents are selected.	Generally applicable.
b.	Low-volume application of mothproofing agents	See Section 5.12.4. In the case of spraying, the excess mothproofing solution is recovered from the textile materials by centrifugation and reused.	Generally applicable.



## 5.11 BAT conclusions for lamination

The BAT conclusion presented in this section applies to lamination and applies in addition to the general BAT conclusions in Section 5.4.

**BAT 54. In order to reduce emissions of organic compounds to air from lamination, BAT is to use hot-melt lamination instead of flame lamination.**

### **Description**

Molten polymers are applied to textiles without the use of a flame.

### **Applicability**

May not be applicable to thin textiles and may be restricted by the strength of the bond between the laminate and textile materials.

## 5.12 Description of techniques

### 5.12.1 Technique to select process chemicals, prevent or reduce emissions to air

Technique	Description
Emission factors	Emission factors are representative values that attempt to relate the quantity of a substance emitted to a process associated with the emission of that substance. Emission factors are derived from emission measurements according to a predefined protocol considering the textile materials and the reference processing conditions (e.g. curing time and temperature). They are expressed as the mass of a substance emitted divided by the mass of textile materials treated at the reference processing conditions (e.g. grams of organic carbon emitted per kg of textile materials treated at a waste gas flow of 20 m <sup>3</sup> /h). The quantity, hazardous properties and composition of the mixture of the process chemicals and their pick-up by the textile material are considered.

### 5.12.2 Techniques to reduce emissions to air

Technique	Description
Adsorption	The removal of pollutants from a waste gas stream by retention on a solid surface (activated carbon is typically used as an adsorbent). Adsorption may be regenerative or non-regenerative. In non-regenerative adsorption, the spent adsorbent is not regenerated but disposed of. In regenerative adsorption, 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.
Condensation	Condensation is a technique that eliminates vapours of organic and inorganic compounds from a waste gas stream by reducing its temperature below its dew point.
Cyclone	Equipment for the removal of dust from a waste gas stream based on imparting centrifugal forces, usually within a conical chamber.
Electrostatic precipitator (ESP)	Electrostatic precipitators (ESPs) operate such that particles are charged and separated under the influence of an electrical field. Electrostatic precipitators are capable of operating under a wide range of conditions. Abatement efficiency may depend on the number of fields, residence time (size), and upstream particle removal devices. They generally include between two and five fields. Electrostatic precipitators can be of the dry or of the wet type depending on the technique used to collect the dust from the electrodes.
Thermal oxidation	The oxidation of combustible gases and odorants in a waste gas stream by heating the mixture of contaminants with air or oxygen to above its auto-ignition point in a combustion chamber and maintaining it at a high temperature long enough to complete its combustion to carbon dioxide and water.
Wet scrubbing	The removal of gaseous or particulate pollutants from a waste gas stream via mass transfer to water or an aqueous solution. It may involve a chemical reaction (e.g. in an acid or alkaline scrubber).

### 5.12.3 Techniques to reduce emissions to water

Technique	Description
Activated sludge process	The biological oxidation of dissolved organic pollutants with oxygen using the metabolism of microorganisms. In the presence of dissolved oxygen (injected as air or pure oxygen), the organic components are transformed into carbon dioxide, water or other metabolites and biomass (i.e. the activated sludge). The microorganisms are maintained in suspension in the waste water and the whole mixture is mechanically

	aerated. The activated sludge mixture is sent to a separation facility from where the sludge is recycled to the aeration tank.
Adsorption	Separation method in which compounds in a fluid (e.g. waste water) are retained on a solid surface (typically activated carbon).
Anaerobic treatment	The biological transformation of dissolved organic and inorganic pollutants in the absence of oxygen using the metabolism of microorganisms. Transformation products include methane, carbon dioxide, and sulphide. The process is carried out in an airtight stirred reactor. The most commonly used reactor types are: <ul style="list-style-type: none"> <li>• anaerobic contact reactor;</li> <li>• upflow anaerobic sludge blanket;</li> <li>• fixed-bed reactor;</li> <li>• expanded-bed reactor.</li> </ul>
Chemical oxidation	Organic compounds are oxidised to less harmful and more easily biodegradable compounds. Techniques include wet oxidation or oxidation with ozone or hydrogen peroxide, optionally supported by catalysts or UV radiation. Chemical oxidation is also used to degrade organic compounds causing odour, taste and colour nuisances and for disinfection purposes.
Chemical reduction	Chemical reduction is the conversion of pollutants by chemical reducing agents into less harmful compounds.
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 carried out by adding polymers, so that collisions of microfloc particles cause them to bond to produce larger flocs. The flocs formed are subsequently separated by sedimentation, air flotation or filtration.
Equalisation	Balancing of flows and pollutant loads by using tanks or other management techniques.
Evaporation	The use of distillation to concentrate aqueous solutions of high-boiling substances for further use, processing or disposal (e.g. waste water incineration) by transferring water to the vapour phase. It is typically carried out in multistage units with increasing vacuums, to reduce the energy demand. The water vapours are condensed, to be reused or discharged as waste water.
Filtration	The separation of solids from waste water by passing them through a porous medium, e.g. sand or membrane filtration (see Membrane filtration below).
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.
Membrane bioreactor	A combination of activated sludge treatment and membrane filtration. Two variants are used: a) an external recirculation loop between the activated sludge tank and the membrane module; and b) immersion of the membrane module in the aerated activated sludge tank, where the effluent is filtered through a hollow fibre membrane, the biomass remaining in the tank.
Membrane filtration	Microfiltration, ultrafiltration, nanofiltration and reverse osmosis are membrane filtration processes that retain and concentrate, on one side of the membrane, pollutants such as suspended particles and colloidal particles contained in waste waters. They differ in terms of membrane pore sizes and hydrostatic pressure.
Neutralisation	The adjustment of the pH of waste water to a neutral level (approximately 7) by the addition of chemicals. Sodium hydroxide (NaOH) or calcium hydroxide (Ca(OH) <sub>2</sub> ) may be used to increase the pH, whereas sulphuric acid (H <sub>2</sub> SO <sub>4</sub> ), hydrochloric acid (HCl) or carbon dioxide (CO <sub>2</sub> ) may be used to decrease the pH. Some pollutants may precipitate as insoluble compounds during neutralisation.
Nitrification/denitrification	A two-step process that is typically incorporated into biological waste water treatment plants. The first step is aerobic nitrification where

	microorganisms oxidise ammonium ( $\text{NH}_4^+$ ) to the intermediate nitrite ( $\text{NO}_2^-$ ), which is then further oxidised to nitrate ( $\text{NO}_3^-$ ). In the subsequent anoxic denitrification step, microorganisms chemically reduce nitrate to nitrogen gas.
Oil-water separation	The separation of oil and water including the subsequent oil removal by gravity separation of free oil, using separation equipment or emulsion breaking (using emulsion-breaking chemicals such as metal salts, mineral acids, adsorbents and organic polymers).
Screening and grit separation	The separation of water and insoluble contaminants such as sand, fibre, fluff or other coarse materials from the textile effluent by filtering through screens or gravitational settling in grit chambers.
Precipitation	The conversion of dissolved pollutants into insoluble compounds by adding precipitants. The solid precipitates formed are subsequently separated by sedimentation, air flotation or filtration.
Sedimentation	The separation of suspended particles by gravitational settling.

#### 5.12.4 Techniques to reduce the consumption of water, energy and chemicals

Technique	Description
Cold pad-batch treatment	In cold pad-batch treatment, the process liquor is applied by padding (e.g. with a foulard) and the impregnated fabric is slowly rotated at room temperature for a prolonged period. This technique allows a reduced consumption of chemicals and does not require subsequent steps such as thermal fixation and thereby reduces energy consumption.
Low-liquor-ratio systems (for batch processes)	A low liquor ratio can be achieved by improving the contact between the textile materials and the process liquor (e.g. by creating turbulence in the process liquor), by advanced process monitoring, by improved dosage and application of process liquor (e.g. by jets or spraying) and by avoiding the mixing of process liquor with washing or rinsing water.
Low-volume application systems (for continuous processes)	The fabric is impregnated with process liquor by spraying, vacuum suction through the fabric, foaming, padding, and dipping in nips (process liquor contained in the gap between two rollers) or in reduced-volume tanks, etc.



## 6 EMERGING TECHNIQUES

[ 272, Nieminen et al. 2007 ] suggested tools for comparison of present with emerging cleaner technologies, including the economic effects. It was found that the new emerging technologies are in key position when striving towards zero emissions in textile processing.

### 6.1 Substitution of hazardous substances

#### 6.1.1 Use of chitosan-based auxiliaries and/or finishing agents

##### Description

Chitosan-based agents are used in dyeing and finishing (e.g. antimicrobial).

##### Technical description

After cellulose, chitin, the main structural component of crustacean shells (crabs, lobsters, etc.) and insects, is the second principal biopolymer. Its deacetylated derivative, chitosan, which is easier to handle due to its higher solubility, is gaining in importance.

Some examples of potential applications of chitosan and its derivatives in the textile sector include the following:

- Antimicrobial blends with cotton and viscose fibres: a permanent antimicrobial effect can be obtained by blending 10 % of chitosan fibres with cotton fibres to produce a mixed fibre yarn or by spraying chitosan solutions on non-woven fabrics. Compared to other commonly used antimicrobials, chitosan is not toxic to aquatic life or to humans (it is therefore of special interest for those fabrics that stay in close contact with the skin, e.g. in medical, health and pharmacological applications).
- Antimicrobial finishing treatment for textiles: chitosan's structure is very similar to cellulose, so it bonds with cotton and viscose fibres. Chitosan-based finishing preparation is applied with impregnation by pad-dry-cure [ 35, RICARDO 2019 ].
- Aftertreatment to improve fastness properties when dyeing with direct dyes: cationic modified derivatives of chitosan are reported to be suitable for this application.
- Dye-fixing (deepening) agent for dyeing with reactive dyes: since it is a cationic polymer, chitosan is considered to be an ideal fixing agent for anionic dyes (it lowers the surface tension/repulsion of fibre) [ 35, RICARDO 2019 ].

##### Achieved environmental benefits

- Reduced chemical consumption.
- Reduced emissions to water.

##### Environmental performance and operational data

The use of chitosan as an exhausting agent reduces the amount of dye necessary for dyeing the cotton fabric and improves the washing and rubbing fastness properties. Cationic modified derivatives of chitosan are reported to be suitable for improving fastness when dyeing with direct dyes. The application of acidic solution of chitosan on cotton fabric before dyeing can boost the exhaustion of the dye bath as well as improve the substantivity of reactive dyes.

For antimicrobial treatment, the antibacterial colloid is prepared by blending chitosan with another antibacterial agent (e.g. AgCl-TiO<sub>2</sub> at a ratio of 1:5) in order to protect against a broad range of microbes (gram positive and negative). The application of chitosan and its derivatives on fabric/fibre is followed by the covalent cross-linking into cellulose or wool substrates (in the pad-dry-cure process).

##### Example plants

No information provided.

### Reference literature

No reference literature provided.

### 6.1.2 Use of natural or biosynthetic dyes

#### Description

Natural or biosynthetic dyes are used instead of conventional synthetic dyes.

#### Technical description

Natural dyes are extracted from plants (e.g. with organic solvents) and used as an alternative to conventional synthetic dyes. An example of such a dye is a natural indigo extracted from plants [ 325, AMA 2019 ].

Biosynthetic dyes are derived from natural waste products of the agricultural and herbal industries, e.g. from non-edible leftovers (i.e. almond shells, orange peel, beet residues), saw palmetto, rosemary leaves [ 326, ARCHROMA 2019 ], microalgae, cyanobacteria as well as seaweed species [ 327, AITEX 2019 ]. Enzymatic processes are used to synthesise biodyes [ 328, UNISI 2019 ].

#### Achieved environmental benefits

Reduced emissions to water.

#### Environmental performance and operational data

These materials are free from priority chemicals (hazardous or toxic species), thus reducing the impact of the dyeing process in the waste water streams. According to a LCA, the use of natural dyes was found to have a much smaller water and CO<sub>2</sub> footprint, and they have a less harmful impact on human health.

These dyes have good affinity for cellulosic fibres (e.g. cotton, viscose, linen) and during the dyeing process they are directly linked to the fibre by covalent bonds. Therefore, these dyes equal the fixation rate, fastness and overall performance of the existing range of sulphur dyes made from conventional petroleum-based raw materials.

The dyes can be applied using common dyeing technologies

#### Example plants

Apparently some denim mills in Türkiye, India, Pakistan, China, Italy and Japan already use natural indigo in their rope dyeing machines. Also, there is a commercially available palette of dyes from chemical suppliers of textile dyes.

#### Reference literature

[ 35, RICARDO 2019 ], [ 325, AMA 2019 ], [ 326, ARCHROMA 2019 ], [ 327, AITEX 2019 ], [ 328, UNISI 2019 ]

### 6.1.3 Use of flame retardants based on nano-clay

#### Description

The process consists of the application of nano-clay finishing by a back-coating technique. Dosage of chemicals is done automatically, in a closed-circuit system connected to the coating machine to avoid possible human contact. During the drying process, the temperature is controlled in order to avoid migration to air of non-fixed nanoparticles.

#### Achieved environmental benefits

Reduced use of halogenated compounds or other hazardous substances.

**Environmental performance and operational data**

The clay (montmorillonite) is biodegradable and has very little effect on the environment and human health.

No differences have been found in the operational conditions between the nano-based and conventional process, such as electricity and gas consumption. As with the conventional process, the generated residues are only related to the jerry cans of chemicals and the scraps of fabric after the cutting stage.

**Cross-media effects**

None identified.

**Technical considerations relevant to applicability**

The treated fabrics may not meet the most stringent fire safety requirements, for example in the UK and Ireland.

**Economics**

The investment cost is related to the machinery needed (knife-coating machine and stenter) and the closed-circuit dosing system. Operating costs are related to the purchase of the montmorillonite nano-clay product, the binder and thickener used to formulate the applied solution, as well as to energy and labour.

**Driving force for implementation**

Legislation related to the use of hazardous substances and to environmental protection.

**Example plants**

The innovative process based on the nano-clay application has not been completely tested at industrial scale due to the lack of methods and equipment necessary for the product formulation in the industry, but the optimal application conditions of the nano-based formula have been investigated. Analysing the results, it has been observed that methods developed at laboratory scale could be escalated to industrial scale without significant differences, and working with nano-based products does not seem to pose a problem in terms of manipulation, preparation and application.

**Reference literature**

[ 42, LEITAT 2016 ]

### 6.1.4 Use of liposomes as a carrier for auxiliary chemicals in dyeing and finishing

**Description**

Liposomes are used as a carrier for auxiliary materials (e.g. levelling, retarding, wetting agents) in dyeing (for wool see Section 4.5.3.4) and finishing processes.

**Technical description**

With respect to the carrier role of liposomes, they can be used in several textile processes such as textile finishing and dyeing, with several types of dyes and fibres.

Liposomes can be prepared according to the type of process, solute material and fibre structure. Due to their structural properties, liposomes can encapsulate hydrophilic dyes (reactive, acid and basic dyes) in the aqueous phase, and hydrophobic dyes (disperse dyes) in the phospholipid bilayers. Several applications have been reported:

- for stabilising the bleaching process using hydrogen peroxide: liposomes can be used to gradually deliver bleaching agent but also stabilisers;
- as dispersing agent in dyeing of polyester fibres with disperse dyes;
- for dyeing wool and wool blends (see Section 4.5.3.4).



### **Achieved environmental benefits**

- Reduced consumption of chemicals.
- Reduced emissions to water.
- Better quality of processing.

### **Environmental performance and operational data**

Conventional dyeing processes consume a lot of energy and chemicals, a significant amount of which is wasted in controlling the process parameters in order to achieve uniform results. With respect to the carrier role of liposomes, they can be used in several textile processes such as textile finishing and dyeing, with several types of dyes and fibres. They are non-toxic, biodegradable, and can encapsulate a wide range of solutes, and help in their precise dosage and application.

### **Example plants**

No information provided.

### **Reference literature**

[ 35, RICARDO 2019 ], [ 329, Drumond Chequer et al. 2013 ]

## 6.2 Dyeing

### 6.2.1 Ultrasonic treatments

#### Description

Use of ultrasounds to disperse dyestuffs and auxiliaries.

#### Technical description

Ultrasonic treatments improve the dispersion of dyestuffs and auxiliaries and enhance their ability to emulsify and solubilise. This allows improved liquor homogenisation, which then results in higher bath exhaustion and level dyeing properties. In addition, ultrasounds produce a de-aeration effect in the liquor and on the fabric, which is normally obtained by adding special auxiliaries (de-aerating agents).

#### Achieved environmental benefits

- Energy savings (lower process temperatures and shorter cycle times).
- Reduction in auxiliaries consumption.

#### Example plants

No information provided. In fact, this technique was not reported in the data collection.

#### Reference literature

[ 4, EURATEX 2000 ], [ 5, UBA 2001 ]

### 6.2.2 Electrochemical dyeing

#### Description

Reduction of the dyestuff by electrolysis.

#### Technical description

Vat and sulphur dyeing involves both a reducing and an oxidising step, which are carried out with chemical oxidants and reducing agents. The environmental concerns associated with the use of these chemicals are described in Section 2.7.8.1. An attractive alternative technique is to reduce and oxidise the dye by means of electrochemical methods.

With direct electrolysis, the dye itself is reduced at the surface of the cathode. In indirect electrolysis, the reducing power of the cathode is transferred to the solution by a soluble reversible redox system (e.g. based on anthraquinone chemistry or iron complexes). With this reversible redox system the reducing agent is continuously regenerated at the cathode, which thus allows full recycling of the dye bath and the reducing agent.

#### Achieved environmental benefits

- Reduced chemical consumption.
- Reduced emissions to water.

#### Environmental performance and operational data

Direct cathodic reduction in an electrochemical cell is applicable to sulphur dyes. Vat dyes are reduced by indirect electrolysis.

#### Example plants

No information provided. In fact, this technique was not reported in the data collection.

#### Reference literature

[ 4, EURATEX 2000 ], [ 5, UBA 2001 ]

### 6.2.3 Salt-free reactive dyeing

#### Description

As an alternative to cationic cotton (see Section 4.5.2.3), a cationic reactive dye is used for exhaust dyeing of cotton, which renders the use of salts obsolete.

#### Technical description

Cationic reactive dyes are synthesised by incorporating cationic groups in the dye formulation, such as quaternary ammonium compounds or pyridinium chloride. This allows the electric charge repulsion between the cotton fibres and the reactive dye to be overcome.

#### Achieved environmental benefits

No emission of salts to water.

#### Environmental performance and operational data

Table 6.1 below gives an overview of the performance of various cationic dyes which were synthesised and tested.

**Table 6.1: Performance of various synthesised cationic dyes**

Dye	Dye type	Cationic group	Reactive group	Exhaustion rate (%)	Fixation rate (%)
Dye 1	Azo	Pyridinium chloride	Vinyl sulphone group	73	NI
Dye 2	Anthraquinone	Quaternary ammonium salt group	Monochlorotriazine	90	60
Dye 3	Anthraquinone	Quaternary ammonium salt group	Monochlorotriazine	90.8	64.4
Dye 4	Anthraquinone	Quaternary ammonium salt group and poly ether amine	Monochlorotriazine	NI	NI
Dye 5	Anthraquinone	Quaternary ammonium salt group	Monofluorotriazine	91.1	76.5
Dye 6	Anthraquinone	N-(2-aminoethyl) pyridinium chloride	Monochlorotriazine	93.6	83.6
Dye 7	Anthraquinone	Quaternary ammonium salt group	Epoxy group	99.7	83.6
Dye 8	Anthraquinone	Quaternary ammonium salt group	Nicotinic acid quaternary triazine	94.2	72.8

*Source: based on [ 330, Aktek et al. 2017 ]*

#### Cross-media effects

No information provided.

#### Technical considerations relevant to applicability

No information provided.

#### Economics

No information provided.

#### Driving force for implementation

Environmental legislation.

#### Example plants

At the time of drafting, cationic dyes are not yet commercialised.

#### Reference literature

[ 330, Aktek et al. 2017 ]

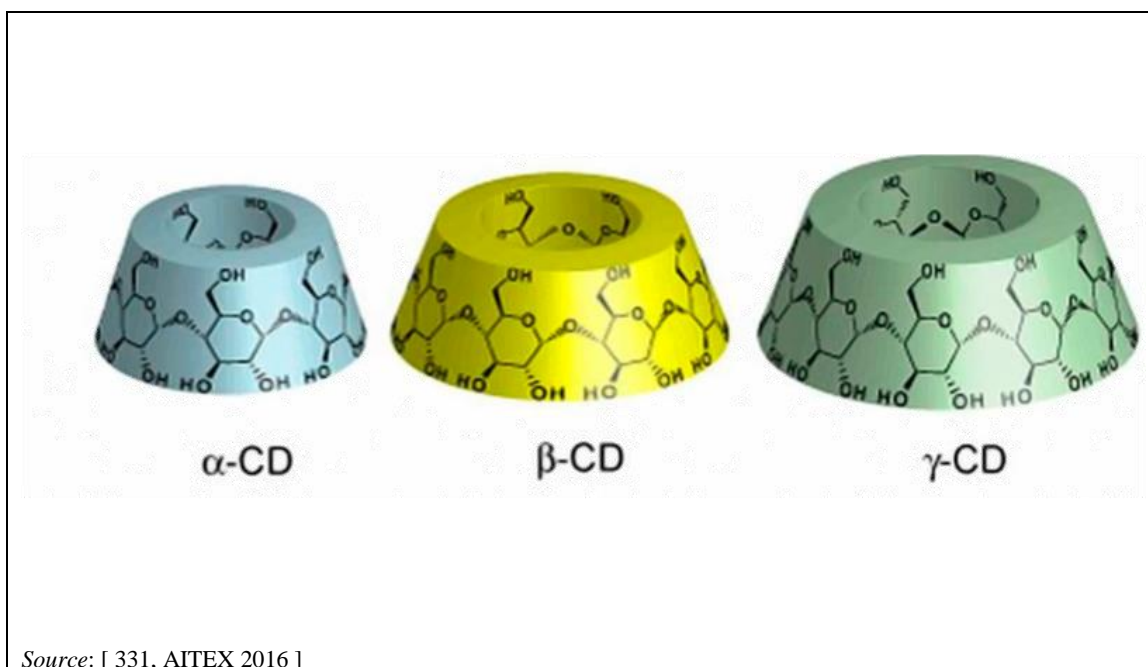
## 6.2.4 Recovery of direct dyes with cyclodextrins

### Description

Cyclodextrins (CD) are used to encapsulate the direct dyes contained in the waste water. The dyes may be then recovered and reused.

### Technical description

Cyclodextrins are a group of structurally related natural products formed during bacterial digestion of cellulose. These cyclic oligosaccharides consist of ( $\alpha$ -1,4)-linked  $\alpha$ -D-glucopyranose units and contain a somewhat lipophilic central cavity and a hydrophilic outer surface. Due to the increased water solubility of lipophilic glucopyranose units, the cyclodextrins are shaped like a truncated cone rather than perfect cylinders (see Figure 6.1 below). The hydroxyl functions orientated to the cone exterior with the primary hydroxyl groups of the sugar residues at the narrow edge of the cone and the secondary hydroxyl groups at the wider edge. The central cavity is lined by the skeletal carbons and ethereal oxygens of the residues, which gives it a lipophilic character.



**Figure 6.1:** Examples of cyclodextrins presented in the literature

The CD are injected in the waste water in a 25-litre device at the outlet of a dye bath. When the waste water has filled the device, the agitator blades provide sufficient energy for the cyclodextrins to encapsulate the dyestuff. After the agitation stage and decantation, the cleaned water is released.

The cyclodextrins are captured on a paper filter located at the bottom of the device. This filter is removed and the dyestuff may be recovered in a solid form, and then reused for dyeing.

CD treatment has allowed the reduction of the COD and BOD concentration in waste water between 2 % and 5 % depending on the dye.

### Achieved environmental benefits

- Reduction of pollutant load in the waste water.
- Reduced consumption of dyestuff.

### **Environmental performance and operational data**

The average temperature of the water during the encapsulation process is 60 °C and depends on the type of materials used. Water is heated up in the upstream dyeing process, so no additional heating is needed.

The recovered encapsulated dyestuff can be used directly for dyeing without it being necessary to separate the dye from the CD. Encapsulated dyestuff has been reused twice with satisfactory results.

Cleaned water may be reused for dyeing, but only in dyeing processes that use dark colours, because the remaining colours in the cleaned water interfere with the final colour of the textile.

### **Cross-media effects**

No information provided.

### **Technical considerations relevant to applicability**

No information provided.

### **Economics**

Currently, the technique has the disadvantage of high costs for raw material (CD-based polymers), which may be higher than the cost of recovered dyes.

### **Driving force for implementation**

Reduced costs for waste water treatment and reduced costs for the purchase of dyestuff.

### **Example plants**

No information provided.

### **Reference literature**

[ 35, RICARDO 2019 ], [ 331, AITEX 2016 ], [ 332, AITEX 2016 ]

## **6.2.5 Online process monitoring for direct reuse/recycling of spent dyeing baths**

### **Description**

A self-monitoring system based on Raman spectroscopy is applied to analyse the bath exhaustion online (in real time) in order to reuse the bath in the subsequent dyeing step.

### **Technical description**

A Raman spectrometer unit (instead of the more common UV-VIS spectrometer) is used to analyse online the exhaustion rate (remaining colourants) of the process bath. The calibration of the system is needed to customise it for the dyes used. It is applicable to all dyes regardless of their chemistry (organic or inorganic).

### **Achieved environmental benefits**

- Reduced consumption of chemicals (including dyes).
- Reduced emissions to water (of dyes).

### **Environmental performance and operational data**

The savings/reductions achieved at a textile plant in Spain are as follows:

- pigments savings: 10-15 %;
- auxiliaries savings: 90-100 %;
- water consumption reduction: 60-80 % (applicable to washing baths);
- waste water pollutant load reduction: 70-90 %

- energy consumption reduction: 20-25 %
- increase in correct dyeing: from 80-98 %.

**Example plants**

A plant in Spain.

**Reference literature**

[ 333, INTEXTER 2019 ]

## 6.3 Printing

### 6.3.1 Use of casein-based printing binders

#### Description

Casein acid is used as a printing binder as an alternative to the acrylic resins used in textile printing.

#### Technical description

The use of acrylic resins is problematic because they require the use of additional additives that may be problematic, such as alkyl phenols, phthalates and organotins.

The casein acid binders are compatible with all existing textile printing pigments and can be used in printing paste for ink-jet printing.

#### Achieved environmental benefits

- Reduced consumption of chemicals.
- Reduced emissions to water.

#### Environmental performance and operational data

This technique provides an alternative to the acrylic resins used in textile printing (reducing the ecotoxicity of water effluents). The discharge of printing waste allows for a simple biological purification and it may be converted into fertiliser. Since the product is bio-based and biodegradable it can easily be attacked by microorganisms and therefore it should be stored in temperature-controlled areas at 10 °C or below.

#### Example plants

No information provided.

#### Reference literature

[ 35, RICARDO 2019 ], [ 334, SUBSPORT 2019 ]

### 6.3.2 Phthalate-free plasticisers for textile printing

#### Description

Polyurethane and polyacrylate are used as alternative materials to substitute phthalates and PVC from wear prints.

#### Technical description

There are several substances that have successfully replaced (ortho)phthalates and PVC plasticisers, although their use is not yet widespread in textile applications: acetyl tributyl citrate (ATBC), (2-ethylhexyl) adipate (DEHA), cyclohexane-1,2-dicarboxylic acid diisononyl ester (DINCH), and trioctyl trimellitate (TOTM).

#### Achieved environmental benefits

- Reduced emissions to water.
- Avoidance of hazardous substances in the textile product.

#### Environmental performance and operational data

By replacing PVC and plasticisers with polyurethanes and polyacrylates, plastisol printing is replaced by water-based printing.

#### Example plants

No information provided.

#### Reference literature

[ 35, RICARDO 2019 ]

## 6.4 Finishing

### 6.4.1 Enzymatic anti-felting

#### Description

Enzymes are used for the second treatment step of the more conventional anti-felting treatments of wool fabric.

#### Technical description

Typically, enzyme treatment is carried out as a secondary (subsequent) step to a milder chemical pretreatment (e.g. with hydrogen peroxide or dichlorodicyanuric acid (DCCA)) or physical pretreatment (e.g. atmospheric plasma) or as a cascade of treatments with different enzymes. Chlorination pretreatment with DCCA followed by protease treatment has been tested for use in the textile industry.

Enzymes used for anti-felting wool treatment are proteases (e.g. savinase, papain), esperase, and porcine trypsin.

#### Achieved environmental benefit

- No chlorine compounds used or emitted.
- Reduced use of hazardous chemicals.

#### Environmental performance and operational data

Using enzymes with DCCA is claimed to reduce the usage of chlorination agents by around half. This does not eliminate the AOX release problem, it only diminishes it. Hydrogen peroxide pretreatment followed by protease treatment offers better anti-felting processing of wool fabric in view of the effluent released, but the effectiveness of the process is lower.

Any novel shrink-resist treatment must meet the following conditions and challenges in order to successfully replace the widely used chlorine/Hercosett process [335, Hassan et al. 2019 ]:

- the processing cost must be similar or marginally higher than the cost of the chlorine/Hercosett process;
- the process needs to be continuous;
- the process must be robust and should provide long-term durability to washing;
- the treatment must not negatively affect the dyeability, lightfastness, yellowness, abrasion resistance, stain-resistance, wash fastness and handle properties of the treated fabric;
- it must be eco-friendly and energy-efficient.

The operational parameters of enzymatic treatment may be challenging (slow treatment, poor shrink-resistance).

#### Cross-media effects

None identified.

#### Technical considerations relevant to applicability

No information provided.

#### Economics

No information provided.

#### Driving force for implementation

- Environmental legislation.
- Reduced load of chlorine in the effluent to be pretreated.



**Example plants**

No information provided.

**Reference literature**

[ 335, Hassan et al. 2019 ]

**6.4.2 Plasma for anti-felting**

**Description**

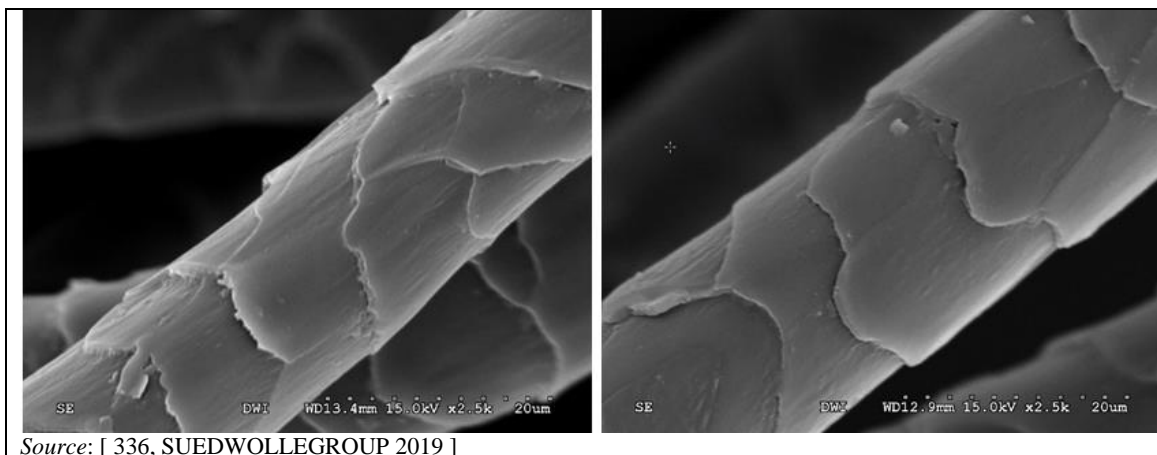
The wool passes through the plasma field where electrons, ions, radical species, UV and visible radiation in the plasma alter the friction profile of the fibre surface, removing the normal felting effect of untreated wool.

**Technical description**

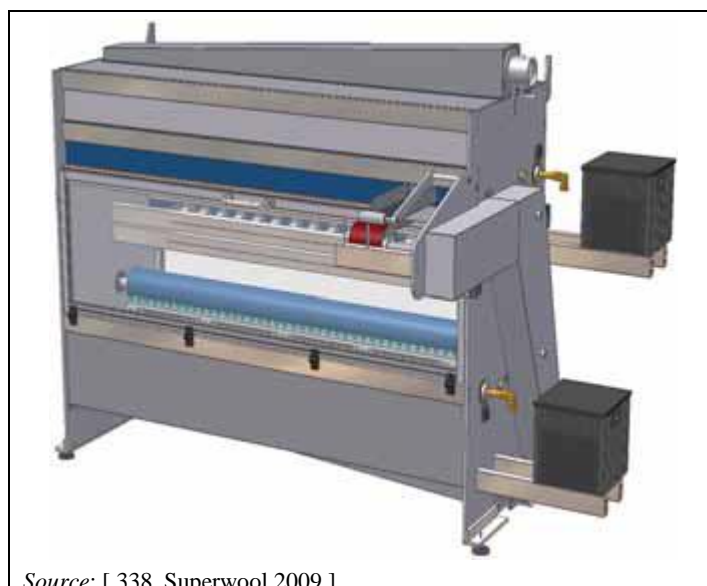
The exposure of the fibres needs to be carefully calibrated - both in intensity and duration. The plasma field oxidises the surface, modifying the wettability of the fibres, and uniformising it throughout the scales of the wool fibre. Depending on the conditions of the plasma treatment, nano-scale roughness may also be created on the surface of the fibre. The improved wettability is related to the decrease in friction of the fibres, restricting entanglement and thus decreasing the shrinkage of wool fabrics [ 336, SUEWOLLEGROUP 2019 ].

The scouring of wool fibres before plasma treatment can be done with aqueous-washing with non-ionic surfactants [ 337, Canal et al. 2008 ].

Figure 6.2 shows the result of the plasma treatment on wool fibres and shows the machine used.



**Figure 6.2: Comparison of untreated wool (left) with wool treated with plasma (right)**



**Figure 6.3: Machine for plasma treatment**

#### **Achieved environmental benefit**

No emissions to water.

#### **Environmental performance and operational data**

Unlike the Hercosett process, the plasma anti-felting process is a physical treatment and it does not use water; there is therefore no generation of waste water.

The plasma process consumes more energy than the Hercosett process but this may not be the case if the drying step following the conventional Hercosett process is also taken into consideration (see below).

**Table 6.2: Water and energy consumption of conventional and plasma anti-felting treatment**

Process	Water consumption	Energy consumption <sup>(1)</sup>
Hercosett	6 000 l/h 17 l/kg of wool	Electricity: EUR 0.02/kg of wool Steam generation for drying: EUR 0.06/kg of wool
Plasma	No water used	Electricity: EUR 0.055/kg of wool
<sup>(1)</sup> 2009 value. Source: [338, Superwool 2009]		

#### **Cross-media effects**

None identified.

#### **Technical considerations relevant to applicability**

Generally, there are no technical restrictions to the applicability of this technique.

#### **Economics**

For operational costs (e.g. for electricity), see Table 6.2.

#### **Driving force for implementation**

Environmental legislation.

**Example plants**

No information provided.

**Reference literature**

[ 336, SUEWOLLEGROUP 2019 ], [ 337, Canal et al. 2008 ], [ 338, Superwool 2009 ]

## 6.5 Laminating and coating

### 6.5.1 Electron beam curing

#### Description

Curing with electron beams.

#### Technical description

Electron beams start free-radical-initiated polymerisation reactions that can then be used for coating, lamination and for graft co-polymerisation reactions on textiles pre-coated with monomers or pre-polymers.

The advantage over thermal curing is that solvent-free formulations can be used. This reduces the emissions of VOCs during drying operations. The technique is already established in other sectors and therefore its implementation in the textile sector is foreseeable.

#### Achieved environmental benefits

Reduced VOC emissions to air

#### Example plants

No information provided.

#### Reference literature

[ 4, EURATEX 2000 ], [ 5, UBA 2001 ]



## 7 CONCLUDING REMARKS AND RECOMMENDATIONS FOR FUTURE WORK

### Timing of the review process

The key milestones of the review process are summarised in Table 7.1 below.

**Table 7.1: Key milestones of the TXT BREF review process**

Key milestone	Date
TWG reactivation	August 2017
Call for initial positions	December 2017
Kick-off Meeting	12-15 June 2018
Data collection	February-April 2019
1st data assessment workshop	1-2 October 2019
Draft 1 (D1) of the revised TXT BREF	19 December 2019
2nd data assessment workshop	21-23 October 2020
End of commenting period on Draft 1 (1 072 comments received)	27 March 2020
Revised proposals for the draft BAT conclusions and Background Paper for the Final TWG Meeting	31 March 2021
Final TWG Meeting (conducted as a series of web-based sessions)	25 May 2021 to 11 June 2021

During the BREF review process, a total of five plants were visited in Belgium (March 2019) and Italy (January 2019), and one textile technological institute in Belgium.

In addition, an informal TWG meeting (19 February 2021) was organised by the EIPPCB to improve the exchange of information on issues of mass flow threshold for emissions to air, waste water treatment strategies and chemicals management systems.

In June 2020, a webinar on emission factors was organised by Germany.

Due to the COVID-19 pandemic the physical Final TWG Meeting was replaced by a series of 7 web-based sessions (between 25 May and 11 June 2021) because of the severe travel restrictions and social distancing measures in place.

### Sources of information and information gaps

The main sources of information for the review process were:

- scientific and technical literature;
- 106 filled-in questionnaires (83 of which contained confidential business information) from operators of textile industry plants;
- additional information from the TWG members;
- 1 072 comments on Draft 1 of the revised BREF;
- 279 comments on the revised version of the draft BAT conclusions (March 2021);
- information gathered from site visits;
- outcomes of the workshops, informal meeting and webinar mentioned above.

In total, approximately 400 documents were posted in BATIS and taken into account for the review of this document; most of them have been referenced in the revised TXT BREF.

**Degree of consensus reached during the information exchange**

At the Final TWG Meeting that took place as a series of web-based sessions during the period 25 May 2021 to 11 June 2021, a high degree of consensus was reached on most of the BAT conclusions. However, 15 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 7.2 below.

**Table 7.2: Split views expressed**

BAT conclusion / Table number	Split view	Expressed by	Alternative proposed level (if any)
BAT 20 / Table 5.3	Replace the word 'or' with the word 'and' between the two conditions in both footnote (5) and footnote (12).	EEB	NA
BAT 20 / Table 5.3 and Table 5.4	Amend footnote (7) in Table 5.3 and footnote (5) in Table 5.4 by requiring an appropriate combination of techniques including precipitation and coagulation/flocculation, and reduce the related higher end of the BAT-AEL range for polyester/modacrylic dyeing.	BE and EEB	0.4 mg/l
BAT 20 / Table 5.3 and Table 5.4	<p>AOX: Delete footnotes (8) direct discharges, and (4) indirect discharges, on AOX.</p> <p>Cr: Delete footnotes (8) direct discharges and (6) indirect discharges, on Cr.</p> <p>Ni: Delete footnotes (9) direct discharges and (7) indirect discharges, on Ni.</p>	EEB	<p>AOX: NA</p> <p>Cr: NA</p> <p>Ni: NA</p>
BAT 8	<p>Change the minimum monitoring frequency for the parameters COD, TOC, sulphide, TSS, TN and TP as follows: once every month.</p> <p>For the parameters COD, TOC, TSS, TN and TP, replace footnote (5) with footnote (2).</p>	EURATEX, supported by CZ and PT	NA
BAT 8	Change footnote (5) as follows: In the case of an indirect discharge, the monitoring frequency may be reduced to once every 6 months if the downstream waste water treatment plant is designed and equipped appropriately to abate the pollutants concerned.	DE	NA
General considerations	Add as an additional standard condition for emissions to air from textile finishing and associated thermal treatments that the BAT-AELs refer to an air-to-textile ratio of 20 Nm <sup>3</sup> /kg textile substrate.	DE	NA

BAT 26 / Table 5.5	Amend in footnote <sup>(3)</sup> the processes concerned and possible associated values of the higher end of the BAT-AEL range: For finishing processes with easy-care agents and water-/oil-/soil-repellents, the higher end of the BAT-AEL range may be higher and up to 10 mg/Nm <sup>3</sup> . For finishing processes with wrinkle-free and flame-retardant agents and for coating processes, the higher end of the BAT-AEL range may be higher and up to 20 mg/Nm <sup>3</sup> where specific technical textiles (e.g. PPE, medical textiles, textiles for public buildings) are produced.	DE and EURATEX	10 mg/Nm <sup>3</sup> and 20 mg/Nm <sup>3</sup>
BAT 9	Add footnote <sup>(4)</sup> for the parameter dust.	IT	NA
BAT 50 (a)	Amend the applicability of technique (a) as follows: The applicability may be restricted by product specifications (e.g. flame retardance for high fire safety applications).	DE, EEB	NA
BAT 50 (c)	Add a new technique (c) on substitution of brominated flame-retardants (BFR) with biodegradable substitutes. The applicability may be restricted by the product specification (e.g. for technical textiles or personal protective equipment).	AT, BE, DE, DK, FI, SE and EEB	NA
BAT 51	Add a new technique to BAT 51 on substitution of per- and polyfluorinated alkyl substances (PFAS) with biodegradable substitutes, only applicable if only water repellence is required. The applicability may be restricted by the product specification (e.g. for technical textiles).	AT, BE, DE, DK, FI, SE and EEB	NA
BAT 42	The applicability of technique (a) could reflect that it may be restricted by product specifications (e.g. colour fastness and shade).	IT	NA
BAT 52	Add a Note below the Applicability: When chlorine anti-felting chemicals are used as an oxidant agent (i.e. when appropriate shrink-proof performance of the wool cannot be reached by the use of chlorine-free chemicals), BAT is to use both of the following techniques: <ul style="list-style-type: none"> <li>• closed system for water reuse and recycling, and</li> <li>• evaporating/concentrating residual waste water streams and handling them as liquid waste.</li> </ul>	CZ	NA
BAT 8	For the BFR parameter, add a footnote with the list of BFR compounds from Section 8.1.8.4 of the BREF as examples.	CEFIC	NA



Description of Emission factor in Section 5.12.1	Change the description of emission factors, so that final text would read: ‘Emission factors are representative values that attempt to relate the quantity of a substance emitted to a finishing process associated with the emission of that substance. Textile substrate based emission factors represent the amount of organic and inorganic substances in grams that can be released from one kilogram of textile treated with a given mixture of chemicals/auxiliary formulation/recipe treated and at a waste gas flow of 20 m <sup>3</sup> /h. The textile substrate-based emission factors are calculated on the basis of the substance-based emission factors, their concentration in the liquor and the liquor pick-up. Whereby the substance-based emission factors represent the mass of substance in [g], that can be emitted under defined process conditions (curing time, curing temperature and type of substrate) from a mixture of chemicals/textile auxiliary [kg].’	DE	NA
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The TWG had extensive debates and some dissenting views were expressed by TWG members during the Final Meeting on the various aspects of the issue of mass flow thresholds used for regulation of emission sources in the TXT sector.

Additionally, the TWG recommended that the issue of substitution of brominated flame-retardants (BFR), per- and polyfluorinated alkyl substances (PFAS) and phthalates be brought to the attention of the IED Article 13 Forum and/or the Industrial Emissions Expert Group.

### **Consultation of the Forum and subsequent formal adoption procedure of the BAT conclusions**

In accordance with Article 13(3) of the Directive, the Forum gave its opinion on the draft Best Available Techniques (BAT) reference document for the Textiles Industry in its meeting of 10 May 2022.

1. The Forum welcomed the draft Best Available Techniques (BAT) reference document for the Textiles Industry as presented by the Commission.
2. The Forum acknowledged the discussions held at its meeting of 10 May 2022 and agreed that the changes to the draft Best Available Techniques (BAT) reference document for the Textiles Industry, as proposed in Annex A of the publicly available Forum opinion, should be included in the final document.
3. The Forum confirmed that the comments included in Annex B of the publicly available Forum opinion represented the views of certain members of the Forum. For these comments, no consensus existed within the Forum and shall not be included 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 Textiles Industry. The IED Article 75 Committee, through a written procedure lasting until 28 September 2022, gave a positive opinion on this draft Commission Implementing Decision.

Subsequently, the Commission Implementing Decision (EU) establishing Best Available Techniques (BAT) conclusions for the Textiles Industry was adopted on 09 December 2022 and published in the Official Journal of the European Union (OJ L 325, 20.12.2022, p. 112–161).

**Recommendations for future work**

The information exchange revealed a number of issues that should be addressed during the next review of the TXT BREF. The recommendations for the next review include the following:

- Related to emissions to water:
  - To collect more data on measurements of bioeliminability/biodegradability of waste water streams.
  - To collect more data on the abatement efficiency for total nitrogen and in particular on the influence of ammonia used in dyeing or printing on that efficiency.
  - To collect more data on the emissions of total nitrogen when shrink-proof finishing is performed.
  - To collect more data on the abatement efficiency for total phosphorus and the factors affecting it.
  - To collect more data on the removal efficiency of waste water treatment for COD and TOC, related to the batch processes and the amount of waste water discharged.
  - To collect more data on AOX emissions when using vat and/or reactive dyes.
  - To collect more data on sources and emissions of metals when using metal-containing dyes (e.g. metal-complex, nickel-containing, zinc-containing).
  - To collect more data on sources and emissions of metals when using metal-containing dyes (e.g. metal-complex, nickel-containing, zinc-containing).
  
- Related to emissions to air:
  - To collect more data on the air-to-textile ratio related to the emissions of formaldehyde.
  - To collect more data on different finishing processes with easy-care agents, water/oil/soil-repellents and/or flame retardants and their emissions, related to the emissions of formaldehyde.
  - To collect more data on the use of 'recipes' leading to low emissions of ammonia and the cross-media effects of the wet scrubbing for abatement of ammonia emissions.
  
- Related to water consumption:
  - The TWG could not set BAT-AEPLs for specific water consumption due to the wide range of processes, articles and raw materials, resulting in a high variability of the specific water consumption. This contextual information should be collected.
  - The amount of water reused and/or recycled should be collected in order to set a specific water consumption based on actual consumption and not on net consumption.
  
- Related to specific energy consumption:
  - The TWG could not set BAT-AEPLs for specific energy consumption due to the wide range of processes, articles and raw materials, resulting in high variability of the energy consumption. This contextual information shall be collected.
  - The impact of the abatement techniques applied and treatment of recycled textile material on the specific energy consumption of thermal treatment shall be considered.
  
- Related to resource efficiency:
  - To collect more information on technical implementation difficulties and potential cross-media effects related to the applicability of the techniques 'Digital jet printing' and 'Transfer printing on synthetic textile materials'.

### **Suggested topics for future R&D work**

According to the LIFE-FLAREX project report, further research work concerning alternative flame retardants are suggested on two topics, i.e. use of ammonium sulphamate + urea +  $\text{PO(OH)}_2\text{-R-PO(OH)}_2$  in bed linen, and nanomaterials as alternative flame retardants [[41](#), [FLAREX 2020](#)].

According to the MIDWOR project report, further research concerning alternative water-, oil-, soil-repellence is suggested for paraffin- and silicone-based products [[37](#), [Manich et al. 2018](#)].

## 8 ANNEXES

### 8.1 Textile auxiliaries

#### 8.1.1 Surfactants

The description of surfactants in this section is somehow anomalous because they do not represent a category of auxiliaries, but rather a category of organic compounds. The reason for dedicating a section to these compounds is that they are used in the textile industry for many different purposes (e.g. lubricants, antistatics, wetting agents, etc.). Dealing with them in a common section such as this avoids repetitions in other parts of this annex.

Surfactants can be the essential active substance in a textile auxiliary or can be used as additives in the formulation of auxiliaries, dyes, printing pastes, coating pastes (e.g. dispersing agents in dyestuffs, emulsifiers in preparation agents, etc.).

The surfactants used in the textile industry are classified under four major headings, namely: scouring agents, dye bath additives, softeners and antistatic agents.

Surfactants are organic polar compounds containing in their molecule at least one hydrophobic and one hydrophilic group. According to their chemical structure, surfactants are classified as non-ionic, anionic, cationic and amphoteric.

##### Non-ionic surfactants

Non-ionic surfactants are widely used in the textile industry for various purposes (e.g. as washing/ dispersing agents, as levelling agents, etc.). Some examples of commonly used non-ionic surfactants are:

- fatty alcohol ethoxylates
- fatty amines ethoxylates
- fatty acids ethoxylates
- triglyceride ethoxylates
- alkylphenol ethoxylates

Ethoxylated fatty alcohols, acids and triglycerides are generally easy to biodegrade. On the other hand, ethylene oxide/propylene oxide adducts and fatty amine ethoxylates are examples of surfactants that are difficult to biodegrade and, due to their solubility in water, are also difficult to eliminate. Fatty amine ethoxylates tend to exhibit strong aquatic toxicity.

Alkylphenol ethoxylates (APEOs) have been under substantial regulatory scrutiny for their environmental hazards; nonylphenol ethoxylates have been recognised as “Priority Hazardous Substances” by the Water Framework Directive. In the EU, the presence of NPEs in textile articles and materials has been restricted under REACH (see section 4.1.6.9.1). Their use in textile manufacturing has been restricted since 2003, except where there are no releases into waste water. As an example, Germany extended this restriction to all APEOs.

##### Anionic surfactants

Anionic surfactants commonly used in textile processing are:

- sulphates (e.g. alcohol ethoxysulphates, alkanolamides sulphates, sulphated vegetable oils)
- sulphonates (e.g. alkylbenzene sulphonates, sulphonated vegetable oils, naphthalene sulphonates, ligninsulphonates)
- alkyl ether phosphates
- carboxylates (fatty acid condensation products, alkali salts of fatty acids).

The linear, more biodegradable compounds are the most commonly used (e.g. alkylbenzene sulphonates, fatty alkyl sulphates, etc.). Examples of recalcitrant anionic surfactants are the common lignin sulphonates and condensation products of naphthalene sulphonic acid with formaldehyde, which are widely used as dispersants for vat, sulphur and disperse dyes.

Anionic surfactants have several advantages: they are good oil emulsifiers and dye dispersants, they are excellent wetting agents and they are not expensive. In turn, they generate high levels of foam, and sulphate surfactants can be sensitive to calcium and magnesium [[30, US EPA 1996](#)].

### **Cationic surfactants**

Cationic surfactants are relatively uncommon in textile processing. One example is quaternary ammonium compounds (salts) used as retarders for cationic dyes, which are water-soluble recalcitrant substances. Cationic surfactants have by far the highest toxicity of all classes of surfactants [[5, UBA 2001](#)].

### **Amphoteric surfactants**

Amphoteric surfactants are not widely used in the textile industry. Their main advantage is the fact that they can be used in alkaline and acidic media and in combination with either cationic or anionic surfactants.

Quaternary ammonium compound derivatives are very rarely applied, while other low-toxicity types are increasing in use. Examples are:

- betaine derivatives
- imidazolines
- modified fatty amino ethylates (they have very good emulsifying and dissolving capacity for removing oligomers in the reductive cleaning of polyester fibres).

Amphoteric surfactants are expensive and their use is required only in specialised situations where wide ranges of compatibility are needed.

### 8.1.2 Auxiliaries and finishing agents for fibre and yarn manufacturing

Within this class are included those organic compounds that are applied to the fibre during its manufacturing and yarn formation processes. The names used for these auxiliaries in this section are taken from the TEGEWA nomenclature ("TEGEWA nomenclature, 1987"). They are classified as follows:

- spinning solution additives, spinning additives and spinning bath additives
- preparation agents for primary spinning
- preparation agents for secondary spinning (conditioning agents and lubricants)
- coning oils, warping oils and twisting oils.

Special attention is given to them because they are removed during textile pretreatment, in most cases contributing to a significant proportion of the emissions to water and to air at finishing mills.

The general chemical composition of yarn and fibre preparation agents is based on four main classes of components, the proportions depending on the function of the specific preparation agent:

- lubricants
- emulsifiers
- wetting agents
- antistatic agents
- additives (e.g. biocides, antioxidants, agents for the compactness of the thread).

#### Lubricants

Typical applied lubricants are:

- mineral oils
- ester oils
- synthetic lubricants (which include synthetic esters, EO/PO adducts, silicones, etc.).

The term "*mineral oils*" is used to indicate lubricants derived from refined crude oil. They are mixtures of hydrocarbons with C<sub>12</sub> – C<sub>50</sub> chain length, having a range of boiling points between 220 °C and 450 °C. Due to the presence of undesirable and unstable impurities, mineral oils smoke and give rise to air emissions during high-temperature treatments.

Mineral oils are poorly biodegradable and can only be removed by absorption. However, as regards water pollution, the main concern is over the presence of polyaromatic hydrocarbons (these compounds are included in the list of priority hazardous substances to be controlled through EU-wide measures under the Water Framework Directive).

The amount of polyaromatic compounds in mineral oils varies according to the refining process adopted and decreases as the oils become less polydisperse (refined mineral oils are commonly known as white oils). Pharmaceutical-grade mineral oils contain less than 0.1 ppm of polyaromatic hydrocarbons, but they are about three times more expensive than conventional mineral oils.

The use of mineral oils is declining. Because of their low cost, however, they are still widely used in applications where cheap products are needed (mainly as coning oils and, to a lesser extent nowadays, as wool processing auxiliaries).

*Esters oils* are usually fatty acids esterified with fatty alcohols, alcohols or polyhydroxylic alcohols. They are normally obtained by saponification of natural fats or oils.

Ester oils are used as lubricants as an alternative to mineral oils. Compared to mineral oils, ester oils are more thermally stable, biodegradable and easier to emulsify. They are increasingly substituting mineral oils in primary spinning, but mineral oils still have the highest market share in secondary spinning.

*Synthetic lubricants* (so-called synthetic oils) are synthetic base fluids especially tailored to the lubrication function. Because synthetic oils are composed of molecules that are uniform in weight and structure, they can withstand temperatures exceeding 200 °C, which also results in higher oxidative and thermal stability than mineral oils. For these reasons they outperform mineral oil-based products in many respects, allowing for higher operating temperatures, less lubricant loss and improved flexibility in a wide range of operating conditions.

Synthetic oils are free of all metals, sulphur, phosphorus and wax. Certain lubricants are highly biodegradable, thereby having reduced negative impact on the environment.

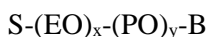
There are several major classes of synthetic lubricants:

- synthesised hydrocarbons, such as polyalphaolefins (PAO) and dialkylated benzenes, which are the most common type
- synthetic esters, such as dibasic acid and polyol esters
- polyglycols
- silicones.

Synthetic esters are synthesised from relatively pure and simple starting materials to produce predetermined molecular structures designed specifically for high performance lubrication.

EO/PO copolymers are used for texturised chemical fibres because they do not interfere with the process as mineral oils do.

The chemical structure of these synthetic lubricants can be schematised as follows:



S = starting component which can be short-chain alcohols (e.g. C<sub>4</sub>-), polyols, organic acids or primary amines;

B = block component which can be ethers (OR), esters (COOR), acetals CH(OR)<sub>2</sub> or OH

The high molecular EO/PO-adducts (sum of EO and PO units is more than 15 moles and the sequence of PO units is higher than 5) are non- or poorly biodegradable.

Silicones are used as lubricants in several areas, including the manufacturing of fibres such as elastane and polyamide. They are chemically inert, non-toxic, fire resistant and water repellent. They are of great value in applications involving extreme temperatures, where high oxidative and thermal stability is required.

Silicones show the highest level of COD of all lubricants and they are poorly biodegradable, but they are bioeliminable. The main disadvantage is that they are difficult to emulsify and remove from the fibre.

### **Emulsifiers**

In order to apply the preparation agent as an aqueous system when the lubricant is not soluble in water, an emulsifier is normally present in the formulation. Anionic and non-ionic surfactants are used as emulsifiers. The main surfactants employed are:

Anionic surfactants: - sulphonated and sulphated vegetable oils

Non-ionic surfactants: - ethoxylated fatty alcohols  
- ethoxylated fatty acids  
- ethoxylated sorbitan esters  
- partial glycerides and ethoxylated triglycerides.

**Wetting agents**

These are usually short-chain alkyl phosphates.

**Antistatic agents**

The anionic surfactants also have anti-electrostatic properties. Mono and diesters of phosphoric acid (mainly their potassium salts) are in use as special anti-electrostatic agents as well as amphoteric surfactants such as sarcosides, amine oxides and sulpho succinates.

**Additives**

Aqueous systems can be attacked by bacteria and may incorporate a bactericide. Biocides such as formaldehyde-containing compounds are applied as preservatives with a load of about 50 mg/kg fibre. Heterocyclic compounds (imidazol and isothiazolinone derivatives) with a load of about 2 mg/kg fibre are also encountered.

When the preparation agents are applied as neat oils or sufficiently stable solutions, instead of aqueous emulsions, the addition of biocides can be avoided, unless they are needed to protect the yarn during storage (see Section 8.1.8.2).

The amounts of active substances added to the fibres and the composition of the applied formulations may vary widely with fibre type and end-use. A rough overview is given in Table 8.1, but a more detailed description of typical formulations used and the load applied on the substrate is given in the following sections (based on an updated version of [ 23, Schönberger H. 1994 ]). In Table 8.1 no distinction has been made between the different types of fibres; only elastomeric fibres and fibres destined for the manufacturing of knitted fabric have been considered separately because of the higher amount applied to the substrate in these cases. Furthermore, the load indicated under the column "Yarn manufacturing" refers to the overall amount of preparation agents applied to the fibre after the production of the fibre itself (including coning oils, twisting oils, oils applied to the filament after the texturing process, etc.).



**Table 8.1: Overview of the loads of auxiliary agents applied on the fibre and yarn during the production process**

		Fibre manufacturing		Yarn manufacturing		Total	
		g/kg substrate	COD mgO <sub>2</sub> /g	g/kg substrate	COD mgO <sub>2</sub> /g	g/kg substrate	COD mgO <sub>2</sub> /g
Flat filament	Non-elastomeric	10	2000	20	3000	30	2700
	Elastomeric	100	1000	50	1000	150	1000
	Filament for knitted fabric	10	2000	30	3000	40	2750
Texturised filament	Non-elastomeric	8	2000	20	3000	28	2700
	Filament for knitted fabric	8	2000	30	3000	38	2800
Staple fibres	Non-elastomeric	3	2000	20	3000	23	2850
	Elastomeric	50	1000	50	1000	100	1000
	Yarn for knitted fabric	3	2000	30	3000	33	2900

Source: [ 354, Bozzetto 2000 ]

### 8.1.2.1 Spinning solution additives, spinning additives and spinning bath additives

Within this group of auxiliaries only those that are washed off during pretreatment operations are mentioned. In this respect, the so-called “modifiers” used for viscose are most relevant. The applied load varies between 5 mg/kg fibres to a few grams per kg of fibre depending on the application field. They mainly consist of ethoxylated fatty amines or polyethylene glycol ethers with molecular weights of about 1500. During pretreatment, more than 90 % of these substances are washed off.

### 8.1.2.2 Preparation agents for primary spinning

These preparation agents are applied (mainly as aqueous solutions) during the manufacture of chemical fibres, directly after primary spinning (see Section 2.2). They enable subsequent processes such as drawing, twisting, warping, texturing and further spinning (secondary spinning, in the case of staple fibres).

The preparation agents give the chemical fibres the necessary properties (optimal friction, avoidance of electrostatic charging and cohesion in the case of multifilament yarns) not only between the fibres, but also between the fibres and the guide elements of the machines.

In general the substances applied have high affinity with water, either because the emulsifiers are already contained in the formulations or because the lubricant molecules themselves are self-emulsifying systems.

The application loads and the characteristics of the formulations applied are given for:

- non-texturised filament fibres (Table 8.2)
- texturised filament fibres (Table 8.3)
- staple fibres (Table 8.4).

**Table 8.2: Load of preparation agents on non-texturised filament yarns (flat yarns)**

Textile substrate	Load (g/kg textile substrate)	Explanations
PES	5 – 10	The content of lubricants is 40 - 70 %, the remaining fraction consists of emulsifiers (mixtures of non-ionic and anionic surfactants such as fatty alcohols and fatty acids ethoxylates, sulphonated and sulphated vegetable oils), wetting agents (short chain alkyl phosphates), antistatic agents (e.g. mono and diesters of phosphoric acid, sarcosides, amine oxides and sulphosuccinates)
PA	8 – 12	Same composition as above
CA	20	The content of lubricants in the formulations is about 60 - 85 %. Less refined mineral oils can be used than for PES and PA fibres
CV	10	
PP	5 – 15	Preparation agents consist of 100 % surfactants (typically 90 % alkoxyated components, 10 % phosphoric esters as anti-electrostatic agents and additives)
EL	30 - 70	Preparation agents mainly consist of dimethyl polysiloxanes
Notes: The reported loads relate to the quantity of active substance, not to the quantity of applied aqueous emulsion		
Source: [ 5, UBA 2001 ]		

**Table 8.3: Load of preparation agents applied on texturised filament yarns (texturised yarns)**

Textile substrate	Load (g /kg textile substrate)	Explanations
PES	3 - 8	Spinning preparation agents consist of 50 - 90 % EO/PO-adducts. As with flat filaments, they contain non-ionic and anionic components (see Table 8.2)
PA	3.5 – 5.5	Preparation agents are based on EO/PO-adducts as well as on ester oils (mineral oils are not used).
	7 - 12	Load used for carpet yarn. In the past, preparation agents consisted of emulsified mineral oils, but today these formulations are very rarely used. They have been substituted by ester oils (trimethylol propane ester and pentaerythritol ester) applied together with non-ionic surfactants
PP	8 – 12	The preparation agents consist of 100 % surfactants (the same used for flat filaments see Table 8.2)
	8 - 15	Load used for carpet yarns
Notes: The reported loads relate to the quantity of active substance, not to the quantity of applied aqueous emulsion		
Source: [ 5, UBA 2001 ]		

Table 8.4: Load of preparation agents applied on chemical staple fibres

Textile substrate	Load (g /kg textile substrate)	Explanations
PES - CO-type - WO-type	1 – 1.8 2 – 2.5	They consist of 50 – 80 % phosphoric esters and their salts and of 20 – 50 % non-ionic surfactants such as fatty acid ethoxylates and fatty alcohol ethoxylates and various additives in minor amounts
PA	4 – 6	PA staple fibres are normally used for carpet yarns. Their preparation agents have compositions similar to those used for PES. Mineral oils and ester oils can also be part of the recipes
CV	3 – 6	Non-ionic surfactants (fatty acid ethoxylates) are used; fatty acid soaps and phosphoric ester salts are additional typical ingredients
PP	5 – 10	The formulations have the same composition as those used for filament yarns (see Table 8.2)
PAC	3 - 8	Different types of formulations are used (e.g. polyamine fatty condensates, short-chain quaternary ammonium compounds). These compounds are difficult to remove in the subsequent processes. Anionic systems as well as non-ionic systems are applied (the same used for PES).
Notes: The reported loads relate to the quantity of active substance, not to the quantity of applied aqueous emulsion		
Source: [ 5, UBA 2001 ]		

### 8.1.2.3 Preparation agents for secondary spinning (conditioning agents and spinning lubricants)

For these agents there is no clear definition. In the following, preparation agents for secondary spinning of synthetic staple fibres and cotton are referred to as "conditioning agents", while preparation agents for wool will be referred to as "spinning lubricants".

Conditioning agents are also required during secondary spinning of synthetic fibres, when the fibres have been previously submitted to bleaching or dyeing processes. The amount initially applied is in fact lost during these processes.

The chemical composition of conditioning agents for synthetic fibres is similar to that of the preparation agents used for primary spinning of staple fibres (see Table 8.4). The load ranges between 1 and 10 g/kg fibres.

Spinning lubricants are applied to wool fibres to assist efficient mechanical processing during yarn manufacturing (spinning). They are generally applied as aqueous emulsions and for this reason they also contain an emulsifier and a biocide to prevent bio-attack during the storage of the emulsion.

When the spinning lubricant is to be applied to wool blends with synthetic fibres, an antistatic agent is also needed.

As regards wool and blends of wool with synthetic fibres, four basic types of spinning lubricants can be identified [ 184, ENCo 2001 ]:

- emulsifiable mineral wool oils based on a mixture of refined mineral oil (<1 % polyaromatic content) and an emulsification system
- water-dispersible lubricants (sometimes referred to as "Super Mineral Oils" or "Semi synthetics") based on a mixture of refined mineral oil, saponifiable fatty oils and an emulsification system. These formulations generally contain a higher proportion of emulsifiers than emulsifiable wool oils

- synthetic water-soluble lubricants based on polyethylene- polypropylene glycols, which are particularly useful when the yarn is to be scoured in the dye bath, but may also be used on yarns that will be scoured in a separate operation
- dry spinning lubricants (only for carpet yarn – see Section 2.13.5.1), which differ from the above in that they are applied at lower levels and they remain on the yarn following conversion to carpet. These materials generally contain a higher proportion of antistatic agents.

The loads for cotton, viscose staple fibres and wool are reported in Table 8.5

**Table 8.5: Load of conditioning agents and lubricants applied on cotton, viscose (staple fibres) and wool**

Textile substrate	Load (g /kg textile substrate)	Explanations
WO and CO-wool-type; (staple fibre length > 60 mm)	30 - 50	Load applied during “oil spinning” of carded yarns
	8 – 10	Load applied during “dry spinning” of carded yarns without subsequent dyeing
	<10	Load applied during spinning of semi-worsted yarn (oil at a level of less than 1 % is normally not removed from the yarn before dyeing)
CO or CV	4	Many recipes are in use, mostly containing white oils and ester oils (30 – 40 %) and non-ionic surfactants. Mineral oil-free systems are also available.
Notes: The reported loads relate to the quantity of active substance, not to the quantity of applied aqueous emulsion <i>Source: [ 5, UBA 2001 ]</i>		

If further processing of dyed yarns or flocs is planned, an additional amount of conditioning agents (3 - 5 g/kg) is applied normally in discontinuous by bath exhaustion at the textile finishing mill. Thereby the exhaustion rates for PES and PA can be very low (10 – 30 %). Conversely, they are relatively high for CO and PAC (>80 %).

#### 8.1.2.4 Coning oils, warping and twisting oils

For processes such as coning, twisting and warping of flat and texturised filament yarns as well as of staple fibre yarns, chemicals have to be applied in order to enhance smoothness, lubrication and antistatic properties.

Oils for coning, warping, twisting and those applied to the filament after the texturing process (sometimes called overlay oils) consist of 70 – 95 % white oils and of 5 – 30 % non-ionic surfactants, especially fatty alcohols and fatty acids ethoxylates. Twisting oils often consist of ester oils which are more biodegradable than white oils. Ester oils are used especially if evaporation has to be avoided or minimised, especially during heat-setting.

The load of coning oils depends on the further processing and the volume of the yarn. It varies for PES from 5 to 30 g/kg (15 g/kg average). For common PA the load is 5 g/kg and in the case of highly elastic PA it is up to 15 - 20 g/kg. It is reported that imported fabric can have loads of coning oils above 50 g/kg.

The load for warping oils and twisting oils is about 5 g/kg.

### 8.1.2.5 Knitting oils

The needles of knitting machines have to be lubricated with so-called knitting machine oils. Due to machine losses, these oils remain on the knitted fabric (about 4 – 8 % of the weight of the fibre). Synthetic oils are used nowadays as substitutes for mineral oil-based formulations. This also means that surfactant aids need to be added in the scouring bath in order to emulsify them.

### 8.1.3 Sizing agents

In this section the following information is presented:

- characteristics of the most common sizing agents
- typical amounts of sizing agents applied on the different substrates (Table 8.6)
- specific COD and BOD5 values for the most common sizing agents (Table 8.7).

### Starch

Starch is the most common natural size and can be derived from various substances, especially corn and potatoes. It is not always suitable for high performance weaving mills. When stored at lower temperatures, it tends to solidify to pulpy mass and lose the hydration water (retrogradation). This retrogradation leads to poor storage properties, skin formation, formation of deposits on the rollers and reduced adhesive strength. As a result, natural starch is commonly used in formulation with other sizes [10, Ullmann's 2011].

Starch is completely biologically removed, but it is only sparingly soluble in water; the action of animal or vegetable enzymes is needed. These enzymes decompose the starch into water-soluble sugars, which are then removed by washing before scouring. As a result starch cannot be recycled and is responsible for most of the COD load in finishing effluents. Moreover, in comparison with other sizing agents, starch must be applied at about twice the rate of carboxymethyl cellulose, because of the poorer sizing effect, thereby leading to a higher COD in the waste water.

### Starch derivatives

Starch derivatives include dextrans, starch esters and starch ethers. They are increasingly replacing natural starches, as their tendency to retrograde is considerably reduced.

The starch esters most commonly used are the esters with phosphoric acid (phosphate starches) and acetic acid (acetyl starches).

The three most important starch ethers are the hydroxyethyl, hydroxypropyl and carboxymethyl starches.

Starch derivatives based on esters can, to a great extent be biologically reduced, while starches based on ethers are more difficult to biodegrade. However, the great variety of possible chemical modifications makes it possible to produce good slashing agents, which can be virtually completely biodegraded.

Like natural starch, starch derivatives must be also applied at about twice the rate of CMC or synthetic agents, thereby leading to higher COD in the effluents.

### **Cellulose derivatives (carboxymethyl cellulose)**

Sodium carboxymethyl cellulose (CMC) is the only water-soluble cellulose derivative used as a sizing agent. It is produced by reacting cellulose with sodium hydroxide and sodium chloroacetate, whereby the cellulose polymer is also depolymerised.

CMC is the preferred additive for increasing the adhesion of starch sizes for cotton.

Its chain length and degree of substitution influence the level of biological reduction. However, carboxymethylcellulose (CMC) must be classified as being very difficult to degrade.

According to UBA, only 20 % of the initial amount is eliminated after 7 days. However, it is also reported that CMC can be reduced after long periods of adaptation (>4 weeks) and favourable conditions (especially higher temperatures) [ 23, Schönberger H. 1994 ]. Other sources mentioned by UBA state that a biological reduction rate of 60 % is attained after 7 days.

### **Galactomannan derivatives**

Hydroxypropyl and carboxymethyl galactomannan derivatives are water-soluble and easy to remove by washing. In general they can reach high levels of biological reduction (greater than 90 %). However, biodegradability as well as other properties can vary significantly with molecular weight and the mannose/ galactose ratio.

### **Polyvinyl alcohol (PVA)**

The parameters that determine sizing properties are the degree of polymerisation and the degree of hydrolysis. There are two grades: the partly hydrolysed grade with a degree of hydrolysis of ca. 88 % and the fully hydrolysed grade with a degree of hydrolysis of ca. 98 %.

Partially hydrolysed PVA grades are preferred for use as sizing agents because they show maximum water solubility and they adhere strongly to non-polar fibres such as PES. In addition to these conventional poly(vinyl alcohol) grades, copolymers with methyl methacrylate or with co-monomers having carboxyl groups are also used as sizing agents.

The degree of polymerisation and the degree of hydrolysis lead to significant differences in terms of biodegradability between the individual types of polyvinyl alcohols. PVA is not acutely toxic to micro-organisms and does not inhibit nitrification. It can be quantitatively eliminated by biological degradation after adaptation of the sludge. The conditions for a 90 % reduction are: relatively high concentrations (20 mg/l), temperature above 18 °C and a regular load over a long period of time (in wintertime and in the holiday period problems can occur) [ 23, Schönberger H. 1994 ]. Given such adaptation, PVA can be classified as having good bioeliminability.

### **Poly(meth)acrylates**

Poly(meth)acrylates show considerable variation in chemical structure (the building blocks can be: acrylic acid, acrylic esters, acrylamide, acrylonitrile, methacrylic acid) and therefore have a very wide range of applications. Hydrophilic monomers like methacrylic acid and its salts and acrylamide give good adhesion to polar fibres and ease of removal by washing. Hydrophobic monomers such as the acrylic esters increase the elasticity of the sizing film and improve the ease of removal from waste water.

Poly(methacrylates) cannot be reduced biologically, not even after a period of adaptation. Hydrophilic products cannot even be eliminated from the aqueous phase, because they behave as hydrophilic polyelectrolytes.

## Polyesters

Polyesters are generally condensates of aromatic dicarboxylic acids with diols (e.g. ethylene glycol, diethylene glycol) and sulphonated aromatic dicarboxylic acids (the latter provide solubility or dispersibility in water, they are mainly added to improve dyeability).

Their biodegradability is bad, but they show a certain degree of bioelimination [ 4, EURATEX 2000 ]. They are mainly used for sizing flat filament yarns. They are also found as co-components in sizing agents for staple fibres made of polyester blends.

**Table 8.6: Amounts of sizing agents applied on different types of substrates**

Textile substrate	Load (g/kg warp yarn) <sup>(1)</sup>	Explanations
<u>Staple fibres</u>		
- CO and CO/PES	80 – 200	As sizing agents starch and starch derivatives, very often in combination with PVA, CMC or polyacrylates are applied. Thereby the ratio of starch/starch derivatives to synthetic sizing agents is generally 3:1, and 1:1 for air jet weaving machines. The loads depend especially on the density of warp yarns and on the kind of sizing agent (for starch/starch derivatives is significantly higher (150 – 200 g/kg)).
- CV	40 – 120	The load is 60 g/kg average. Normally combinations of all available sizing agents are applied, e.g. polyacrylates in combination with CMC and/or starch derivatives
- WO	0 – 20 <sup>(2)</sup>	Woven fabric consisting of wool is usually produced with twisted yarn, so the warp yarns for the weaving process do not need to be sized. In the case of simple yarns (in practice not very significant) up to 200 g/kg starch/starch derivate (80 %) in combination with synthetic sizing agents are applied.
<u>Filament yarns</u>		
- PES	40 – 60	For 90 % of PES flat yarns polyester sizing agents (which can be dispersed) are applied; the rest is sized with modified PVA and polyacrylate.
	80 – 120	This is the load for texturised yarns; about 80 g/kg for polyester sizing agents, about 120 g/kg for PVA and about 100 g/kg for polyacrylates
- PA	20 – 50	Polyacrylic acid is used as sizing agent; 50 g/kg is applied for very thin fabric only
- CV	15 – 30	Mostly for linings for which polyacrylates are used as sizing agents
- CA	15 - 60	Polyacrylates and polyvinylacetate are applied
Notes: <sup>(1)</sup> the figures refer to woven fabrics with 60 % of warp yarn <sup>(2)</sup> as wax Source: [ 5, UBA 2001 ]		

Knowing the loads of sizing agents on the different substrates the calculation/estimation of organic loads as BOD<sub>5</sub> and COD is possible, provided that specific BOD<sub>5</sub> and COD values are available. These values are given in Table 8.7.

**Table 8.7: Specific COD and BOD<sub>5</sub> values for the most common sizing agents**

Kind of sizing agent	Specific COD-value (mg O <sub>2</sub> /g)	Specific BOD <sub>5</sub> -value (mg O <sub>2</sub> /g)
Starch	900 – 1000 * <sup>1</sup>	500 – 600
CMC	800 – 1000 * <sup>1</sup>	50 – 90
PVA	c. 1700 * <sup>1</sup>	30 – 80 * <sup>2</sup>
Polyacrylates	900 – 1650	< 50
Galactomannans	1000 – 1150 * <sup>1</sup>	400
PES-dispersions	1450 – 1700	< 50
Protein sizing agents	1200	700 – 800
Protein sizing agents	1200	700 – 800

Notes:  
\*<sup>1</sup> Considering the usual moisture content of commodity  
\*<sup>2</sup> For non-adapted "inocula"  
Source: [ 5, UBA 2001 ]

### 8.1.4 Detergents/ wetting agents

These auxiliaries are mainly used in pretreatment operations (scouring, mercerising, bleaching) in order to allow:

- thorough wetting of the textile material
- emulsification of lipophilic impurities
- dispersion of insoluble matter and degradation products.

Non-ionic and anionic surfactants are the compounds more frequently used for this purpose (see also Section 8.1.1). Some examples of products available on the market are listed in Table 8.8.

**Table 8.8: Typical compounds used as detergents/ wetting agents**

Class	Examples of products available on the market	Bio-degradability ( <sup>1</sup> )	Bio-eliminability ( <sup>2</sup> )
Non-ionic	Alcohol and fatty alcohols ethoxylates	>90 %	80 – 85 %
	Fatty acids ethoxylates	>90 %	80 – 85 %
	Alkylphenol ethoxylates (APEOs)	~60 %	54 – 58 % (toxic metabolites)
	Fatty amines ethoxylates	60 – 80 %	72 – 73 %
Anionic	Alkyl sulphonates	>98 %	
	Alkyl aryl sulphonates	>98 %	
	Alkyl sulphates	>98 %	
	Dialkylsulphosuccinates	>98 %	
	Alkyl carboxylates (e.g. sodium palmitate, -stearate)	>98 %	
	Sulphated alkanolamides	n.d.	

Notes:  
(<sup>1</sup>) OECD-test 301 E  
(<sup>2</sup>) OECD-test 302 B  
Source: [ 4, EURATEX 2000 ], [ 354, Bozzetto 2000 ]



### 8.1.5 Auxiliaries containing sequestering agents

The presence of ions of alkaline earth metals (calcium and magnesium) and/or other metals (especially iron) may have important negative effects on various wet processes not only in pretreatment, but also in dyeing. Purified and soft/softened water is used in textile finishing mills, but often this is not enough and specific auxiliary formulations containing complexing agents need to be added to the baths.

Auxiliaries with this effect are often classified according to the specific process for which they are applied (*extractants, sequestering agents/ dispersants, etc.*). NTA acid derivatives (derivatives of phosphonic, gluconic, succinic, glutamic and citric acid have largely substituted EDTA and DTPA. Concerning the other organic substances used as complexing agents, gluconates are biodegradable; phosphonates are poorly biodegradable [4, EURATEX 2000]).

The *hydrogen peroxide stabilisers* represent another important category of auxiliaries containing complexing agents. The uncontrolled decomposition of hydrogen peroxide gives rise to OH\* radicals. These radicals attack the cellulose fibre starting with oxidation of the hydroxyl groups and eventually ending with the cleavage of the cellulose molecules, decreasing the degree of polymerisation. This reaction is catalysed by heavy metals such as iron, manganese, copper and cobalt; these stabilisers are not to be confused with stabilisers such as acetanilide, intended to increase the shelf life of hydrogen peroxide.

In order to inhibit these reactions, bleach stabilisers, containing sequestering agents, are usually applied. EDTA, DTPA, NTA, gluconates, phosphonates and polyacrylates are typical stabilisers.

### 8.1.6 Dyeing auxiliaries

#### 8.1.6.1 General characteristics and environmental aspects

Auxiliaries are essential components in dyeing processes. This section describes the ones most commonly used to assist the dyeing process. They are presented based on their function in the process as follows:

- wetting, penetrating agents
- dispersing agents
- levelling agents
- acid donors
- antifoaming
- carriers.

Other auxiliaries such as, for example, the complexing agents that are also commonly used in dyeing processes but that can also be encountered in other operations, are described in other parts of this annex.

Commercial products are in general preparations containing several components. These are mainly surfactants, but non-surface-active substances such as water-soluble polymers and oligomers and polymer dispersions are also frequently employed.

With a few exceptions dyeing auxiliaries are released to waste water. Some of them are biodegradable (e.g. fatty alcohol ethoxylates, linear alkylbenzene sulphonates), while others have poor biodegradability, but they are sparingly soluble in water and are therefore largely eliminated by absorption on the activated sludge in waste water treatment plants. There is, however, a list of substances that are soluble in water and poorly eliminable in common waste water systems. Compounds that belong to this category and that are frequently encountered in dyeing auxiliaries are listed as follows:

Compounds	Additional remarks
- Condensation products of beta-naphthalene sulphonic acids and formaldehyde	Modified condensation products of naphthalene sulphonic acid with formaldehyde are reported to have about 70 % bioeliminability, according to test method OECD 302 B (see also Section 4.5.1.1)
- Lignin sulphonates	
- Acrylic acid-maleic acid co-polymers	<b>Elimination rate depends on the content of Ca<sup>++</sup> ions in the waste water</b>
- o-phenylphenol derivatives	<b>Also toxic for aquatic species</b>
- Cyanamide-ammonia salt condensation products	
- Polyvinylpyrrolidones	
- Quaternary ammonium compounds	<b>Also toxic for aquatic species</b>
- Ethoxylated fatty amines	
- Biphenyl derivatives (carriers)	Also characterised by high acute toxicity

### 8.1.6.2 Wetting, penetrating and de-aerating agents

This group of products is perhaps the most difficult to define in terms of technical function. Wetting and de-aerating agents often perform the same function: that of expelling air from the textile assembly contained in the dye bath. The use of penetrating agents is invariably associated with the dyeing of yarns with a high twist factor, where they enhance transport of the dye into the yarn assembly. In this respect it could be argued that they are in fact a levelling agent. All the products in this class are invariably powerful surfactants.

Commonly used commercial products are mainly readily bio-eliminable compounds such as alcohol polyglycol ethers and esters (also in blends with alkane sulphone), but poorly degradable products such as ethoxylated amines can also be encountered.

### 8.1.6.3 Dispersing agents

Vat, disperse and sulphur dyes already have a high content of dispersing agents in their formulation, which allows the application of these colourants in the form of aqueous dispersions. Additional amounts of dispersants are usually added (also for other classes of dyes) in the subsequent steps of the dyeing process to maintain the stability of the dispersion throughout the dyeing (or printing) process.

Substances commonly used as dispersing agents are condensation products of naphthalene sulphonic acid with formaldehyde, lignosulphonates. Anionic and non-ionic surfactants (e.g. ethoxylated alcohols, phosphated alcohols and naphthalene sulphonates) are also applied. Environmental aspects of these substances are reported in Section 8.1.6.1, whereas more general information about surfactants can also be found in Section 8.1.1. Dispersing agents with improved bioeliminability are now available for some dye formulations (see Section 4.5.1.1).

### 8.1.6.4 Levelling agents

Levelling agents are used in batch dyeing processes to improve the uniform distribution of the dye in the fibre. They are probably the most important class of dyeing auxiliaries, as a grossly unlevel dyeing is of no commercial value and is difficult to correct. They are employed for different types of fibres, therefore the substances employed can be different. Nevertheless two main groups of levelling agents can be identified: products which have an affinity for the fibre and products which have an affinity for the dye. Products which have an affinity for the fibre compete with the dye for dye-sites on the fibre. In this way they reduce the rate of absorption of the dye and improve their migration. The second group comprises substances that form loosely

bound complexes with the dye, reducing its mobility and in some cases neutralising the electrostatic attraction between the dye and the fibre.

The most common substances used as levelling agents are reported below, divided on the basis of the fibre to which they are applied and dyestuff.

**Table 8.9: Typical compounds encountered in levelling agents**

Fibre	Dye	Possible components
Cellulose fibres	Vat dyes	Fatty alcohol ethoxylates Fatty amines ethoxylates Polyamide amines Polyvinylpyrrolidone
	Direct dyes	Non-ionic surfactants such as ethoxylated fatty alcohols, fatty amines, fatty acids or propylene oxide polymers Anionic surfactants such as fatty alcohol sulphates and alkyl aryl sulphates Polyvinylpyrrolidone
Wool	Acid, metal complex and reactive dyes	Ethoxylated fatty amines Quaternary ammonium compounds Bisulphate anion ( $\text{HSO}_4^-$ ) Other non-ionic surfactants such as ethoxylated fatty alcohols, fatty acids, alkylphenol and fatty mercaptans may also be found in specific products
Polyamide	Acid and metal complex dyes	Anionic, cationic and non-ionic surfactants used for wool Condensation products of aromatic sulphonic acids, alkyl sulphates (also called "PA reserving/ blocking agents")
	Disperse dyes	Non-ionic surfactants
Polyester	Disperse dyes (at HT conditions)	Ethoxylated castor oil, stearic acid, alkylphenols Mixtures of alcohols, esters or ketones of medium chain length with emulsifying systems
Polyacrylonitrile	Basic dyes	Quaternary ammonium salts with $\text{C}_{12}$ - $\text{C}_{14}$ fatty alkyl side chains (also known as retarders) Quaternary ammonium salts with aromatic ring systems

Consideration of the environmental aspects associated with the use of these compounds is reported in Section 8.1.6.1 and more general information about surfactants can be found in Section 8.1.1.

#### 8.1.6.5 Acid donors

The so-called acid donors represent a more sophisticated range of formulated products designed to create shifts in dye bath pH. They are hydrolysable acid esters which break down during dyeing, progressively lowering the pH. The shift of pH occurs as the acid is released by hydrolysis during heating or as one of the acid/base components is transferred to another phase such as the fibre or the air, e.g. ammonia release to air with ammonium sulphate.

They are widely used for wool and/or polyamide fibres to control the absorption of anionic dye onto the fibre. They are also employed for cotton and polyester blends when dyeing with disperse and reactive dyes in the one-bath one-step procedure.

Organic acid esters, fatty alcohol ethoxylates and aromatic sulphonates are commonly found in commercial products. They usually have good bio-eliminability.

### 8.1.6.6 Antifoaming agents

Formulated products designed to suppress foam formation are used, which do not adversely influence the quality of the resultant dyeing. The majority are based on silicone derivatives and esters.

### 8.1.6.7 Carriers

Dyeing accelerants (so-called carriers) are used in batch dyeing of synthetic fibres (particularly polyester fibres) to promote the absorption and diffusion of disperse dyes into the fibre under low-temperature conditions. They are still important for dyeing blended fibres of wool and polyester, as wool cannot withstand dyeing under high temperature conditions (above 100 °C). Typical carrier formulations contain 60 – 80 % of active substance and 10 – 30 % of emulsifier and sometimes a small percentage of solvent.

More than 20 years ago before the date of writing it was reported that active substances for dyeing accelerants include:

- halogenated benzenes (1,2 dichlorobenzene)
- aromatic hydrocarbons such as alpha- and beta-methylnaphthalene, diphenyl, trimethyl benzene, etc.
- phenols such as o-phenylphenol, etc.
- carboxylic acid and their esters such as methyl, butyl and benzyl benzoate, methylsalicylate, phthalic acid, dimethyl phthalate, dibutylphthalate and diethylhexylphthalate
- alkyl phthalimides such as N-butylphthalimide.

Most of the above-mentioned substances are toxic to humans, aquatic organisms and sewage sludge.

Carboxylic acid esters and phthalimide and fatty alcohol polyether derivatives are most frequently used in Europe today as carriers. However, it is reported that carriers such as methyl naphthalene, mono-, di-, tri-chlorobenzene, biphenyl, orthophenyl phenol and benzyl alcohol are still found in use [32, Bettens L. 1999].

## 8.1.7 Printing auxiliaries

### 8.1.7.1 Auxiliaries for dye printing

Thickening agents are essential components of printing pastes. They are responsible for preventing capillary flow between the threads of the fabric, thus inhibiting dye diffusion. Oil/water emulsions, used in the past as thickeners, have now been largely replaced by formulations similar to those used for warp sizes. Standard components of modern thickeners include natural polysaccharides, both unmodified and chemically modified (e.g. seed derivatives, starch degradation products, alginates) and fully synthetic polymers (mainly based on polyacrylic acid). Thanks to the improvements made in the characteristics of the starting materials, thickening agents are now supplied almost exclusively in cold-soluble form.

## 8.1.7.2 Auxiliaries for pigment printing

### Thickening agents

Modern thickeners can still contain approximately 10 % of mineral oils, which are ultimately found in exhaust air. New generation thickeners have been developed which do not contain any volatile solvents. They are supplied in the form of non-dusting granules [ 33, BASF 1994 ].

### Binders

The pigment has no affinity for the fibre. Therefore, in order to coat the pigment and protect it from mechanical abrasion, a binder is added to the printing paste. Binders are in general self-cross-linking polymers which reticulate during the fixation step. They are supplied as aqueous polymer dispersions, based mainly on acrylates and less commonly on butadiene and vinylacetate.

### Fixing agents

Additional fixing agents are sometimes necessary to enhance the level of wet-fastness, especially with smooth fibres such as PES. Melamine-formaldehyde condensates with low formadehyde content are used for this purpose.

### Plasticisers

Plasticisers are mainly silicones or fatty acid esters, which are used to improve the dry rubbing fastness and give a smooth dry handle to the fabric.

### Emulsifiers

In high- and low solvent pigment printing pastes, the emulsifiers serve to stabilise the solvent (white spirit). In solvent-free pigment printing they are used to prevent agglomeration of the pigment, screen blocking and separation of components of the print paste [ 10, Ullmann's 2011 ]. Non-ionic surfactants such as aryl- and alkyl polyglycol ethers are the most commonly used for this purpose.

## 8.1.8 Finishing auxiliaries

### 8.1.8.1 Easy-care finishing agents

Easy-care finishing agents are chemical finishes which are applied to woven and knitted fabrics composed of cotton, other cellulosic fibres and their blends with synthetic fibres. Their function is to reduce the propensity of cellulose-containing fabrics for wrinkling when treated under wet and dry conditions and to stabilise them against progressive shrinkage during laundering. Their action is based on the introduction of cross-links between the cellulose molecules of cotton and viscose, thus reducing swellability and extensibility of the fibre (the fabric tends to return to the state in which it was when the cross-links were introduced).

Other names also commonly used to name these finishing agents are: resin-finishing, wash-and-wear finishing, no-iron, wrinkle resistant, etc.

Recipes for resin-finishing liquors are in general aqueous solutions or dispersions which consist of a cross-linking agent, a catalyst, a wetting agent/emulsifier (mainly a non-ionic surfactant) and a number of additives.

Among the additives a distinction is drawn between those that are used to improve the handle and to compensate the adverse effects of the cross-linking agent and some others that serve to

impart additional functional properties to the final textile good (e.g. water-repellents, hydrophilising agents, etc.). Only the first group of additives is discussed in this section while the others, being less specific to this finishing treatment, are described in other parts of this Annex.

### Cross-linking agents

The cross-linking agents play an essential role in this finishing treatment: they are also the major components in the formulation (they represent approximately 60 to 70 % of the total preparation).

From a chemical point of view there are three distinct groups:

- cross-linking agents based on melamine and formaldehyde
- cross-linking agents based on urea and formaldehyde
- heterocyclic linking agents based on urea, formaldehyde and various other substances such as diamines and, in particular, glyoxal.

All these products may potentially produce emissions of free formaldehyde and methanol. In particular, formaldehyde is classified under CLP as a Cat. 1B carcinogen and its presence in these finishing agents represents a potential source of pollution or risk not only for waste water and emissions to air, but also for the workplace and the final user of the textile good.

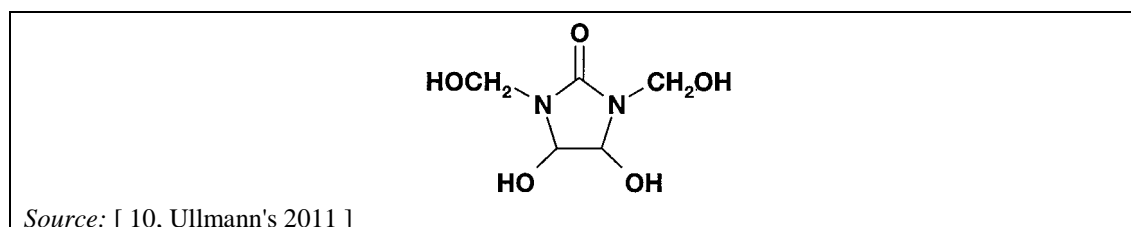
Manufacturers produce cross-linking agents with a low to very low content of free formaldehyde (for instance, a mixture containing > 0.1% of free formaldehyde would be labelled a Cat. 1B carcinogen and would be subject to workplace regulation) and one compound is also available on the market, which is formaldehyde-free.

Existing cross-linking agents are therefore better classified as:

- formaldehyde-rich
- formaldehyde-poor or very poor
- formaldehyde-free.

The first group includes compounds (so-called “self-crosslinking” agents) like (HOCH<sub>2</sub>-NH-CO-NH-CH<sub>2</sub>OH) hydroxymethyl urea and (CH<sub>3</sub>OCH<sub>2</sub>-NH-CO-NH-CH<sub>2</sub>OCH<sub>3</sub>) (bis(methoxymethyl) urea or the correspondent melamine derivatives (hydroxymethyl melamine and bis(methoxymethyl) melamine).

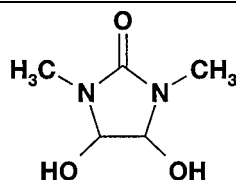
Low to very low levels of free formaldehyde are achievable with heterocyclic compounds (so-called “reactant cross-linking” agents) which are mainly based on the derivatives of the molecule better known as bis(hydroxymethyl)-dihydroxyethylene urea (see Figure below).



**Figure 8.1** Structural formula of the molecule bis(hydroxymethyl)-dihydroxyethylene urea

Modified derivatives of this compound with methanol and diethyleneglycol are among those reported to have a very low free-formaldehyde content in the product (<0.5 %, but also <0.1 % for some products is now achievable).

In the absence of other sources of formaldehyde such as fixing agents and preservatives, the finishes obtained using these cross-linking agents are formaldehyde-free.



Source: [ 10, Ullmann's 2011 ]

**Figure 8.2 Structural formula of the glyoxal**

The emissions of formaldehyde, methanol and other volatile organic substances in the exhaust air (from curing and drying operations) and in the workplace (especially with melamine resins) represent the main environmental issue in the application of these agents.

Water pollution is also an issue since these active substances (ethylene urea and melamine derivatives), when in their not-cross-linked form, are water-soluble and in general poorly biodegradable. This problem is, however, restricted to residual liquors, which as a fundamental rule should not be discharged together with the other effluents in order to avoid contamination with these concentrated liquors.

### Catalyst

The function of the catalyst in the resin-finishing recipe is to allow the curing reaction to be carried out at the usually employed curing temperatures (130 – 180 °C) and times.

The most commonly used catalyst is magnesium chloride. In many cases liquid mixtures are used, based on magnesium chloride and organic acids (e.g. alpha-hydroxycarboxylic acids) or inorganic Lewis acids.

Ammonium salts (e.g. chloride, sulphate and nitrate) commonly used in the past, particularly with cross-linkers based on urea and formaldehyde or melamine, are in decline today, following the corresponding decline in importance of these cross-linking agents.

### Additives (softeners, stiffening agents, etc.)

As mentioned above, easy-care recipes contain various different additives. Attention is given here only to:

- products that are added to easy-care recipes to offset the reduction in softness, tear strength and abrasion resistance that is produced on the fibre as a secondary effect of the cross-linking reaction (their content in easy-care recipes is in general in the range of 10 – 40 %): these can be dispersions of polyacrylates, polysiloxanes, polyethylene waxes (partially oxidised polyethylenes), polyurethanes
- products that are added as softeners to improve the handle of the fabric: fatty acid condensation products (cationic softeners) represent the most important group. They can also be supplied as emulsified mixtures with other products (e.g. polyethylene wax)
- products that are used as stiffeners, hand builders: these can be dispersions of polyvinyl acetate or polyacrylate derivatives.

These substances are responsible for emissions of VOCs in the exhaust air from curing and drying operations.

The poor biodegradability of the above-mentioned polymer dispersions has also to be taken into account when considering water pollution.

### 8.1.8.2 Biocides

Biocides are regulated in the EU under the Biocidal Products Regulation or BPR (Regulation 528/2012) [ 348, EU 2012 ]; use of biocidal active substances and biocidal products is subject to review, approval and authorisation under that legislation.

Some commonly used biocides are those that are applied in the carpet sector to impart wool fibre lifetime protection against a range of textile pests (a product type 9 application under the BPR). These auxiliaries are usually known as mothproofing agents.

Currently used mothproofing agents are formulated from the following active ingredients:

- permethrin (synthetic pyrethroid)
- cyfluthrin (synthetic pyrethroid)

Permethrin-based formulations account for approximately 90 % of the market and cyfluthrin based products are only available in the UK.

Permethrin and synthetic pyrethroids in general are reported to be harmful if inhaled or swallowed, and may cause an allergic skin reaction to humans but mostly to have high aquatic toxicity [ 339, ECHA 2014 ].

Dyphenylurea derivatives may exhibit less aquatic toxicity but, in some cases, are less biodegradable [ 30, US EPA 1996 ].

The current approved biocides for textile industry are [ 340, ECHA 2021 ]:

- Propiconazole
- Azoxystrobin
- Chlorocresol
- Fludioxonil
- Folpet

Active substances which are still under evaluation are still on the market and may be authorised under national schemes in the EU.

All textile-relevant biocides give rise to environmental concern when they are discharged in waste water, because of their toxicity to aquatic life.

### 8.1.8.3 Antistatic agents

This section focuses on the antistatic agents that are applied as functional finishes to selected textile materials for use in static-sensitive environments. They are commonly used in the carpet sector.

From a chemical point of view, formulated products are mostly based on:

- quaternary ammonium compounds
- phosphoric acid ester derivatives.

Quaternary ammonium compounds are highly toxic to aquatic life. Furthermore, the discharge of these substances in waste water can give rise to high levels of AOX due to incomplete quaternisation (epichlorohydrin and chloromethane are often used as initial reagents).

Alkylphosphates and alkyetherphosphates used as antistatic agents are water-soluble, hard-to-treat substances which may pass undegraded through common waste water systems. Nevertheless the use of phosphoric acid esters in antistatic finishing treatment leads to emissions loads that are negligible if compared with other potential sources of this pollutant. According to [ 4, EURATEX 2000 ], in fact, the pollutant load released during pretreatment and



attributable to antistatics from preparation agents is more than 100 times higher compared to the amount of antistatics discharged in waste water from antistatic finishing treatments.

On the other hand, for air emissions, the use of phosphoric esters-based antistatics may lead to the release of non-reacted alcohols (mostly n-butanol, which is odour intensive) and phosphoric acid (corrosive).

#### 8.1.8.4 Flame retardants

In addition to the information given in Section 4.7.4, it is useful to differentiate between durable and non-durable treatments. Durable flame retardants react with the fibre, thereby providing permanent fire retardancy properties to the treated product. This is not the case with non-durable retardants, which although effective, are removed by laundering; while they may be re-impregnated after laundering, the laundering must be considered as a source of pollution.

Flame retardant (FR) agents function by different mechanisms depending on their chemical characteristics. The most commonly used FR agents in the textile sector belong to the following chemical classes:

- inorganic compounds
- halogenated organic compounds
- organo-phosphorus compounds.

##### Inorganic flame retardance agents

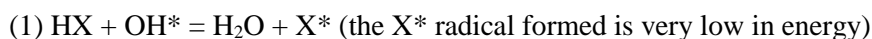
Inorganic flame retardance agents, used for cellulosic fibres, are water-soluble salts such as diammonium phosphate, aluminum sulphate, ammonium sulphate, etc. They are applied from aqueous solution by padding or spraying followed by drying. They are non-durable retardants, i.e. they render the product flame retardant until it is laundered or otherwise exposed to water.

Other types of inorganic flame retardance agents are used in the wool carpet sector. Although wool may be generally regarded as resistant to burning, the introduction of stringent flammability standards for floorcoverings fitted in aircraft and public service buildings necessitates the use of flame retardance agents in some specific cases. Zirconium and titanium salts are used on wool and wool blends to meet flammability requirements of the aircraft interior industry. Zirconium salts, commonly referred to as "Zirpro treatments", are the most widely used (potassium hexafluorozirconate) [ 341, Uddin F. 2016 ]. They do not give rise to significant water pollution. However, emissions of zirconium- and fluorine-containing compounds along with fairly high water consumption levels (four rinsing-baths are needed with the conventional IWS procedure) should be taken into account [ 22, TWG 2002 ].

Aluminum hydroxide ( $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ ) is another flame-retardant widely used in the carpet sector, partially replacing  $\text{CaCO}_3$  an inactive filler in the foam coating of the carpet. Depending on the test conditions, it is commonly accepted that aluminum hydroxide starts to break down around  $200^\circ\text{C}$ , the conversion to aluminium oxide taking place in an endothermic reaction.

##### Halogenated FR agents

Halogenated flame retardants react in the gas phase by free-radical inhibition. The hydrogen and hydroxyl free radicals formed during the combustion process are high in energy and give rise to highly exothermic chain radical reactions (flame propagation). Halogenated flame retardants are capable of interrupting this radical reaction. The halogen deactivates the free radical in the vapour phase according to the reaction (1):



The effectiveness of halogen-containing flame retardants increases in the order  $F < Cl < Br < I$ , of which bromine and chlorine have been industrially successful.

*Brominated* compounds are the most effective ones. Bromine can be bound aliphatically or aromatically; the aromatic derivatives are widely used because of their high thermal stability.

Compounds in which *antimony trioxide* ( $Sb_2O_3$ ) is used together with halogens represent another group of halogen-containing flame retardance. Antimony trioxide is almost totally ineffective if used on its own. However, it shows a good synergistic effect with bromine. Antimony trioxide acts as a radical interceptor and with HBr forms a dense white smoke ( $SbBr_3$ ) that snuffs the flame by excluding oxygen from the front of the flame [ 10, Ullmann's 2011 ]. Antimony trioxide is used as a synergist for halogenated flame retardants Decabromodiphenyl ether, hexabromocyclododecane and chloroparaffins.

Halogenated flame retardants have come under intense environmental scrutiny in recent years. Their properties and their effects on the environment vary depending on the different type of chemicals used.

Polybrominated flame retardants include the following compounds [ 342, Drees et al. 2019 ]

- polybrominated diphenyl ethers (PBDE, sometimes also referred to as PBBE)
  - 2,4,4'-Tribromodiphenyl ether (BDE 28)
  - 2,2',4,4'- Tetrabromodiphenyl ether (BDE 47)
  - 2,2',4,4',5-Pentabromodiphenyl ether (BDE 99)
  - 2,2',4,4',6-Pentabromodiphenyl ether (BDE 100)
  - 2,2',4,4',5',5'-Hexabromodiphenyl ether (BDE 153)
  - 2,2',4,4',5',6'-Hexabromodiphenyl ether (BDE 154)
  - 2,2',3, 4,4',5',6'-Heptabromodiphenyl ether (BDE 183)
  - 2,2',3,3' 4,4',5, 5',6, 6-Decabromodiphenyl ether (BDE 209)
- Hexabromocyclododecane (HBCD)

Polybrominated flame retardance used for textiles applications are almost mainly diphenyl ethers.

All european regulation in force regarding the ban of certain chemical products should be enforced as e.g. deca BDE is subject to restriction as per REACH regulation EC/1907/2006, penta BDE is subject to the POP regulation EC/850/2004, also hexa BDE and hepta BDE are subject to the POP regulation EC/850/2004, and other brominated fire retardants such as HBCD are subject to the POP regulation EC/850/2004.

As for chlorinated flame retardants, short chain- (SCCP C10-13) and medium chain chlorinated paraffins (MCCP C14-17) have been the object of a risk assessment under the Council Regulation 793/93/EEC. SCCP and MCCP are acutely toxic for aquatic life. For SCCP long-term toxicity is observed in algae, fish and mussels. Medium-chain chlorinated paraffins are toxic to Daphnia, whereas no toxicity has been observed in the available experiments with fish, other invertebrates or algae. For both classes of compounds the hormonal effects seen in animals are considered unlikely to be relevant to humans [ 355, CIA 2002 ]. No studies have been carried out on long-chain chlorinated paraffins.

Short-chain chloroparaffins ( $C_{10-13}$ ) have been identified as “Priority Hazardous Substances” targeted for priority regulatory action under the Water Framework Directive 2000/60/EC and SCCP's ( $C_{10-13}$ ) are subject to the POP regulation EC/850/2004 too. Moreover, both SCCP and MCCP are included on the List of Substances for Priority Action set under the OSPAR Convention.

Discharges of halogenated flame retardants into waste water from textile finishing operations may come from excess liquor dumps, end-of-run bath drops and draining of washing water.

Deca-BDE is poorly water-soluble and should be largely retained by the sludge in the waste water treatment system. Chlorinated paraffins are also potentially bioeliminable by adsorption to the sludge (93 % removal from water during waste water treatment has been reported) [ 355, CIA 2002 ]. However, since the amount/load of active substance applied on the fabric is typically in the order of 20 – 30 % w/w, the amount of flame retardants not retained by the sludge and therefore potentially released into the environment may be significant. Process design and operation should avoid the discharge of concentrated liquors to waste water, minimise losses to the effluent, and ensure that adsorption to the sludge is effective in the waste water treatment plant (see Section 4.1.7.2).

Furthermore, special care should be taken for the disposal of the sludge and solid waste containing these halogenated compounds. As all, halogenated organic substances, flame retardants (less for aliphatic derivatives), are involved in the formation of dioxins and furans when submitted to high temperature treatments. Dioxins and furans can be formed in small amounts during the synthesis of these compounds and as a side reaction when they are subjected to combustion/ burnt for disposal [ 356, VITO 2002 ]. Incineration should therefore only be carried out in properly constituted incinerators, running at consistently optimal conditions, such as modern incinerators that operate according to the Waste Framework Directive and the BREF WI (Waste Incineration).

For the widely used antimony-organo-halogen flame retardants systems, in addition to the considerations reported above for brominated and chlorinated compounds, dust emissions of  $Sb_2O_3$  (carcinogenic) from dried pastes and mechanical treatment (cutting, etc.) on finished fabrics also need to be taken into account.

### Phosphor-organic flame retardance agents

Phosphorus-based flame retardants can be active in the vapour phase or in the condensed phase. Phosphine oxides (Tris(aziridinyl)phosphin oxide is restricted under REACH Regulation, entry 7 of Annex XVII) and phosphate esters are thought to act in the vapour phase through the formation of  $PO^*$  radicals, which terminates the highly active flame propagating radicals ( $OH^*$  and  $H^*$ ). The condensed phase mechanism arises as a consequence of the thermal generation of phosphoric acids from the flame retardant, e.g. phosphoric acid or polyphosphoric acid. These acids act as dehydrating agents on the polymer (they decompose to form water vapour and phosphorus oxides which then react with the polymer matrix and dehydrate it, reforming phosphoric acids). The fire retardancy effect is produced via the alteration of the thermal degradation of the polymer and the formation of a very high melting point char at the interface of the polymer and the heat source [ 10, Ullmann's 2011 ].

Organo-phosphorus compounds used in textile applications, particularly for cotton, are available as reactive (durable) and non-reactive (non-durable) systems.

There are two principle chemical types of *reactive phosphor-organic* flame retardance agents. Both of them are halogen-free formulations, one is commercialised as Afflamit and Pyrovatex and the other is commercialised as Proban

The active substance of Afflamit/Pyrovatex “DMPPA” (dimethyl [3-[(hydroxymethyl)amino]-3-oxopropyl]phosphonate with CAS: 20120-33-6) is applied to cotton via the pad-dry-bake technique in combination with a melamine resin, a fabric softener and phosphoric acid. After padding, the fabric is dried and cured thermally to achieve fixation. No ammonia is used in curing. Because of the presence of melamine resins as cross-linking agents, formaldehyde and methanol are evolved as off-gases (emissions are normally abated via scrubbers). Following the curing process, the fabric is washed off, resulting in some unreacted P-containing reagents being discharged to the waste water. Because of their water-solubility Phosphor-organic flame retardants agents may pass undegraded through the waste water treatment system.

A recent study conducted on a plant using DMPPA with a downstream public WWTP, concludes that the limited biological availability of DMPPA implies also a limited contribution

to the eutrophication of surface water due to the organic phosphorus component [ 302, EURATEX 2020 ]. According to the ECHA website, this substance is considered Carcinogenic by a majority of companies.

Residual finishing liquors and rinsing water containing phosphor-organic flame retardant of this type should be collected and not mixed with the other effluent in the waste water treatment system [ 9, TWG 2001 ], see Section 4.1.7.2. For instance, Sweden reported that 10 m<sup>3</sup> of the first rinsing water from Pyrovatex process containing organic phosphorus were sent to a WWTP, built for 100 000 pe, and caused exceeded ELV for Total Phosphorus for three to five days from the WWTP. The dissolved organic phosphorus from the textile baths disturbed the WWTP, and thus the total emissions of P-tot also become higher than normal [ 299, Swedish EPA 2020 ], [ 324, TWG 2020 ]. Another study of a company using phosphor-organic flame retardant under the Afflamit process showed that 70 to 80% of the active substance DMPPA was eliminated in the WWTP, without having the possibility to determine which processes were responsible for it. Biological conversion and physico-chemical adsorption on sludge were retained as the most important mechanisms. However, this did not prevent the exceeding of the phosphorus discharge standard of the plant [ 299, Swedish EPA 2020 ], [ 324, TWG 2020 ].

Ecotoxicologic information (available in 2020) on main phosphorous-based flame retardants has been collected by [ 343, EEB 2020 ] and [ 344, Derden A. 2020 ] and is presented in the Table 8.10 below.

**Table 8.10: Information from the Reach registration dossiers (at the time of writing this document in 2021), on main phosphorous-based flame retardants**

Acronym	Trade name	Producer / Reach registrant	EC number	(Eco)toxicological summary*
DMPPA (THPC)	Pyrovatex ® Aflammit KWB	Huntsman Thor	243-528-9	Persistent Carcinogenic
THP	Proban ®	Solvay Thor	Various related substances: 613-239-6 436-230-7 500-057-6 etc.	Toxic to aquatic life Skin corrosion Eye damage Reprotoxic Skin sensitising STOT
NB: * Based on the information in the registrants' dossiers. Source: [ 343, EEB 2020 ] and [ 344, Derden A. 2020 ]				

With the other type of reactive phosphor-organic flame retardance (self-reactive systems), the fabric is impregnated with phosphonium salt and urea precondensates. The phosphor-organic compound is represented by the molecule: tetrakis (hydroxymethyl) phosphonium chloride (THPC) – CAS 27104-30-9. The subsequent drying process step does not require complete drying. Processing temperatures are therefore low (between 60 and 100°C). After drying, the fabric is treated with ammonia to produce an insoluble polymer within the fibres. The fabric is subsequently oxidised with hydrogen peroxide and washed. In this process there is no curing treatment other than the treatment with ammonia. According to the ECHA website, this substance is considered Carcinogenic and very toxic to aquatic life with long lasting effects.

Phosphonium salt and urea precondensates have been shown to have levels of fixation of 95 % or higher [ 355, CIA 2002 ]. However, since washing is necessary with these flame retardants to remove unreacted agents and by-products, and since these compounds are water-soluble and

non-readily biodegradable, manufacturers instruct users to incinerate waste water or treat them oxidatively with 2-fold excess of hydrogen peroxide [ 345, EEB 2021 ].

Concentrated padding liquors and rinsing water containing phosphor-organic flame retardants of this type should be collected and not discharged with the other effluents in the waste water treatment [ 9, TWG 2001 ] see Section 4.1.7.2.

*Non-durable phosphor-organic* flame retardants do not react with the fibre.

As articles treated with *non-durable phosphor-organic* flame retardants are not washed after the finishing treatment (and also as the final product is rarely washed) [ 355, CIA 2002 ].

### **Expandable Graphite (EG) [ 41, FLAREX 2020 ]**

Expandable Graphite (EG) can be used as an alternative for upholstery application, and is considered convenient FR compound for eco-friendly FR applications on account of its low cost, low smoke, anti-dripping and halogen-free characteristics. Expandable graphite is granular graphite in which sulphuric acid has been introduced between the layers of the graphite structure with some oxidation of the carbon. The acid is tightly held and does not leach out. Grades are available with an acidic or neutral character. During a fire, the graphite expands very quickly to over 100 times its original volume, resulting in a heat and mass transfer barrier. This effect is visible in almost any thermoplastic and is sometimes used in combination with other flame retardants like ammonium polyphosphate (APP). A higher amount of EG does not have a significant influence on the flame-retardant characteristics of the textile. Additionally, the stiffness of the fabric increases with higher add-ons of EG, contrarily to what it would be desired. The stiffness of the textile sample coated with 50 % of EG is assessed to be moderate.

### **8.1.8.5 Hydrophobic/ Oleophobic agents**

In addition to the information given in Section 4.7.5, the most commonly applied commercial formulations fall under the following categories:

- wax-based repellents (paraffin -metal salt formulations)
- resin-based repellents (fatty modified melamine resins)
- silicone repellents
- fluorochemical repellents.

#### **Wax-based repellents**

These formulations consist of ca. 25 % of a paraffin and 5 – 10 % of zirconium-, aluminium-based salts. They are usually applied to natural and synthetic fibres by padding and drying without curing. The discharge of residual liquors leads to emissions of metals. Concentrations can be high in some cases. However, from a global point of view the amounts discharged can be considered negligible compared to emissions of metals from dyeing and printing.

Moreover metals like Zr and Al should not be confused with more hazardous metals such as Cu, Ni, Co, Cr used in dyeing processes (note that Zr is also used in the “Zirpro process” in carpets – see Section 8.1.8.4) [ 22, TWG 2002 ].

Concerning exhaust air emissions, the presence of paraffin waxes may produce fumes and high levels of volatile organic carbon during heat treatments.

#### **Resin-based repellents**

Resin-based repellents (mainly applied as “extenders”) are produced by condensing fatty compounds (acids, alcohols or amines) with methylolated melamines. Formulations often also contain paraffin wax. They are applied by the pad-dry-cure process, often together with cross-linking agents in the presence of a catalyst.

Depending on the degree of completeness of the cross-linking reaction and on the temperature employed in heat treatments, different levels of formaldehyde and aliphatic alcohols are found in the exhaust air. The presence of paraffin wax contributes to increased levels of volatile organic carbon in the emissions.

### **Silicone repellents**

These products are generally supplied as aqueous emulsions consisting of polysiloxane-active substances (dimethylpolysiloxane and modified derivatives), emulsifiers, hydrotropic agents (glycols) and water.

In the case of modified polysiloxanes with reactive functional groups, and depending on the drying and curing conditions, cyclic dimethylsiloxanes can be released in the exhaust air.

### **Fluorochemical repellents**

The success of these agents, despite their high cost compared to other types of water repellents, is especially due to the fact that they are permanent and they provide both oil and water repellence.

Commercial fluorochemical repellents are mostly copolymers of C6 and C4 fluoroalkyl acrylates and methacrylates, so-called side-chain fluorinated polymers. Marketed formulations contain the active agent together with emulsifiers co-formulants. ) and other by-products which are often solvents such as:

- acetic acid esters (e.g. butyl/ethyl acetate)
- ketones (e.g. methylethyl keton and methylisobutyl ketone)
- diols (e.g. ethandiol, propandiol)
- glycolethers (e.g. dipropylenglycol).

Fluorochemical repellents are usually applied in combination with other finishing auxiliaries by a pad-dry-cure process. In many cases they are applied with extenders which can be other repellents themselves (e.g. melamine resins repellents or polyisocyanates). The use of extenders allows a reduction in the required amount of fluorochemical, with a corresponding reduction in costs for this treatment.

Finishing treatments with fluorochemical repellents produce emissions of volatile organic compounds in exhaust air. These emissions are attributable to:

- the solvents contained in the formulations (as regards ketons, esters, alcohols, diols)
- the “extenders”, which under high-temperature conditions give rise to cracked by-products such as alcohols and ketones, but also oximes and in particular butanoxime (which is carcinogenic)
- the organo-fluoro components which also release cracked fluor-organic by-products.

Fluorinated treatments have become under increased regulatory scrutiny (restrictions under REACH) for their propensity to liberate persistent molecular species. Extreme persistence is often coupled with different toxicological properties, bioaccumulability or high mobility.

As regards water pollution, it has to be taken into account that polysiloxanes, melamine and fluorocarbon resins are all characterised by poor biodegradability and bio-eliminability.

### **8.1.8.6 Softeners**

This group of chemicals is designed for hand modification of fabric. Softeners reduce the fibre/fibre friction, an effect which hand-feel describes as “soft or smooth”.

Quite often softeners are used together with resins and/or optical brighteners in sometimes complex finishing recipes.

Fabric softeners are water-based emulsions or dispersions of water-insoluble active materials such as:

- non-ionic surfactants
- cationic surfactants
- paraffin and polyethylene waxes
- organo-modified silicones.

Note that phthalates are plasticisers for e.g. PVC, but never textile softeners [[9, TWG 2001](#)].

The formulation of the above-mentioned ingredients often requires additives such as emulsifiers and compatibilisers (e.g. glycols). Problematic APEO emulsifiers are no longer used by European producers.

As for surfactant-type softeners the trend is towards mainly non-ionic and cationic compounds.

Non-ionic softeners do not have substantivity for the fibres and are as wash-fast as the cationics. In spite of this, their usage is increasing as the volume of textiles with more permanence and increased wrinkle resistance is growing. Non-ionic surfactants such as fatty acids, fatty esters and fatty amides belong to this group.

Because of their substantivity, cationic softeners produce a more permanent softening effect than non-ionic compounds. Furthermore, they are more effective at much lower concentrations. Their substantivity for synthetic hydrophobic fibres is limited, increasing in the order: polyester, polyamide, acetate, cotton, viscose and wool. Some disadvantages of cationic agents are their lack of compatibility with anionic compounds typically employed as detergents and soaps, etc. As such, cationic softeners are applied after the complete removal of anionic detergents from the fabric [[252, Pharma 2001](#)].

Cationics used as softeners are [[252, Pharma 2001](#)]:

- quaternary ammonium compounds such as stearyl or distearyl dimethyl ammonium chloride
- amido amines formed by reaction of a fatty acid or a glyceride and a substituted or unsubstituted short chain polyamine (e.g. diethylene triamine, N, N-diethyl ethylenediamine). The amide thus formed is quaternised with acetic acid or hydrochloric acid to give the cationic softener (especially used for chlorinated wool)
- imidazolines which can be acetylated or reacted with ethylene oxide.

Polyethylene wax emulsions are widely used for towelling, where a good “bunch” hand is required, rather than in applications such as dress apparel. Among the advantages, it is worth mentioning their compatibility with cationic, non-ionic and anionic softeners [[252, Pharma 2001](#)].

Silicone softeners, used as emulsions or additives to other softeners, are increasing in importance. They have good effectiveness and besides softening they impart to the fabric additional properties such as water repellence.

Softeners are mostly applied by forced application (padding, spraying) from relatively concentrated solutions, which transfers all of the liquor onto the fabric [[9, TWG 2001](#)].

In batch processing softeners are often applied by exhaustion from diluted baths on machines such as jet, overflow or winch. Here the exhaustion rate is relevant to ecological considerations of waste water loads. Machine technology with extremely short liquor ratios and skilled formulation of products help to minimise losses of active material [[9, TWG 2001](#)].

If softeners enter the waste water, their behaviour in biological waste water treatment has to be taken into account:

- Fatty derivatives generally are highly biodegradable.
- Cationic softeners are known to be toxic to aquatic life.
- Silicones and waxes are partially removed from the waste water by adsorption onto the sludge, after the stabilising emulsifiers have been degraded. However, they are only slowly biodegraded in the sludge.

As the active ingredients of softener formulations are chemicals with high molecular weight (even polymers), the volatility is low. Volatile by-products of silicones are stripped before the production of the softener. Cyclic species such as D4, D5 and D6 have been added to the REACH Candidate List of SVHC; their presence at concentrations above 0.1% has to be communicated through the value chain. Some waxes or fatty ingredients, however, may have some sensitivity towards cracking, if stenter temperatures are too high [ 9, TWG 2001 ].

### 8.1.9 Coating compounds and auxiliaries

According to their chemical composition, coating agents can be classified as follows [ 5, UBA 2001 ].

#### Coating powders

They can be based on polyolefins (especially polyethylene), polyamide 6, polyamide 6.6, copolyamides, polyester, polyurethane, polyvinylchloride, polytetrafluoroethylene.

#### Coating pastes

They are based on the chemicals mentioned above, but they also contain additives such as:

- dispersing agents (surfactants)
- solubilising agents (glycols, N-methylpyrrolidone (NMP), hydrocarbons)
- foaming agents (mineral oils, fatty acids, fatty acid ammonia salts)
- softeners (especially phthalates, sulphonamides)
- thickeners (polyacrylates)
- ammonia.

The use of NMP is restricted under REACH und requires special handling in factories; several phthalates are also restricted or subject to authorisation.

#### Polymer dispersions (aqueous formulations)

They contain approximately 50 % water and are based on:

- poly(meth)acrylate (butyl, ethyl, methyl etc.)
- polyacrylic acid
- polyacrylonitrile
- polyacryloamide
- 1,3-polybutadiene
- polystyrene
- polyurethane
- polyvinylchloride
- polyvinylacetate
- and copolymers of the above-mentioned polymers.

Additives are also present, as they are in coating pastes.



**Melamine resins**

They are produced by reaction of melamine and formaldehyde and subsequent etherification mainly with methanol in aqueous medium (water content 50 – 70 %).

**Polymers dispersions (organic solvent-based formulations)**

They are based on polyurethane and silicones dispersed in organic solvent.

## 8.2 Dyes and Pigments

Textile dyes can be classified according to their chemical composition (azo, anthraquinone, sulphur, triphenylmethane, indigoid, phthalocyanine, etc.) or according to their application class. At the industrial level the second method is preferred: this is also the approach in the present section.

The environmental issues related to chemicals and auxiliaries (i.e. other than the dyes) employed in the dyeing process are dealt with in a Section 8.1.

### 8.2.1 Acid dyes

#### *Applicability*

Acid dyes are mainly applied to polyamide (70 – 75 %) and wool (25 – 30 %). They are also used for silk and some modified acrylic fibres. Acid dyes exhibit little affinity for cellulose and polyester fibre.

#### *Properties*

Colours are generally bright and fastness to light and washing range from poor to excellent, depending on the chemical structure of the dyestuff.

#### *Chemical characteristics and general application conditions*

Acid dyes are azo (the largest group), anthraquinone, triphenylmethane, Cu phthalocyanine chromophoric systems which are made water-soluble by the introduction in the molecule of up to four sulphonate groups.

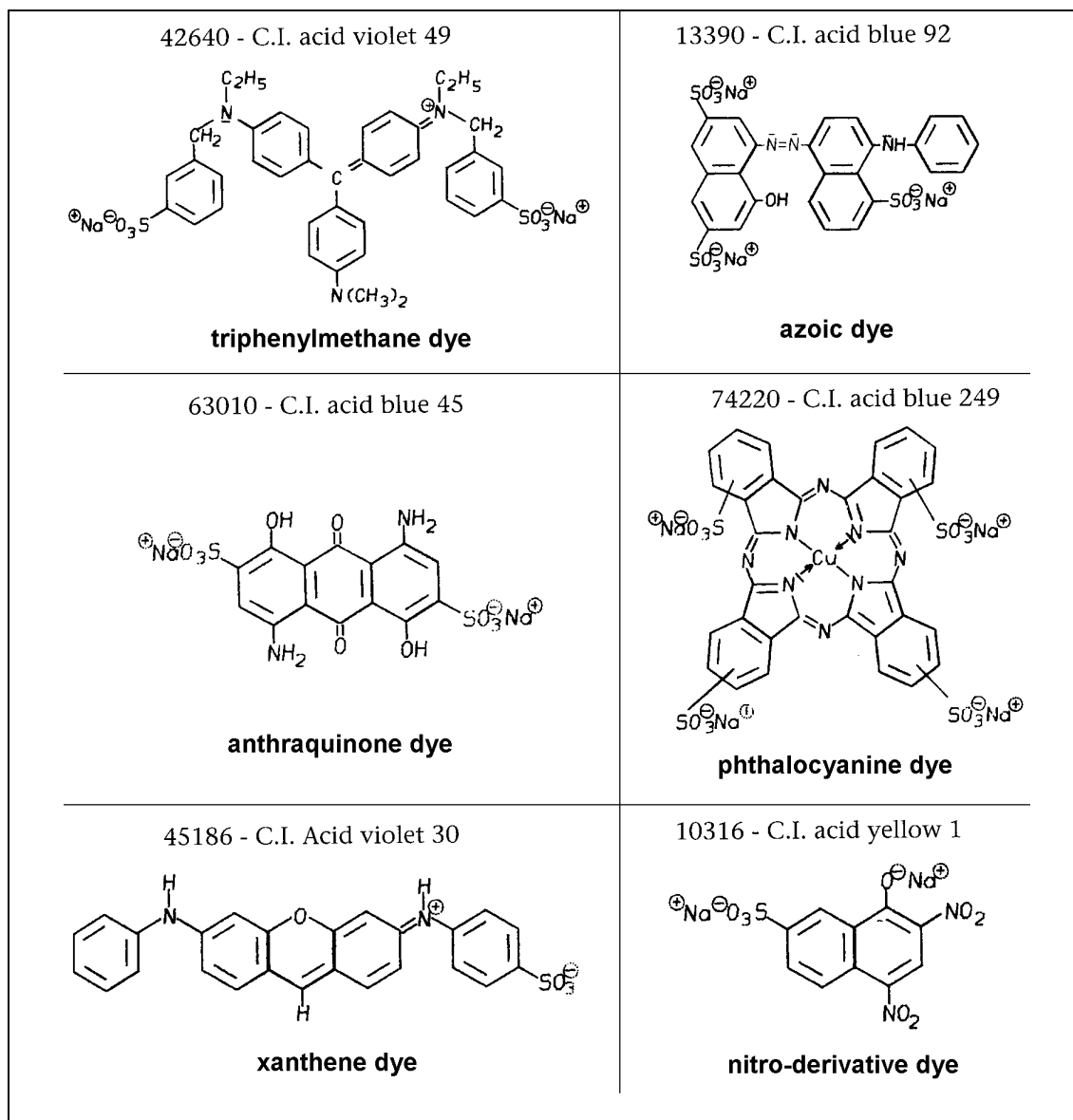
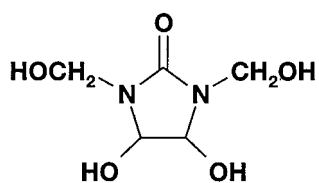
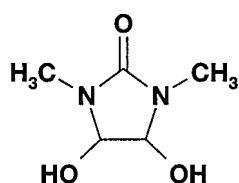


Figure 8.3: Examples of acid dyes

Their interaction with the fibre is based partly on ionic bonds between sulphonate anions and the ammonium groups of the fibre, as shown below for wool



and for polyamide, at different pH conditions.



Moreover, the fibre/dye interaction is based on secondary bonds such as Van der Waals forces. Secondary bonds are established in particular in the case of higher molecular weight dyes, which form aggregates with high affinity for the fibre.

In use, acid dyes are classified by their dyeing behaviour and wet-fastness properties, rather than chemical composition, hence the generic term acid dyes includes several individual dye classes. The arbitrary classification normally adopted, in order of increasing fastness is:

- level-dyeing or equalising acid dyes
- fast acid, half-milling or perspiration-fast dyes
- acid milling dyes
- supermilling dyes.

*Level-dyeing or equalising dyes* are subdivided into two classes, monosulphonated (mainly for PA) and disulphonated (mainly for wool). Due to their poor affinity for the fibre, they all have very good levelling properties. Their wet-fastness is, however, sometimes poor, limiting their use to pale/medium shades.

*Fast acid dyes* (also known as half-milling dyes or perspiration-fast dyes) are only used for PA. They are generally monosulphonated and exhibit superior fastness properties to level-dyeing acid dyes, while retaining some of the migration properties. The shade range available in this class is not as wide as that of the levelling or milling dyes and they therefore tend only to be used when alternatives would have poorer fastness properties.

*Acid milling dyes* are so named because they have a degree of fastness to the wet treatments employed when milling (mild felting) woollen fabrics. The class is further subdivided to include supermilling dyes, which have good wet-fastness properties, arising from long alkyl side-chains attached to the chromophore. Due to their high molecular weight, milling dyes have a good affinity for the fibre and do not migrate well at the boil. Milling dyes are used mainly for wool for those applications where good wet-fastness is required, for example in the dyeing of loose fibre which will receive a further wet treatment during hank scouring.

Depending on the class they belong to, acid dyes are applied under pH conditions that vary from strongly acidic to more neutral ones (3 – 7.5). For low-affinity dyes it is necessary to increase the level of cationisation of the fibre (by acidification) in order to improve dye uptake. Conversely, dyes with higher molecular weight and high affinity would adsorb too rapidly on the fibre if applied under such strongly acidic conditions.

The most common *chemicals and auxiliaries* applied *when dyeing* with acid dyes are:

- sodium sulphate (for level-dyeing and fast acid dyes), sodium acetate and ammonium sulphate (for acid milling dyes)
- pH regulators: acetic, formic and sulphuric acid, but also (typically for PA in the carpet sector) NaOH, NH<sub>3</sub> salts, phosphoric acid salts and higher (hydroxy)carboxylates
- levelling agents, mainly cationic compounds such as ethoxylated fatty amines.

The most common *chemicals and auxiliaries* applied *when printing* with acid dyes are:

- thickening agents
- solubilising agents such as urea, thiourea, thiodiglycol, glycerine
- acid donors: ammonium sulphate, tartrate or oxalate
- antifoaming agents (e.g. silicone oils, organic and inorganic esters) and “printing oils” (mainly mineral oils)
- after-treatment agents such as formaldehyde condensates with aromatic sulphonic acids.

*Environmental issues*

The environmental properties of acid dyes are assessed under the following parameters.

**Table 8.11: Overview of the ecological properties of acid dyes**

Parameters of concern	Comments
Bio-eliminability	
Organic halogens (AOX)	
Eco-toxicity	Specific, depending on the individual dyestuff. Acid dyes are in general not toxic. The acid dyes may also be some of the restricted azo dyes – where the ecotoxicologically relevant properties come from the aromatic structures around the azo group. However, two dyes (Acid orange 156 and Acid orange 165) have been classified as <i>toxic</i> by ETAD.  Acid Violet 17(triphenylmethane dye) is reported to have an <i>allergenic effect</i>
Heavy metals	
Aromatic amines	
Unfixed colourant	Degrees of fixation in batch dyeing are found to be in the range of 85 - 93 % for monosulphonated dyes and in the range of 85 - 98 % for di- and tri-sulphonated dyes
Effluent contamination by additives in the dye formulation	

## 8.2.2 Basic (cationic) dyes

### *Applicability*

Basic dyes were initially used to dye silk and wool (using a mordant), but they exhibited poor fastness properties. Nowadays these dyestuffs are almost exclusively used on acrylic fibres, modified polyamide fibres, and blends.

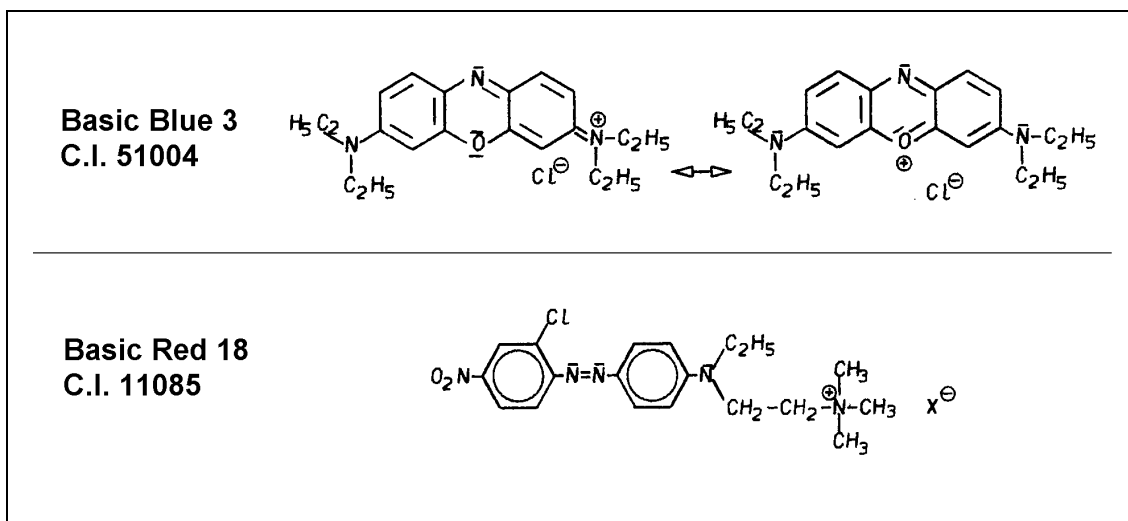
### *Properties*

On acrylic fibres fastness performances are excellent.

### *Chemical characteristics and general application conditions*

Cationic dyes contain a quaternary amino group which can be an integral part (more common) or not of the conjugated system. Sometimes a positively-charged atom of oxygen or sulphur can be found instead of nitrogen.

Ionic bonds are formed between the cation in the dye and the anionic site on the fibre.



**Figure 8.4:** Examples of typical basic dyes

*Cationic dyes are slightly soluble in water, while they show higher solubility in acetic acid, ethanol, ether and other organic solvents. In dyeing processes, they are applied in weak acid conditions. Basic dyes are strongly bound to the fibre and do not migrate easily. In order to achieve level dyeing, specific levelling auxiliaries, (also called retarders) are normally employed (unless a pH controlled absorption process is used). The most important group of retarders is represented by quaternary ammonium compounds with long alkyl side-chains (cationic retarders). Electrolytes and anionic condensation products between formaldehyde and naphthalenesulphonic acid may also be found.*

#### *Environmental issues*

Many basic dyes exhibit high aquatic toxicity but, when applied properly, they show fixation degrees close to 100 %. Problems are more often attributable to improper handling procedures, spill clean-up and other upsets [ 30, US EPA 1996 ].

### **8.2.3 Direct (substantive) dyes**

#### *Applicability*

Direct dyes are used for dyeing cotton, rayon, linen, jute, silk and polyamide fibres.

#### *Properties*

Colours are bright and deep, but light-fastness can vary greatly depending on the dyestuff. Wash-fastness properties are also limited unless the textile is after-treated. Only occasionally are direct dyes used in direct printing processes.

#### *Chemical characteristics and general application conditions*

Direct dyes (also called substantive dyes) can be azo compounds, stilbenes, oxazines, or phtalocyanines. They always contain solubilising groups (mainly sulphonic acid groups, but carboxylic and hydroxyl groups can also be found) that ionise in aqueous solution.

Direct dyes are characterised by long planar molecular structures that allow these molecules to align with the flat cellulose macromolecules, the dye molecules being held in place mainly through Van der Waals forces and hydrogen bonds.

Direct dyes may require the use of the following *chemicals and auxiliaries* for satisfactory dyeing:

- electrolytes, usually sodium chloride or sodium sulphate. Their function is to favour the aggregation of dye ions on the fibre
- wetting and dispersing agents: mixtures of non-ionic and anionic surfactants are used for this aim
- after-treatment agents: they are used to improve wet-fastness properties. So-called fixative cationic agents are the most commonly used. They are usually quaternary ammonium compounds with long hydrocarbon chains. Formaldehyde condensation products with amines, polynuclear aromatic phenols, cyanamide or dicyandiamide may also be used for this purpose.

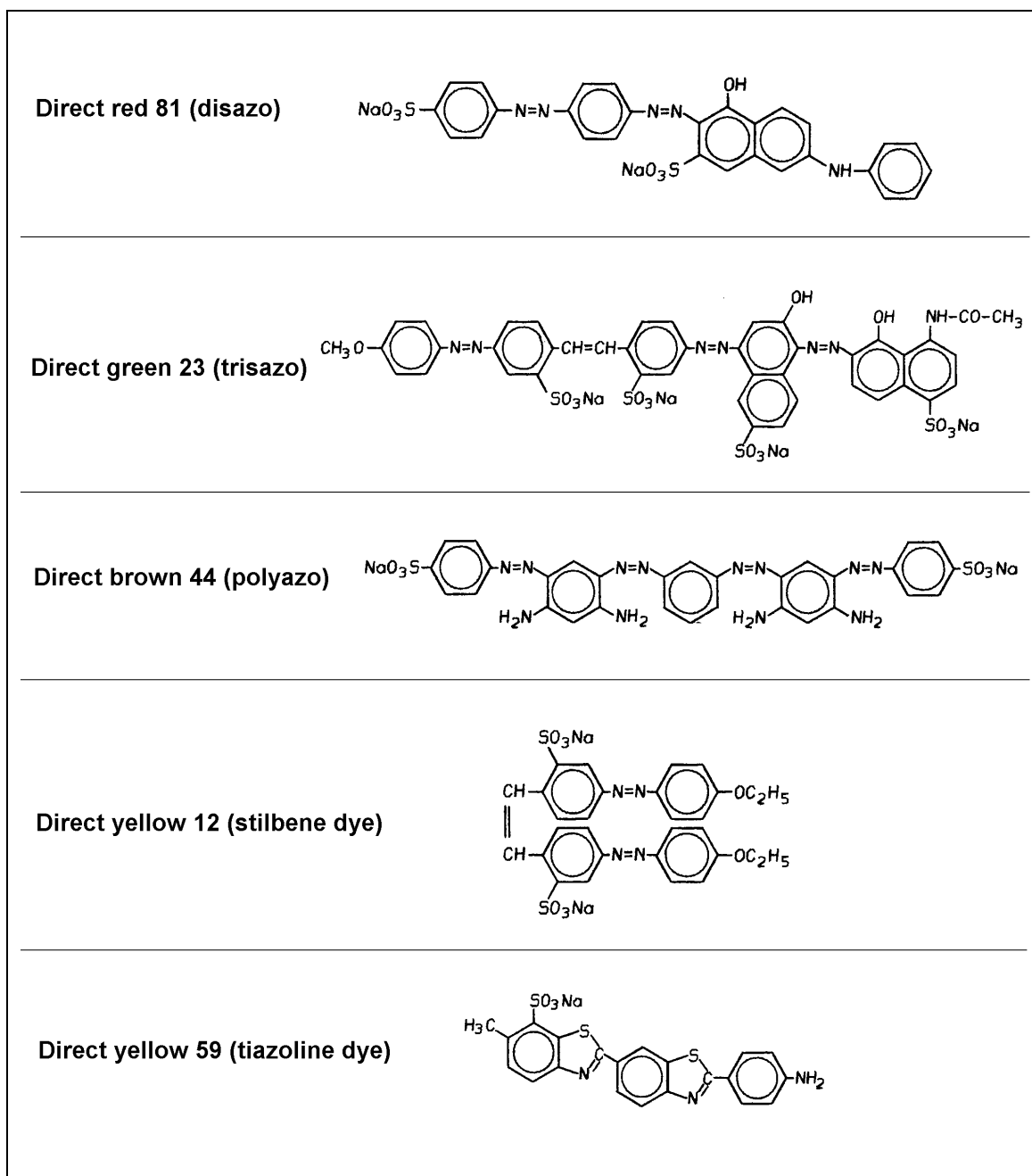


Figure 8.5: Examples of typical direct dyes

*Environmental issues*

The environmental properties of direct dyes are assessed under the following parameters.

**Table 8.12: Overview of the ecological properties of direct dyes**

Parameters of concern	Comments
Bio-eliminability	
Organic halogens (AOX)	
Eco-toxicity	Direct Orange 62 has been classified as toxic by ETAD
Heavy metals	
Aromatic amines	The main emphasis of research for direct dyes was actually on the replacement of possibly carcinogenic benzidine dyes [ 10, Ullmann's 2011 ]
Unfixed colourant	Degree of fixation in batch dyeing processes ranges from 64 - 96 % [ 4, EURATEX 2000 ] (70 - 95 % according to [ 30, US EPA 1996 ])
Effluent contamination by additives in the dye formulation	

## 8.2.4 Disperse dyes

### *Applicability*

Disperse dyes are used mainly for polyester, but also for cellulose (acetate and triacetate), polyamide and acrylic fibres.

### *Properties*

Fastness to light is generally quite good, while fastness to washing is highly dependent on the fibre. In particular, in polyamides and acrylics they are used mostly for pastel shades because in dark shades they have limited build-up properties and poor wash fastness.

### *Chemical characteristics and general application conditions*

Disperse dyes are characterised by the absence of solubilising groups and low molecular weight. From a chemical point of view more than 50 % of disperse dyes are simple azo compounds, about 25 % are anthraquinones and the rest are methine, nitro and naphthoquinone dyes.

The dye-fibre affinity is the result of different types of interactions:

- hydrogen bonds
- dipole-dipole interactions
- Van der Waals forces.

Disperse dyes have hydrogen atoms in their molecule, which are capable of forming hydrogen bonds with oxygen and nitrogen atoms on the fibre.

Dipole-dipole interactions result from the asymmetrical structure of the dye molecules, which makes possible electrostatic interactions between dipoles on the dye molecules and polarised bonds on the fibre.

Van der Waals forces take effect when the molecules of the fibre and colourant are aligned and close to each other. These forces are very important in polyester fibres because they can take effect between the aromatic groups of the fibre and those of the colourant.

Disperse dyes are supplied as powder and liquid products. Powder dyes contain 40 – 60 % of dispersing agents, while in liquid formulations the content of these substances is in the range of



10 – 30 %. Formaldehyde condensation products and ligninsulphonates are widely used for this purpose.

*Dyeing* with disperse dyes may require the use of the following *chemicals and auxiliaries*:

- dispersants: although all disperse dyes already have a high content of dispersants, they are further added to the dyeing liquor and in the final washing step
- carriers: for some fibres, dyeing with disperse dyes at temperatures below 100 °C requires the use of carriers. Because of environmental problems associated with the use of these substances, polyester is preferably dyed under pressure at high temperature (e.g. 130 °C) without carriers. However, carrier dyeing is still important for polyester-wool blends, as wool must not be submitted to wet treatment at temperatures significantly above 100 °C, in this case, chlorine-free and biodegradable carriers are selected.
- thickeners: polyacrylates or alginates are usually added to the dye liquor in padding processes. Their function is to prevent migration of the dye liquor on the surface during drying
- reducing agents (mainly sodium hydrosulphite): they are added in solution with alkali in the final washing step.

Disperse dyes are widely used not only for dyeing, but also for printing synthetic fibres.

#### *Environmental issues*

The environmental properties of disperse dyes are assessed under the following parameters.

**Table 8.13: Overview of the ecological properties of disperse dyes**

Parameters of concern	Comments
Bio-eliminability	Waste water streams containing high loads can be pre-treated. Residual dye is largely eliminated by adsorption on activated sludge owing to the low water solubility
Organic halogens (AOX)	Some disperse dyes contain organically bound halogens; release to the environment is avoided by pre-treatment of waste water and adsorption of residual loads to activated sludge (see also Section 2.7.8.1)
Toxicology	Several disperse dyes are classified as sensitizers
Heavy metals	
Unfixed colourant	Level of fixation is in the range of 88 - 99 % for continuous dyeing and 91 - 99 % for printing
Effluent contamination by additives in the dye formulation	Conventional dispersants (formaldehyde condensation compounds, lignosulphonates, etc.) are poorly biodegradable. Some dyes are formulated with more readily eliminable dispersants. More information is reported in Section 4.5.1.1

## 8.2.5 Metal-complex dyes

### *Applicability*

Metal-complex dyes (also called pre-metallised dyes) have great affinity for protein fibres. Among metal-complex dyes, 1:2 metal-complex dyes are also suitable for polyamide fibres.

### *Properties*

No other class of dyes provides such a generally high level of fastness, particularly lightfastness.

### *Chemical characteristics and general application conditions*

Metal-complex dyes may be broadly divided into two classes, 1:1 metal-complexes, in which one dye molecule is co-ordinated with one metal atom and 1:2 metal complexes, in which one metal atom is co-ordinated with two dye molecules. The dye molecule will be typically a monoazo structure containing additional groups such as hydroxyl, carboxyl or amino groups, which are capable of forming strong co-ordination complexes with transition metal ions, typically chromium (III), cobalt, nickel and copper.

Typical examples of pre-metallised dyes are shown in Figure 8.6 and Figure 8.7.

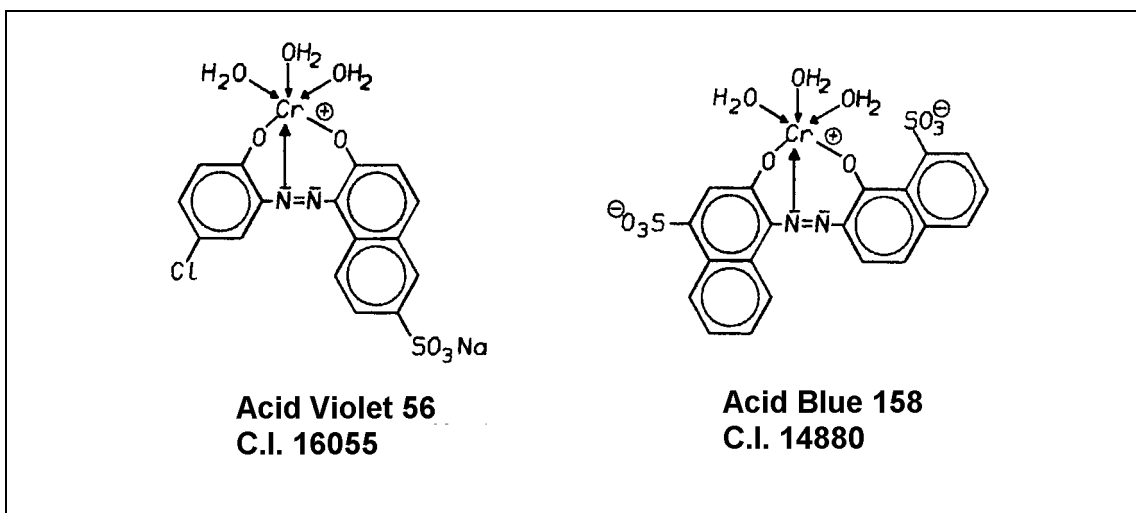
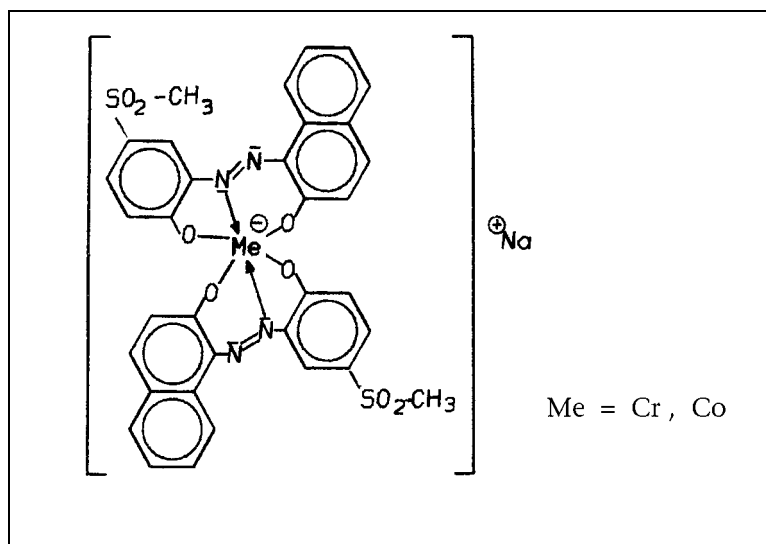


Figure 8.6: Examples of molecular structures typical of 1:1 metal-complex dyes



**Figure 8.7:** Molecular structure typical of 1:2 metal-complex dyes

Metal-complex dyes do not represent a specific application dye class. Metal-complex dyes belong in fact to many application classes of dyes (i.e. they can be found, for example, among acid, direct and reactive dyes). When used in dyeing processes, metal-complex dyes are applied in pH conditions regulated by the user class and the fibre type (wool, polyamide, etc.). The pH levels for wool range from strongly acidic (1.8 - 4 for 1:1 metal-complex dyes) to moderately acidic neutral (4 - 7 for 1:2 metal-complex dyes). For polyamide fibres higher pH conditions are becoming more and more common.

*1:1 metal-complex dyes* exhibit excellent level dyeing and penetration characteristics and have the ability to cover irregularities in the substrate. Their light and wet-fastness properties are good even in deep shades. They are particularly suitable for yarn and for piece dyeing of carbonised wool.

*1:2 metal-complex dyes are used for both wool and polyamide. They form the most important group in this class and may be divided into two sub-groups:*

- weakly polar 1:2 complexes – solubilised by the inherent anionicity of the complex or containing non-ionic, hydrophilic substituents such as methylsulphone ( $-\text{SO}_2\text{CH}_3$ ). These dyes exhibit excellent fastness to light and wet treatments and excellent penetration properties.
- strongly polar 1:2 complexes – solubilised by one or more sulphonic or carboxylic acid residues, these dyes possess lower levelling power than the weakly polar dyes mentioned above but superior wet-fastness properties and are generally suitable for use in those applications where mordant dyes are used. This second group is also more suitable for dyeing polyamide fibres.

*Dyeing with metal-complex dyes may require the use of the following chemicals and auxiliaries:*

- pH regulators: sulphuric, formic, acetic acid
- electrolytes: sodium sulphate, ammonium acetate and sulphate
- levelling agents: mixtures of anionic and non-ionic surfactants (these auxiliaries are not needed when using pH controlled adsorption dyeing techniques).

#### *Environmental issues*

The environmental properties of metal-complex dyes are assessed under the following parameters.

**Table 8.14: Overview of the ecological properties of metal complex dyes**

Parameters of concern	Comments
Bio-eliminability	Great differences from dye to dye (bio-eliminability can be <50 %)
Organic halogens (AOX)	Some products contain organic halogens: AOX in waste water, therefore depends on the eliminability of the dyes concerned (see also Section 2.7.8.1)
Eco-toxicity	
Heavy metals	Metals can be found in the effluent due to unfixed dye and could be removed by pre-treating relevant wastewater streams
Aromatic amines	
Unfixed colourant	Degree of fixation ranges from moderate to excellent (from 85 to 98 % and greater in some cases)
Effluent contamination by additives in the dye formulation	Inorganic salts are present in the preparation of powder dyes

## 8.2.6 Mordant dyes (chrome dyes)

### *Applicability*

Mordant dyestuffs are generally used for protein (wool).

### *Properties*

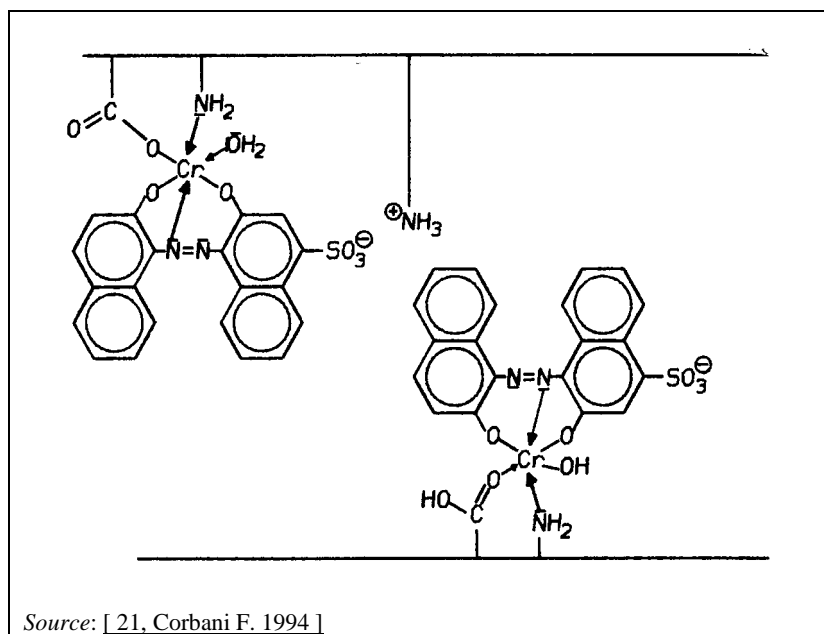
Thanks to their good levelling properties and very good wet-fastness after chroming, chrome dyes are used principally to obtain dark shades (greens, blues and blacks) at moderate cost. There are disadvantages, however, in their use: long dyeing times, difficulties with shading, the risk of chemical damage to the fibre during chroming and the potential release of chromium in waste water. Because of the (eco)toxicological properties of Cr(VI) salts, sodium dichromate is subject to authorisation under REACH. It has been authorised for repackaging and subsequent use as a mordant in the dyeing of wool.

### *Chemical characteristics and general application conditions*

The *Colour Index* classifies these colourants as mordant dyes, but chromium has become the almost universally used mordant and the class is commonly referred to as chrome dyes.

From a chemical point of view they can be regarded as acid dyestuffs that contain suitable functional groups capable of forming metal complexes with chrome. They do not contain chromium in their molecule, which instead is added as dichromate to allow dye fixation.

Interaction with the fibre is established through ionic bonds formed between the anionic groups of the colourant and ammonium cations available on the fibre. In addition chromium acts as a link between dye and fibre. This gives rise to a very strong bond, which is reflected in excellent fastness. Figure 8.8 shows the ionic and coordination bonds in the case of wool.



**Figure 8.8:** Representation of possible ionic and coordination bonds between wool and chrome dyes

The use of chrome dyes in *dyeing* processes requires the use of the following chemicals and auxiliaries:

- potassium and sodium dichromate or chromate
- formic or acetic acid as pH regulators
- other organic acids such as tartaric and lactic acid. They are used to enhance the degree of conversion of Cr VI to Cr III
- sodium or ammonium sulphate.

#### *Environmental issues*

The environmental properties of chrome dyes are assessed under the following parameters.

**Table 8.15:** Overview of the ecological properties of chrome dyes

Parameters of concern	Comments
Bio-eliminability	
Organic halogens (AOX)	
Eco-toxicity	
Heavy metals	Special care must be taken to avoid releases of Cr(VI) from mordant use.
Aromatic amines	
Unfixed colourant	
Effluent contamination by additives in the dye formulation	

### 8.2.7 Naphthol dyes (azoic dyes developed on the fibre)

#### *Applicability*

Azoic dyes, also known as naphthol dyes, are used for cellulosic fibres (particularly cotton), but may also be applied to viscose, cellulose acetate, linen and sometimes polyester. As opposed to

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all other types of dyes, the chromophore of the dye is synthesised in situ, on the fibre, from two components reacting covalently with each other.

### *Properties*

Azoic dyes have excellent wet-fastness properties as well as good light, chlorine and alkali fastness, while rubbing fastness is poor.

### *Chemical characteristics and general application conditions*

From a chemical point of view naphthol dyes are very similar to azo dyes, the main difference being the absence of sulphonic solubilising groups.

They consist of two chemically reactive compounds that are applied to the fabric in a two-stage process. The insoluble dye is synthesised directly in the fibre as the result of the coupling reaction between a diazotised base (developing agent) and a coupling component.

The coupling components are usually derivatives of the anilides of 2-hydroxy-3-naphthoic acid (also called naphthol AS). These naphthols are available in powder form or in liquid form (in this case the solution also contains caustic soda, the naphthol concentration ranges between 30 % and 60 %).

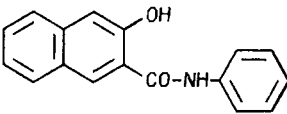
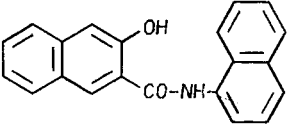
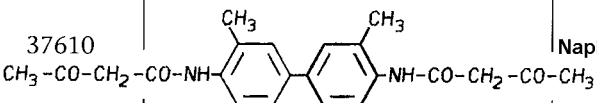
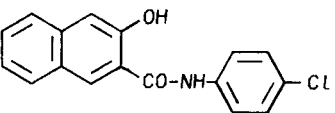
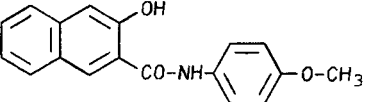
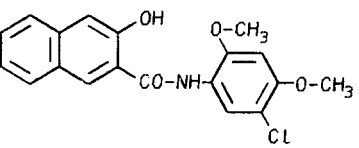
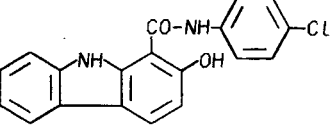
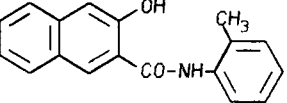
Colour Index III ed.		Formula	Name of the commercial product
Coupling component n°	Chemical composition n°		
2	37505		Naphthol AS (P,L)
4	37560		Naphthol AS-BO (P,L)
5	37610	$CH_3-CO-CH_2-CO-NH$  $-NH-CO-CH_2-CO-CH_3$	Naphthol AS-G (P)
10	37510		Naphthol AS-E (P)
11	37535		Naphthol AS-RL (P)
12	37550		Naphthol AS-ITR (P,L)
15	37600		Naphthol AS-LB (P,L)
18	37520		Naphthol AS-D (P,L)

Figure 8.9: Examples of typical coupling components for naphthol dyes

Developing agents can be derivatives of aniline, toluidine, orto and meta anisidine, diphenyl amine. They are available as:

- free bases (fast colour bases)
- liquid bases (these formulations are aqueous dispersions of the aromatic amines, they are safer and simpler to apply than solid bases)
- fast colour salts (these are already diazotised diazonium compounds that are marketed in stabilised forms and do not need to be diazotised before use in dyeing: some examples are given in the figure below).

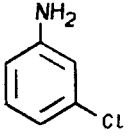
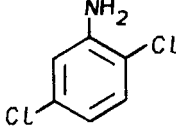
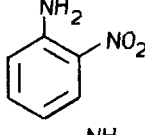
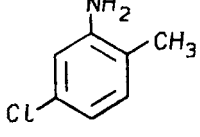
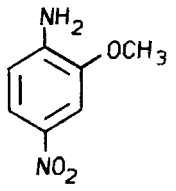
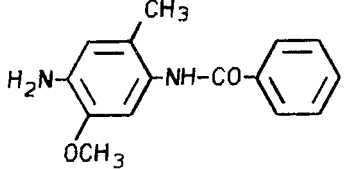
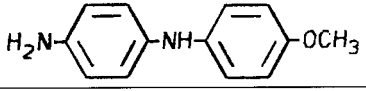
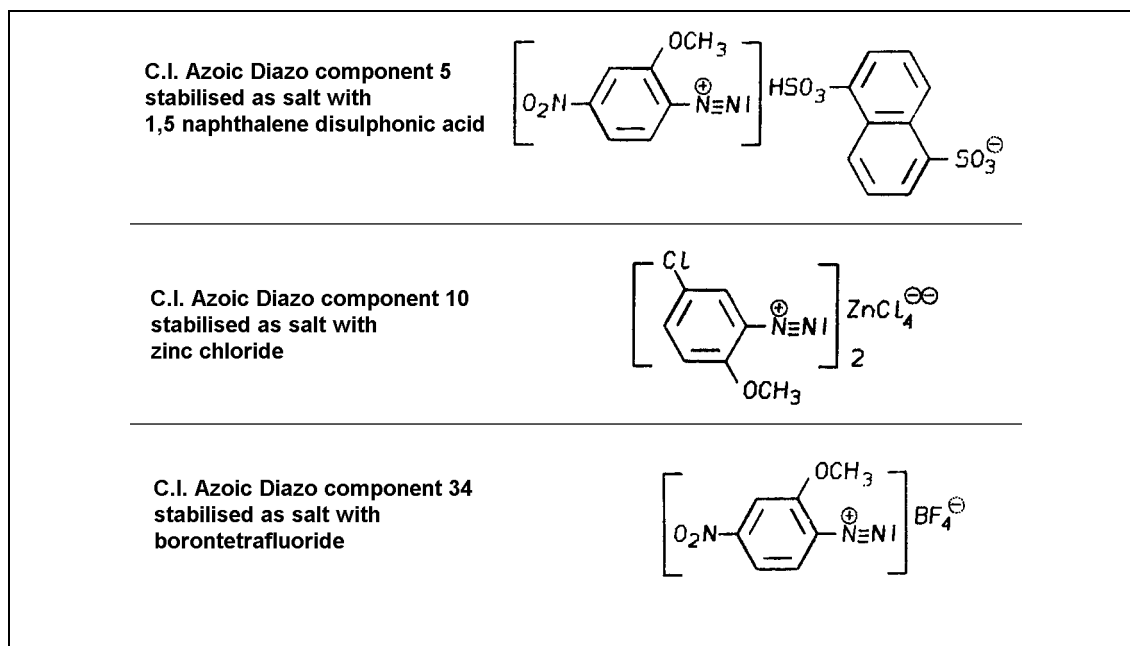
Colour Index		Formula
Diazo component n°	Chemical composition n°	
2	37005	
3	37010	
6	37025	
32	37090	
5	37125	
41	37165	
35	37255	

Figure 8.10: Examples of typical developing agents (fast colour base) for naphthol dyes





**Figure 8.11: Examples of typical fast colour salts**

Application of azoic colourants involves a number of steps:

- preparation of the naphtholate solution: naphthol is converted to the naphtholate form to be able to couple with the diazonium salt
- application of the naphtholate to the fibre
- preparation of the diazotised base: in order to make the coupling reaction possible, the base must first be diazotised in the cold, using sodium nitrite and hydrochloric acid (this step can be avoided when using fast colour salts)
- formation of the azoic dye into the fibre.

#### *Environmental issues*

The environmental properties of naphthol dyes are assessed under the following parameters.

**Table 8.16: Overview of the ecological properties of naphthol dyes**

Parameters of concern	Comments
Bio-eliminability	
Organic halogens (AOX)	
Eco-toxicity	
Heavy metals	
Aromatic amines	Developing agents may be diazotisable amines or diamines or substituted anilines, toluidines, anisidines, azobenzenes or diphenylamines.
Unfixed colourant	Degree of fixation in continuous dyeing processes ranges between 76 and 89 % and between 80 and 91 % in printing processes [4, EURATEX 2000.]
Effluent contamination by dispersants and additives in the dye	

## 8.2.8 Reactive dyes

### *Applicability*

Reactive dyes are mainly used for dyeing cellulose fibres such as cotton and viscose, but they are also increasingly gaining importance for wool and polyamide.

### *Properties*

They provide high wet-fastness (better than the less expensive direct dyes), but their use is not always viable because of the difficulty in obtaining level dyeing. Chlorine fastness is slightly poorer than that of vat dyes, as is lightfastness under severe conditions.

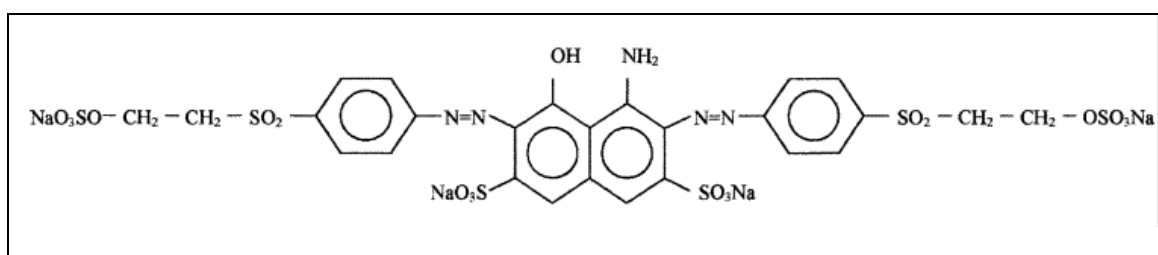
The range of available reactive dyes is wide and enables a large number of dyeing techniques to be used.

### *Chemical characteristics*

Reactive dyes are unique in that they contain specific chemical groups capable of forming covalent links with the textile substrate.

The energy required to break this bond is similar to that required to degrade the substrate itself, thus accounting for the high wet-fastness of these dyes.

The structure of Reactive Black 5, one of the most important reactive dyestuffs in terms of volumes consumed, is illustrated in Figure 8.12.



**Figure 8.12: Reactive Black 5**

Chemical structure of reactive dyes can be schematically represented by the following formula: Col-B-R, where:

- Col is the chromophore that is in general constituted by monoazoic, anthraquinone, phthalocyanine and metal-complex compounds
- B is the linking group between the chromophore and the reactive group
- R represents the reactive group (anchor system with the leaving group). The anchor systems are characterised by their reactivity. Based on this, they are classified as hot, warm or cold dyers.

Some typical examples of reactive systems for cellulose and wool or polyamide fibres are reported in the following tables.

Table 8.17: Typical anchor systems for cellulose fibres

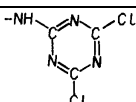
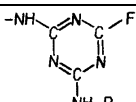
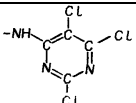
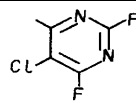
Anchor system	Denomination	Commercial name
	Dichloro-s-triazine (cold dyer)	Procion MX
	Amino-fluoro-s-triazine (warm dyer)	Cibacron F
	Trichloro-pyrimidine (hot dyer)	Cibacron T-E Dimaren X, Z
-SO <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -O-SO <sub>3</sub> Na	Beta-sulphate-ethyl-sulphone (warm dyer)	Remazol

Table 8.18: Typical anchor systems for wool and polyamide fibres

Anchor system	Denomination	Commercial name
	2,4-difluoro 5-chloro pyrimidine	Verofix Drimalan F
-SO <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -O-SO <sub>3</sub> Na	Beta-sulphate-ethyl-sulphone	Remazolan
-SO <sub>2</sub> -NH-CH <sub>2</sub> -CH <sub>2</sub> -O-SO <sub>3</sub> H	Sulphate-ethyl sulphonamide	Levafix
-NHCO-CBr=CH <sub>2</sub>	Bromoacrylamide	Lanasol

The reactive groups of the colourant react with the amino groups of the fibre in the case of protein and polyamide fibres, and with the hydroxyl groups in the case of cellulose.

In both cases, depending on the anchor system, two reaction mechanisms are possible: a nucleophilic substitution mechanism or a nucleophilic addition mechanism.

An important issue to consider when dealing with reactive dyes is the fact that two competing reactions are always involved in the colouring process:

1. alcoholysis: dye + fibre → dye fixed on the fibre
2. hydrolysis: dye + water → hydrolysed dye washed away after dyeing (undesired reaction)

This fact has important consequences, especially in the case of cellulose fibres. In fact, the alkaline conditions in which reactive dyes react with cellulose fibres, increase the rate of the hydrolysis reaction. The characteristics of the resulting hydrolysed dye are such that the dye is no longer a reactive substance and it is therefore discharged in the effluent.

*Dyeing cellulose fibres* with reactive dyes may imply the use of the following *chemicals* and *auxiliaries*:

- alkali (sodium carbonate, bicarbonate and caustic soda)
- salt (mainly sodium chloride and sulphate)
- urea may be added to the padding liquor in continuous processes in the one-bath method (see also Section 4.5.2.6 for alternative techniques)
- sodium silicate may be added in the cold pad-batch method (see also Section 4.5.2.2).

Reactive dyes are applied to wool or polyamide fibres under different conditions. In the case of *wool and polyamide fibres*, reactivity of the amino groups is considerably higher than that of hydroxyl groups in cellulose.

Levelling properties are often achieved with the use of speciality amphoteric levelling agents.

Reactive dyes are generally applied at pH values of between 4.5 and 7, depending on depth of shade, in the presence of ammonium sulphate and the specialised levelling agents mentioned above.

In *cellulose printing*, moderately reactive dyes are generally employed (mainly mochlorotriazine systems). Highly reactive sulphoethyl sulphones are also sometimes used.

Printing with reactive dyes requires the use of:

- thickening agents (mainly polyacrylates in combination with alginates)
- urea
- alkali (e.g. sodium carbonate and bicarbonate)
- oxidising agents (mainly benzenesulphonic acid derivatives): they are used to prevent reduction of more sensitive dyes during steaming.

#### *Environmental issues*

Poor dye fixation has been a long-standing problem with reactive dyes in particular in batch dyeing of cellulose fibres, where a significant amount of salt is normally added to improve dye exhaustion (and therefore also dye fixation). On the other hand, shade reproducibility and level dyeing were the major obstacle in “right-first-time” production using the most efficient dyes (high exhaustion and fixation rate).

With the use of sophisticated molecular engineering techniques it has been possible to design reactive dyes (e.g. bifunctional dyes and low-salt reactive dyes) with considerably higher performances than traditional reactive dyes. These recent developments are described in more detail in Sections 4.5.2.2, 4.5.2.4 and 4.5.2.6.

The environmental properties of reactive dyes are assessed in Table 8.19. Note that the table does not consider the environmental issues related to chemicals (e.g. salt) and auxiliaries employed in the dyeing process because these issues are dealt with in a specific annex.

**Table 8.19: Overview of the ecological properties of reactive dyes**

Parameters of concern	Comments
Bio-eliminability	Because both unfixed reactive dye and its hydrolysed form are readily soluble they are difficult to eliminate in biological waste water treatment plants. Spent dye baths can be segregated and pre-treated.
Organic halogens (AOX)	Many reactive dyes contain organic halogens as leaving groups (i.e. halogens bonded to the anchor group) (see Section 2.7.8.1 for more detailed discussion).
Eco-toxicity	
Heavy metals	Heavy metals can be present both as impurities from the production process (limits have been set by ETAD) and as an integral part of the chromophore especially in phthalocyanine dyes, which are widely used especially for blue and turquoise shades (see also Section 2.7.8.1)
Aromatic amines	

Unfixed colourant	Fixation rate can be poor <sup>(1)</sup> (see also discussion in Section 2.7.8). Efforts have been made to increase the level of fixation. Some reactive dyes can reach >95 % of fixation even for cellulosic fibres (see Sections 4.5.2.2 and 4.5.2.5 for recent developments)
Notes: <sup>(1)</sup> [ 4, EURATEX 2000 ] Fixation degree for: - cotton batch dyeing: 55 - 80 % - wool batch dyeing: 90 - 97 % - printing (general): 60 %	

## 8.2.9 Sulphur dyes

### *Applicability*

Sulphur dyes are mainly used for cotton and viscose substrates. They may also be used for dyeing blends of cellulose and synthetic fibres, including polyamides and polyesters. They are occasionally used for dyeing silk. Apart from black shades, sulphur dyes play almost no part in textile printing.

### *Properties*

Bleach and wash fastness properties are very good, while lightfastness varies from moderate to good. Although they encompass a broad shade range, sulphur dyes are mostly used for dark shades because lighter shades have poor resistance to light and laundering. Sulphur dyes tend to be dull compared with other dye classes.

### *Chemical characteristics and general application conditions*

Sulphur dyes are made up of high molecular weight compounds, obtained by reaction of sulphur or sulphides with amines and phenols. Many colourants exist that contain sulphur in their molecule, but only dyestuffs which become soluble in water after reaction with sodium sulphide under alkaline conditions can be called sulphur dyes.

The exact chemical structure is not always known because these are mixtures of molecules of a high level of complexity. Amino derivatives, nitrobenzenes, nitro and aminobiphenyls, substituted phenols, substituted naphthalenes, condensed aromatic compounds, indophenols, azines, oxazine, thiazol, azine and thiazine rings can be part of these compounds. Sulphur dyes contain sulphur both as an integral part of the chromophore and in polysulphide side chains.

As has already been mentioned, sulphur dyes are insoluble in water, but after reduction under alkaline conditions they are converted into the leuco-form, which is water-soluble and has high affinity for the fibre. After absorption into the fibre they are oxidised and converted back to the original insoluble state.

Sulphur dyes are available in various modifications, which are classified under the following names:

- sulphur dyes - available as amorphous powders or dispersible pigments. Amorphous powders are insoluble or partially soluble in water and are brought into solution by boiling with sodium sulphide and water. Dispersible pigments can be used in this form for pad dyeing in presence of a dispersing agent. They can contain a certain amount of reducing agent already in the formulation and in this case are called "partly reduced pigments".
- leuco-sulphur dyes (ready-for-use dyes) - available in liquid form and already contain the reducing agent required for dyeing. Therefore they must simply be diluted with water before application. Low-sulphide types are also available on the market

- water-soluble sulphur dyes - available in the form of Bunte salts (Col-S-SO<sub>3</sub>Na) obtained by treating the dye in its insoluble form (Col-S-S-Col) with sodium hydrosulphite. They can be dissolved in hot water, but they do not have affinity for the fibre. The addition of alkali and reducing agent makes them substantive for the fibre.

Sodium sulphide and sodium hydrogensulphide are generally employed as reducing agents solubilise the dye (unless ready-for-use sulphur dyes are applied). Binary systems made of glucose and sodium dithionite (hydrosulphite) or thiourea dioxide are also used as alternative reducing agents.

In all processes the dye is finally fixed on the substrate by oxidation. Nowadays, hydrogen peroxide or halogen-containing compounds such as bromate, iodate and chlorite are the most commonly used oxidising agents.

Apart from the above-mentioned reducing and oxidising agents, additional chemicals and auxiliaries required when dyeing with sulphur dyes are:

- alkali (mainly caustic soda)
- salt (sodium chloride and sulphate)
- dispersing agents: usually they are naphthalenesulphonic acid-formaldehyde condensates, ligninsulphonates and sulphonated
- oils complexing agents

#### *Environmental issues*

The environmental properties of sulphur dyes are assessed under the following parameters. Note, however, that Table 8.20 does not consider the environmental issues related to chemicals and auxiliaries employed in the dyeing process because these issues are dealt with in a specific annex.

**Table 8.20: Overview of the ecological properties of sulphur dyes**

Parameters of concern	Comments
Bio-eliminability	Spent dye baths can be segregated and pre-treated. Most sulphur dyes are water-insoluble after oxidation; residues in rinsing waters can be largely be eliminated by adsorption on the activated sludge in the waste water treatment plant
Organic halogens (AOX)	
Eco-toxicity	
Heavy metals	
Aromatic amines	
Unfixed colourant	Degree of fixation ranges between 60 and 90 % in continuous dyeing and 65 - 95 % in printing [ <a href="#">4</a> , <a href="#">EURATEX 2000</a> ]; spent dye baths and printing pastes can be pre-treated appropriately
Effluent contamination by additives in the dye formulation	Poorly biodegradable dispersants are present. New formaldehyde condensation products with higher elimination (>70 %) are already available (see Section 4.5.1.1)

## 8.2.10 Vat dyes

### Applicability

Vat dyes are used most often in dyeing and printing of cotton and cellulose fibres. They can also be applied for dyeing polyamide and polyester blends with cellulose fibres.

### Properties

Vat dyes have excellent fastness properties when properly selected and are often used for fabrics that will be subjected to severe washing and bleaching conditions (towelling, industrial and military uniforms, etc.). The range of colours is wide, but shades are generally dull.

### Chemical characteristics and general application conditions

From a chemical point of view, vat dyes can be distinguished into two groups: indigoid vat dyes and anthraquinoid dyes. Indigo dyes are almost exclusively used for dyeing warp yarn in the production of blue denim.

Like sulphur dyes, vat dyes are normally insoluble in water, but they become water-soluble and substantive for the fibre after reduction in alkaline conditions (vatting). They are then converted again to the original insoluble form by oxidation and in this way they remain fixed into the fibre.

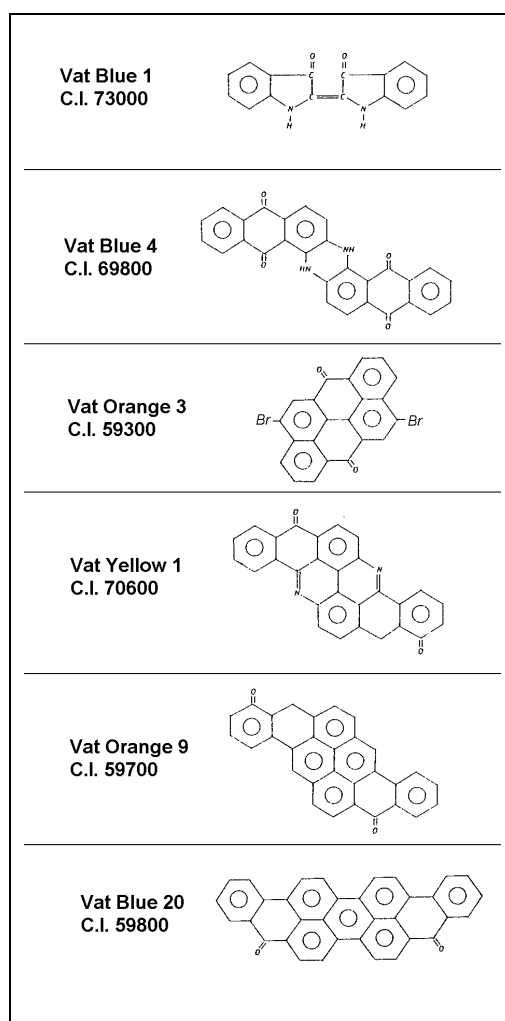


Figure 8.13: Examples of typical vat dyes

Vat dyes are preparations that consist of a vatable coloured pigment and a dispersing agent (mainly formaldehyde condensation products and ligninsulphonates). They are generally supplied in powder, granules and paste form.

A wide range of different techniques are used in colouring processes with vat dyes. Nevertheless, all processes involve three steps:

- vatting
- oxidation
- after-treatment.

The step in which the reduction of the dyestuff into its leuco-form takes place is called *vatting*. Vat dyes are generally more difficult to reduce than sulphur dyes. Various reducing agents are used. Sodium dithionite (hydrosulphite) is still the most widely employed although it has some limits. Sodium dithionite is consumed by reduction of the dye and also by reaction with atmospheric oxygen, therefore an excess of reducing agent has to be used and various techniques have been proposed to reduce these losses (see also Section 4.5.2.1). In addition sodium dithionite cannot be used for high temperature or pad-steam dyeing processes because over-reduction can occur with sensitive dyes. In these application conditions and also for printing, sulphonylic acid derivatives are normally preferred.

Thiourea dioxide is also sometimes used as a reducing agent, but a risk of over-reduction exists as its reduction potential is much higher than that of hydrosulphite. Furthermore the oxidation products of thiourea dioxide contribute to nitrogen and sulphur contamination of waste water.

Following increasing environmental pressures, biodegradable sulphur-free organic reducing agents such as hydroxyacetone are now available. Their reducing effect, however, is weaker than that of hydrosulphite, so they cannot replace it in all applications. Nevertheless hydroxyacetone can be used in combination with hydrosulphite, thus reducing to a certain extent the sulphite load in the effluent.

After absorption by the fibre, the dye in its soluble leuco-form is converted to the original pigment by *oxidation*. This process is carried out in the course of wet treatment (washing) by addition of oxidants such as hydrogen peroxide, perborate or 3-nitrobenzenesulphonic acid to the liquor.

The final step consists in *after-treating* the material in weakly alkaline liquor with a detergent at boiling temperature. This soap treatment is not only aimed at removing pigment particles, but also allows the crystallisation of amorphous dye particles, which gives the material the final shade and the fastness properties typical of vat dyes.

Vat dyeing conditions can vary widely in terms of temperature and the amount of salt and alkali required, depending on the nature of the dye applied. Vat dyes are therefore divided into the following groups, according to their affinity for the fibre and the amount of alkali required for dyeing:

- IK dyes (I = Indanthren, K = cold) have low affinity, they are dyed at 20 – 30 °C and require little alkali and salt to increase dye absorption
- IW dyes (W = warm) have higher affinity, they are dyed at 40 – 45 °C with more alkali and little or no salt
- IN dyes (N = normal) are highly substantive and applied at 60 °C and require much alkali, but no addition of salt.

The following *chemicals and auxiliaries* may be found in *dyeing* processes:

- sodium dithionite, thiourea dioxide and sulphonylic acid derivatives as reducing agents
- caustic soda
- sodium sulphate
- polyacrylates and alginates as anti-migration agents in padding processes



- formaldehyde condensation products with naphthalenesulphonic acid and ligninsulphonates as dispersing agents
- surfactants (including ethoxylated fatty amines) and other components such as betaines, polyalkylenamines, polyvinylpyrrolidone as levelling agents
- hydrogen peroxide, perborate, 3-nitrobenzenesulphonic acid as oxidants
- soap.

The following *chemicals and auxiliaries* may be found in *printing* processes:

- thickening agents (starch esters with seed flour derivatives)
- reducing agents: various chemicals are used depending on the printing method (all-in or two-phase process), dye selected and steaming conditions. Sulphoxylic acid derivatives are the most common, but hydrosulphite can also be used (in the two-phase process when very short steaming time is required)
- alkali: potassium carbonate, sodium carbonate, sodium hydroxide
- oxidising agents (the same used for dyeing)
- soap.

### *Environmental issues*

The environmental properties of vat dyes are assessed under the following parameters.

**Table 8.21: Overview of the ecological properties of vat dyes**

Parameters of concern	Comments
Bio-eliminability	Spent dye bats can be segregated and pre-treated. Vat dyes can be regarded as highly eliminable due to the fact that they are water-insoluble and therefore largely adsorbed on the activated sludge in the waste water treatment plant.
Organic halogens (AOX)	
Eco-toxicity	Since they are sparingly soluble they are not bio-available [ 33, BASF 1994 ]
Heavy metals	Vat dyes contain heavy metal impurities (Cu, Fe, Mn, Ba and Pb) due to their production process
Aromatic amines	
Unfixed colourant	Vat dyes show high exhaustion levels (70 - 95 % in continuous dyeing processes and 70 - 80 % in printing)
Effluent contamination by additives in the dye formulation	Dispersants are present in the dye formulation. As they are water-soluble and poorly degradable, their release can be reduced by pre-treatment of segregated waste water streams. (see Section 4.5.1.1)

## 8.2.11 Pigments

Pigments are widely used in printing processes (pigment printing).

Pigments are insoluble in water and organic solvents. Pigments can be subdivided in the following groups:

- Organic pigments are mostly derived from benzoids.
- Inorganic pigments are mostly metallic oxides such as iron oxide and titanium dioxide.
- Copper phthalocyanines are widely used for blue and green shades.

- Special effect pigments are generally aluminium flakes and variously coated silica platelets.
- Calcium carbonate and barium sulphate may be used as extender pigments.

## 8.3 Wet Processes: Machinery and Techniques

### 8.3.1 Loose fibre

#### 8.3.1.1 Autoclave

Various types of machines are used for processing fibres in loose form. These include conical pan machines, pear-shaped machines and radial flow machines. They are used for all wet operations, that is, pretreatment, dyeing, application of finishing agents and washing.

In conical pan machines (Figure 8.14) the fibre is packed into a removable fibre carrier, which is located onto a central spigot in the base of the vessel. Liquor circulation is provided, via this connection, by an external pump. Associated pipework allows liquor to be circulated either from the base of the pack or from the top.

Pear-shaped machines have a removable perforated base plate through which liquor is circulated via an impeller, returning to the dyeing vessel via a weir. Fibre is loaded directly into these machines and a further perforated plate is positioned on top. Liquor circulation packs the fibre into the base of the machine between the two plates. To unload the machine both plates are removed by crane and the fibre manually removed.

Radial flow machines are characterised by a fibre carrier, equipped with a central perforated column from which liquor flows across the pack to the perforated walls of the carrier.

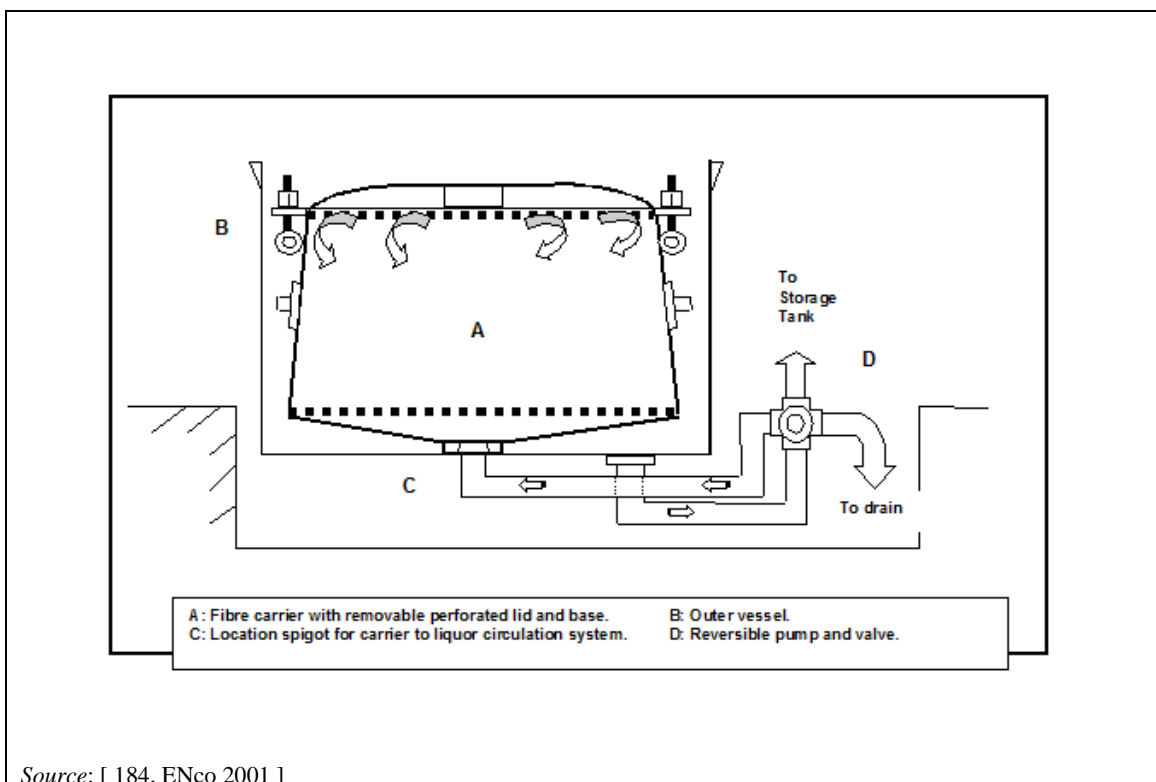
Loose fibre is typically packed into these machines manually. Capacity varies between 200 - 300 kg, with a working volume equivalent to between 7 and 10 litres per kg fibre. The low packing density in these machines allows liquor to circulate freely through the fibre pack at modest pressures, thus minimising mechanical damage to the fibre while ensuring level dyeing.

The bath is heated by closed steam coils in the base of the machine. In many cases the level of automation on these machines is low and temperature may be controlled manually with a simple steam valve. In other cases electro/pneumatic programmers or logic controllers may be installed to regulate time / temperature and to control the direction of liquor circulation.

Autoclaves can be equipped for operation at higher pressure (this is not the case when they are used for dyeing wool fibres).

Autoclaves of all designs may be fitted with an external holding tank, capable of accommodating at least the volume of the dyeing vessel. Such tanks are used to facilitate reuse of liquors in more than one dyeing. Occasionally more than one dyeing vessel may be connected to a common tank, allowing liquor to be shared between vessels.

The liquor ratio for loose fibre can vary between 1:4 to 1:12, depending on the type of machine, level of loading, type of fibre [184, ENco 2001].



**Figure 8.14: Schematic layout of a conical pan loose fibre dyeing machine**

## 8.3.2 Yarn

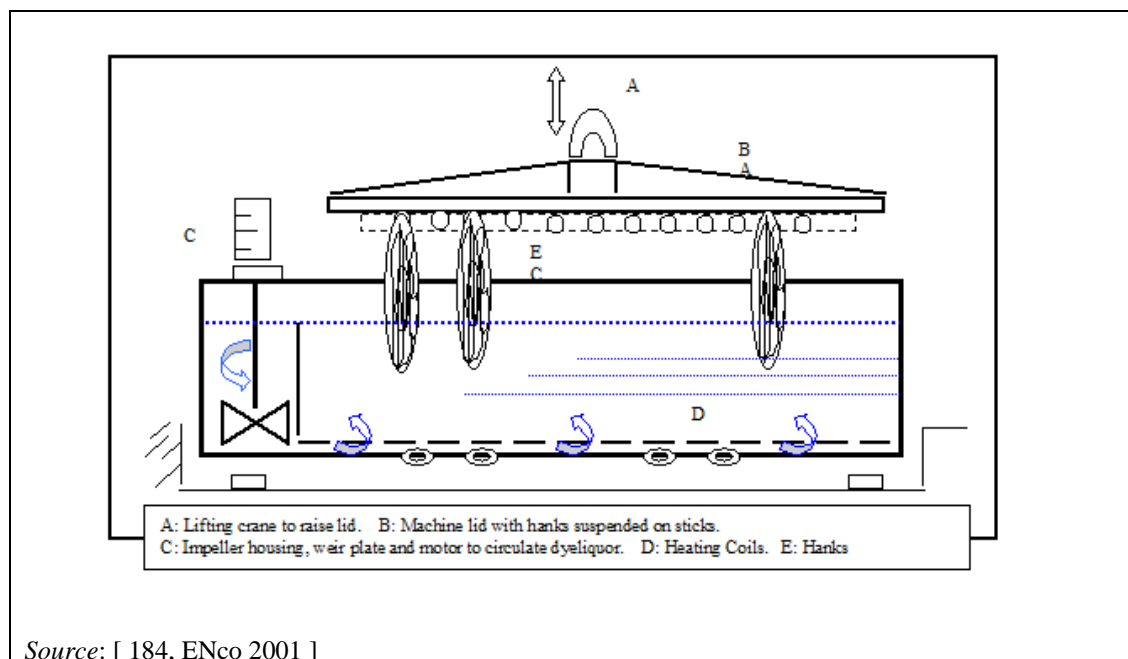
Yarn can be processed either in hank form or in package. Different machines are used depending on the method chosen. They are used for all wet operations, that is, pretreatment, dyeing, application of finishing agents and washing.

### 8.3.2.1 Hank dyeing machines

Hank dyeing machines are mostly of the single stick (Husson) design, in which hanks are hung from the underside of the dyeing vessel lid on removable sticks. (Figure 8.15) The lid is lowered vertically onto the dyeing vessel, which consists of a simple box with a perforated false bottom. Liquor is circulated by a reversible impeller, located vertically in a weir chamber at one end of the machine. Heating is typically by closed steam coils beneath the false bottom and on smaller machines by live steam injection. Temperature control is provided by electro-mechanical or programmable logic controllers. These devices may also control/time the timing of chemical and dye additions and any required cooling cycles. Machine capacities vary from 10 kg sample machines to 1000 kg machines. These larger machines may be coupled together in pairs with interconnecting pipework in such a way that yarn loads of up to 4000 kg can be dyed while still retaining the flexibility to dye individual 1000 kg lots.

Variations of this design may utilise a horizontal circulation impeller passing through a sealing gland at the base of the weir chamber. Such machines invariably have a concave bottom, which is said to improve circulation and reduce fibre to liquor ratio by a small margin [ 184, ENco 2001 ].

Liquor ratios from 1:15 to 1:25 are typical for these machines.



**Figure 8.15: Schematic diagram of a Hussong type hank dyeing machine**

### 8.3.2.2 Package dyeing machines

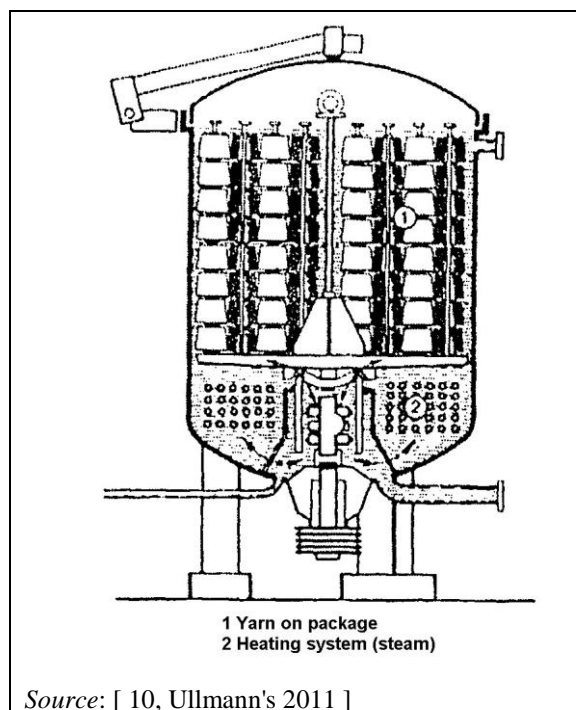
Three basic types of machine may be used for package dyeing wool yarns: horizontal or vertical spindle machines or tube type machines.

**Horizontal spindle machines** may be rectangular in design, similar to hank dyeing machines, but modified to take frames, onto which yarn packages are inserted horizontally, or alternatively may be a horizontal autoclave into which is wheeled the carrier containing the yarn packages. Both types operate with high flow rate pumps, which are necessary to give good circulation of the dye liquor. These machines are usually used for bulky yarns, which are wound onto soft packages, again to increase dye liquor penetration.

**Vertical spindle machines** are the most commonly used (see Figure 8.16). The packages may be press packed onto vertical carrier spindles to increase payload, assist in dye liquor circulation and minimise liquor to fibre ratio.

**Tube type machines** consist of a number of vertical or horizontal tubes into which package carriers are inserted, the tubes forming individual dyeing vessels linked by common pipework and circulation pumps. These machines are more flexible than the above types because individual tubes can be blanked off to vary the overall load capacity of the machine.

Liquor ratios employed in package dyeing are close to 1:12 (typically from 1:8 to 1:15). Machines with capacities of up to 500 kg are used in dyeing carpet yarns, with the facility to link two or more machine together when dyeing larger single batches [ 184, ENco 2001 ].



**Figure 8.16: Schematic layout of a package dyeing machine**

### 8.3.3 Fabric in rope form

Wet treatments on fabrics in rope form can be carried out both in batch and in continuous processes.

#### 8.3.3.1 Batch processes

##### 8.3.3.1.1 Winch beck

The common element in all winch beck machines is the winch mechanism used to move the fabric. The winch draws the fabric via a guide roller out of the bath and returns it in folds into the bath. In the conventional winch beck (see Figure 8.17), the bath stands still, while the fabric is kept in circulation by a reel positioned in the upper part of the machine. In modern winches both the bath and the fabric are kept in circulation, which improves homogenisation and exchange of the liquor with the fabric.

Greige goods are loaded into the winch either in rope form or in open width, which means that the winches must be 5 - 6 meters in width. The ends of the fabric piece to be dyed are sewn together to form endless loops over the rotating boom (winch).

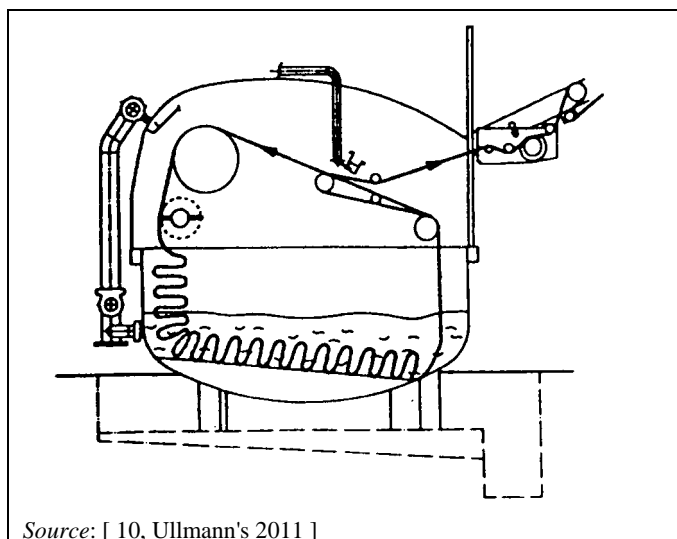
Winch becks are primarily machines for dyeing, but for practical reasons both preparation and dyeing are normally carried out in the same machine.

These machines are essentially operated at atmospheric pressure although the development of synthetic fibres has led to the production of pressurised machines (HT machines may reach 130 – 140 °C).

Winch beck is a very versatile machine and it can be used for all types of fabric. It is a very common technique for dyeing carpets (they are usually dyed in full width).

Typical bath ratios vary from 1:15 to 1:40 (typically 1:30 in the carpet sector) [ 28, GuT 2001 ], which makes this technique fairly expensive due to high water and energy consumption.

However, recent technological developments have been made to improve its environmental performance (see Section 4.5.1.7.1)



Source: [ 10, Ullmann's 2011 ]

**Figure 8.17: Schematic representation of a winch beck dyeing machine**

#### 8.3.3.1.2 Jet

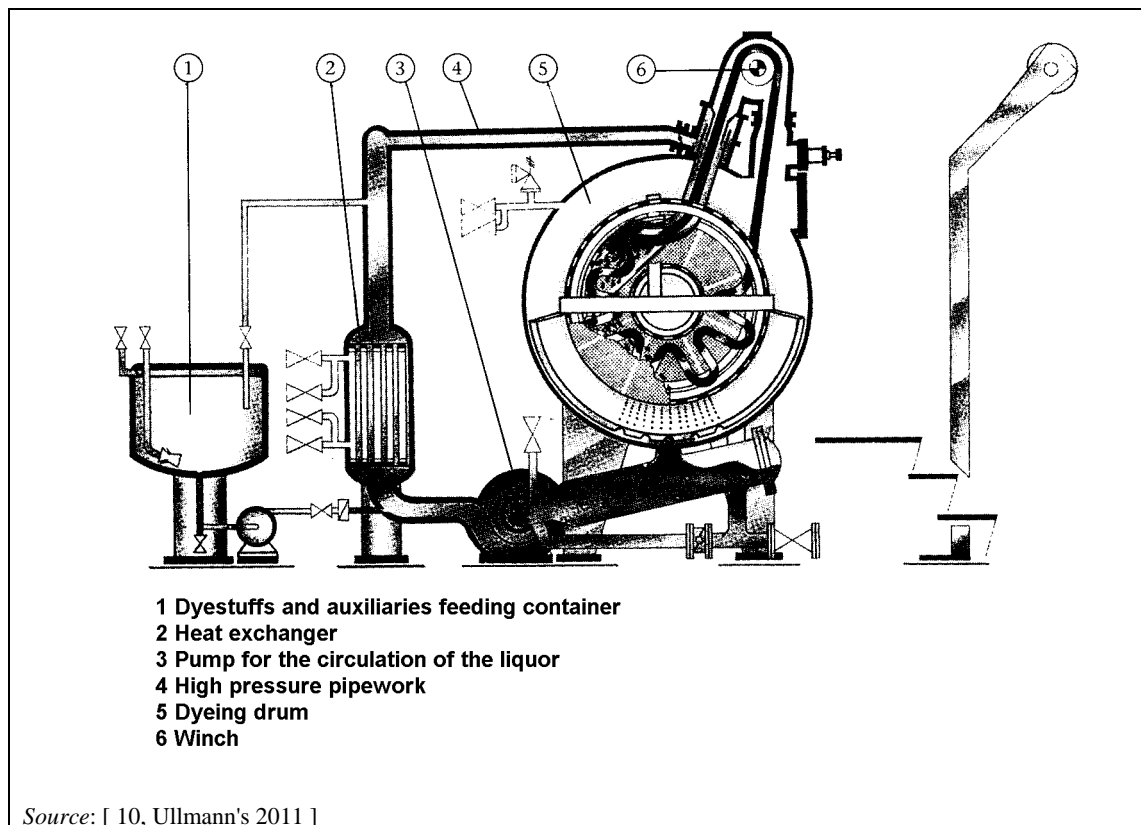
Jet machines (see Figure 8.18) have been designed with the aim of eliminating some of the problems associated with the use of winch machines.

The reel is eliminated and the fabric is placed in a closed tubular system. A jet of dye liquor is supplied through a venturi to transport the fabric through the tube. Turbulence created by the jet aids in dye penetration and prevents the fabric from touching the walls of the tube.

Since the fabric is frequently exposed to high liquor concentrations within the transport tube, relatively little dye bath is needed in the bottom of the vessel: just enough to ensure smooth movement from rear to front. Advantages of this machine are therefore low consumption of water and short treatment time (e.g. short dyeing time). Typical liquor ratios vary between 1:4 and 1:20, ranging from 1:4 to 1:10 for fabric and from 1:6 to 1:20 for carpet (lower values apply to synthetic fibres while higher values are typical for cotton) [ 28, GuT 2001 ].

Jets can usually be operated at high temperatures, which makes them very suitable for dyeing polyester fibres. A disadvantage, however, is the high mechanical stress on the textile, caused by the speed difference between the bath and the fabric. For this reason jets are not suitable for some delicate fabrics.

Depending on the shape of the fabric storage area (long shape machine or J-box compact machine), the type of nozzle and its position (above or below the level of the bath) various types of jets exist. Overflow, soft-flow and airflow dyeing machines can be regarded as developments of the conventional jet. The main features of these machines are reported in the following sections, while the latest developments in this dyeing technology are further described in Section 4.5.1.7.1.



**Figure 8.18: Schematic representation of a jet dyeing machine**

### 8.3.3.1.3 Overflow

Overflows (see Figure 8.19) have been designed for delicate knitted and woven fabrics made of natural and synthetic fibres. They are also found in the carpet sector.

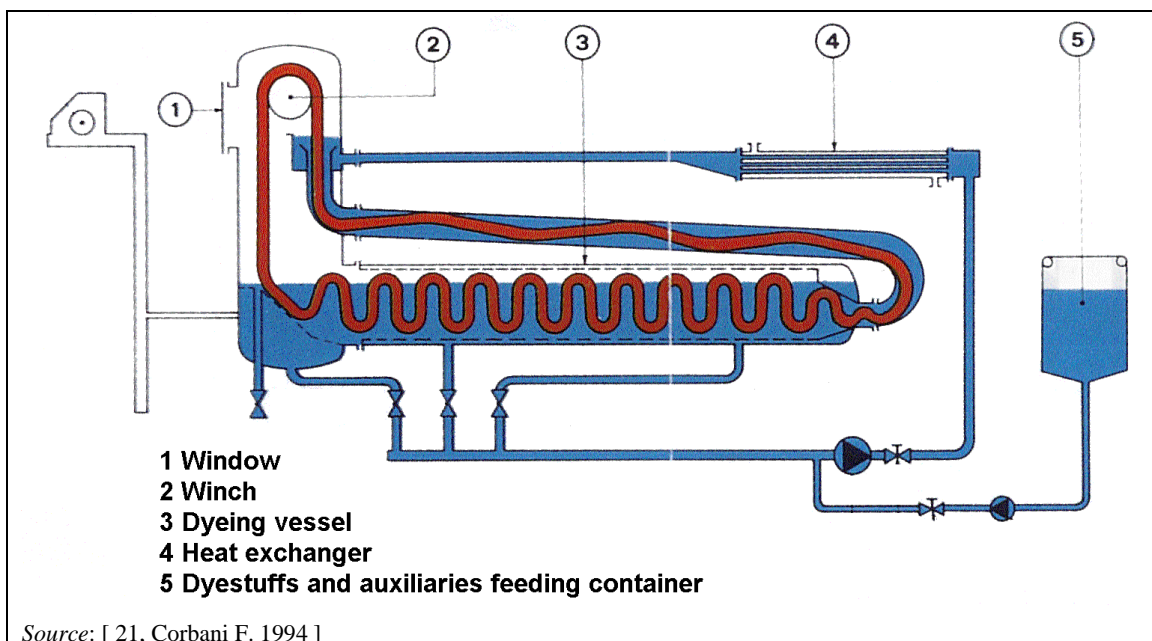
The main difference between jet and overflow machines remains in the fact that in jet machines the fabric is transported by the bath flowing at high speed through the nozzle, while with overflows the fabric is transported by the gravitational force of the liquor overflow.

A winch (usually not motor driven) is located in the upper part of the machine and the fabric hangs over it. A longer length of textile hangs from the exit side of the winch than from the inlet side. Gravitational forces pull the longer length of textile downward more strongly than the shorter. The fabric is therefore soaked in the bath without any tension (transportation is very gentle).

Different designs are available on the market and some of them can operate under pressure and consequently at higher temperatures.

Typical liquor ratios for overflows range between 1:12 and 1:20.





**Figure 8.19:** Schematic representation of an overflow dyeing machine

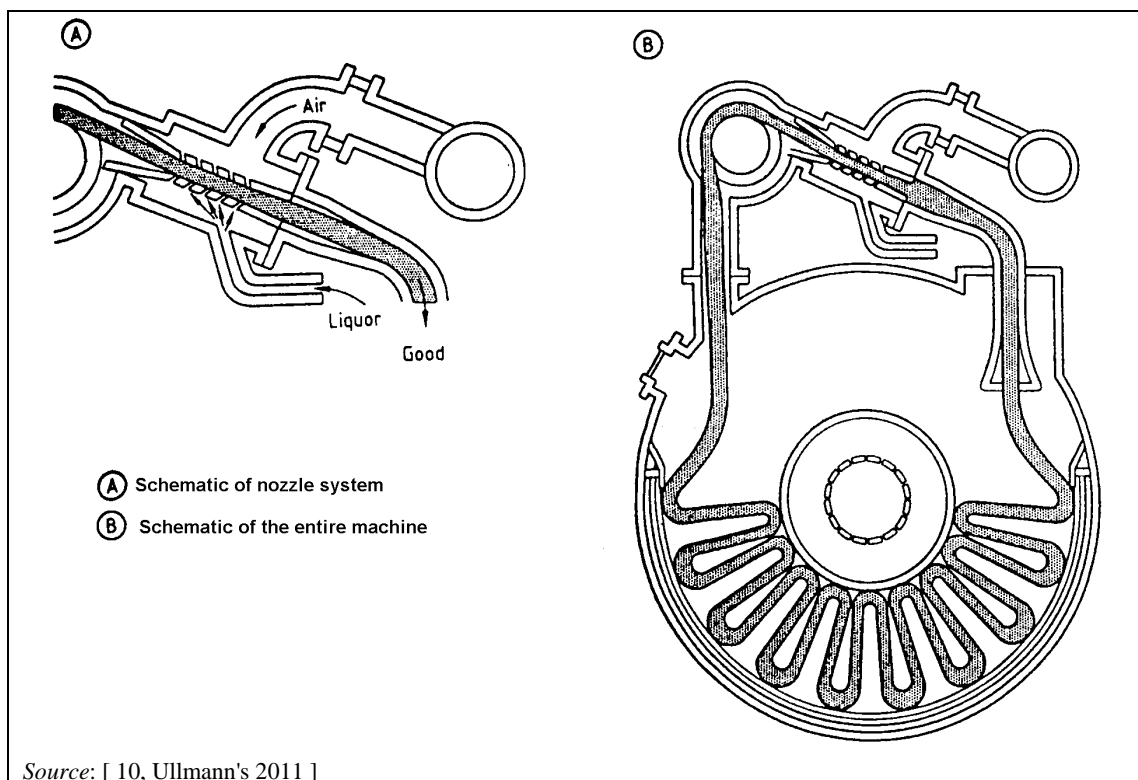
#### 8.3.3.1.4 Soft-flow

The so-called "soft-flow" machines use the same transport tube principle as overflow machines where the fabric is transported in a stream of dye liquor. However, while in overflow machines the reel is not motor driven, in soft-flow equipment the reel and the jet work in constant harmony to remove the fabric from the front of the storage area, expose it briefly to a high concentration of liquor within the transport tube, then return it to the rear of the vessel. The soft flow machines are more gentle on the fabric than conventional jet overflow machines.

#### 8.3.3.1.5 Airflow

The difference between air jet (see Figure 8.20) and jet machines is that in the former an air jet instead of a water jet keeps the fabric in circulation. The fabric passes into the storage area which contains a very small amount of free liquor. As a result, a reduction in water, energy and chemical consumption can be achieved.

Because of the short liquor ratios achievable (from 1:2 to 1:5) the dye must be highly water-soluble.



Source: [ 10, Ullmann's 2011 ]

**Figure 8.20: Schematic representation of jet dyeing machine**

### 8.3.3.2 Continuous processes

Machines for treatment in continuous processes of fabrics in rope form are essentially composed of the following parts:

- a padding device for impregnating the fabric in rope form
- a storage area for the fixation of the chemicals applied
- a washing machine for fabric in rope form.

The padding device is composed of a long basin equipped with two or three rotating rollers at the inlet and another two at the outlet. The basin contains a concentrated solution of the chemicals and auxiliaries that have to be applied (desizing agents, bleaching agents, etc.). The fabric is pressed by the rotating rollers at the inlet in order to obtain a homogeneous absorption of the chemicals and the elimination of air. The other two rollers only squeeze the fabric. After squeezing, the fabric retains only a relatively low amount of bath. As a result high concentrations of the chemicals are needed, moreover the solutions must be adequately stabilised to avoid unwanted oxidation reactions, etc.

The storage area (also called reaction chamber) can have different shapes: one typical model is the J-Box. The J-Box is filled to 1/3 of its capacity with the treatment bath.

The main advantage of this technique is the high production capacity. On the other hand there is the risk of longitudinal creases, which can negatively affect the dyeing process. As a result this technique is mainly applied for white end-products for pretreatment operations (e.g. bleaching).

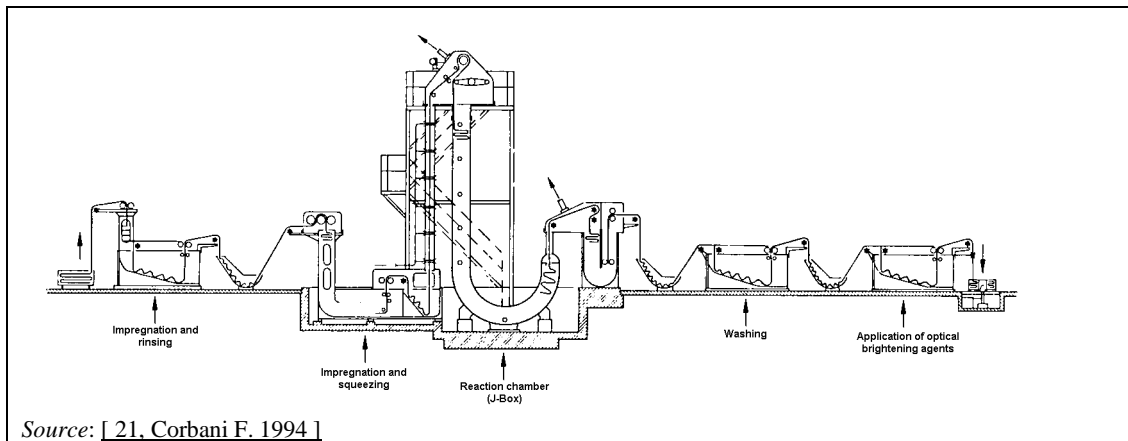


Figure 8.21: Example of continuous process for knitted fabric in rope form

### 8.3.4 Fabric in open-width

#### 8.3.4.1 Batch processes

##### 8.3.4.1.1 Beam

The fabric is wound in open-width on a perforated cylinder called a beam (see Figure 8.22). The fabric is stationary and the bath is pumped through the beam. The direction of the flow is normally from the inside to the outside of the roll of textile.

The ends of the beam are covered with metal sheets before the fabric is wound on, to prevent a short circuit of the liquor.

Beams can operate both under pressure and at atmospheric pressure.

These machines are suitable for pretreatment operations like scouring and bleaching and also for dyeing of lightweight, wide and delicate goods. One disadvantage is represented by the risk of non-homogeneous penetration of chemicals and auxiliaries used for the treatment.

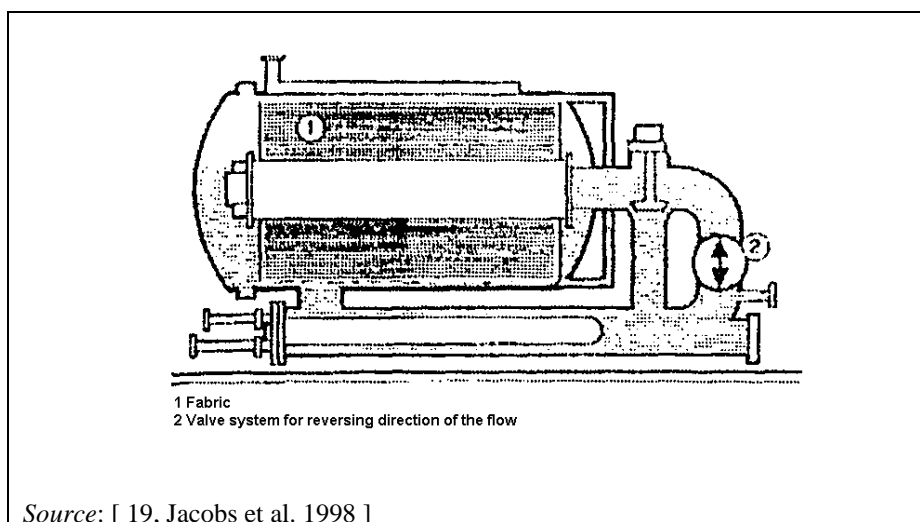


Figure 8.22: Schematic representation of a beam dyeing machine

### 8.3.4.1.2 Jigger

A jigger (see Figure 8.23) is composed of a trapezoidal tub containing the bath and two rolls on which the fabric is alternatively wound. In this type of machine the bath is stationary while the fabric is in motion. The fabric, initially wound on the first roll, flows through the bath and then is wound on the other one; the rotation is then reversed and the cycle continues. The fabric is led in its path by a few small guide rollers.

HT jiggers are also produced, allowing treatments at temperatures above 100 °C. This type of machine is used not only for dyeing, but also for various wet treatments on fabrics in full width.

The main disadvantage of this system is the risk of non-homogeneity between the initial and final part of the roll. This is due to variations in feed speed and tension of the fabric, or temperature and chemicals concentration in the bath during the period of the treatment. However, in modern jiggers tension of the fabric is kept constant during the whole process, thanks to special devices.

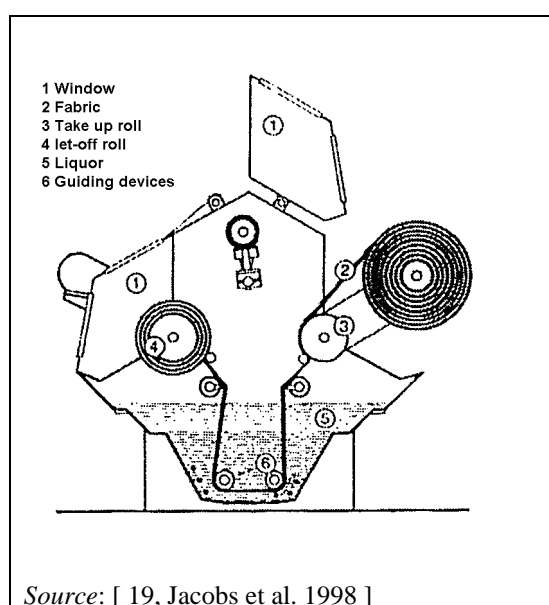


Figure 8.23: Schematic representation of a jigger

### 8.3.4.2 Semi-continuous and continuous processes

Some of the most widely used continuous and semi-continuous processes are:

- pad-batch
- pad-roll
- pad-jig
- pad-steam
- pad-dry
- thermosol.

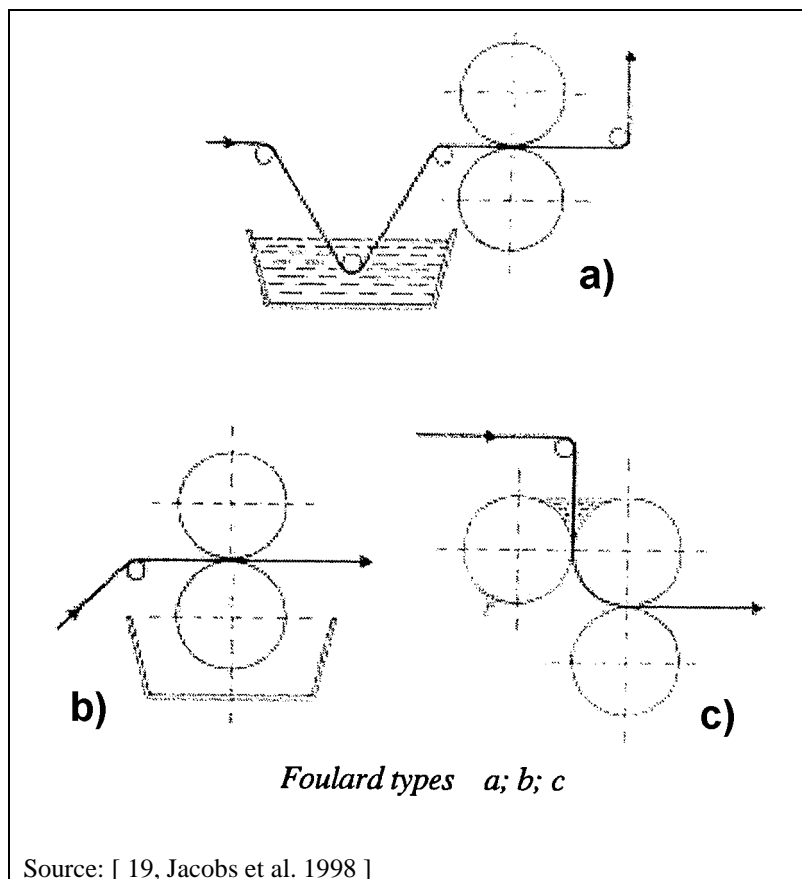
They are briefly described in the following sections.

Typical treatment steps in both semi-continuous and continuous processes are:

- application of the dye or finishing agent either by impregnation (using a padding device) or by means of other types of application systems (see Figure 8.25)
- storage/fixation, which can be carried out in different ways depending on the process applied (e.g. dry heat, steam)
- washing in continuous mode in open width.

Padding machines (foulards) are used to apply dyestuffs or other chemicals onto the fabric in open-width form. The fabric passes through the pad trough where it picks up the liquor. After leaving the pad trough, the fabric is squeezed between rubber rolls. The amount of liquor picked up depends mainly on the pressure produced by the two rolls, the speed at which the fabric is transported and the type of substrate. The level in the trough is automatically maintained to compensate for liquor picked up by the fabric. The liquor is kept in circulation to avoid differences in temperature and/or concentration.

Different designs of foulards exist: some examples are shown in Figure 8.24.



**Figure 8.24: Foulard types**

Padding is the most common application technique in textile finishing, but other application systems (see figure below) are more common in the carpet industry. Due to their higher ecological performance, some of them are increasingly used in the textile finishing sector.

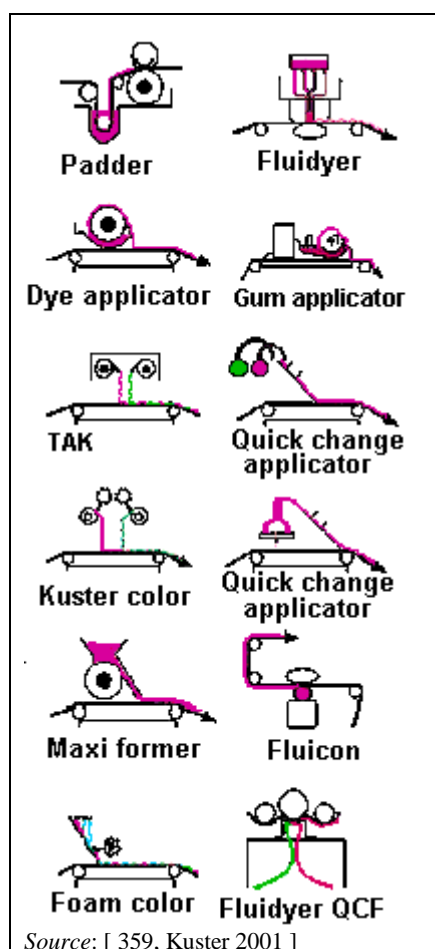


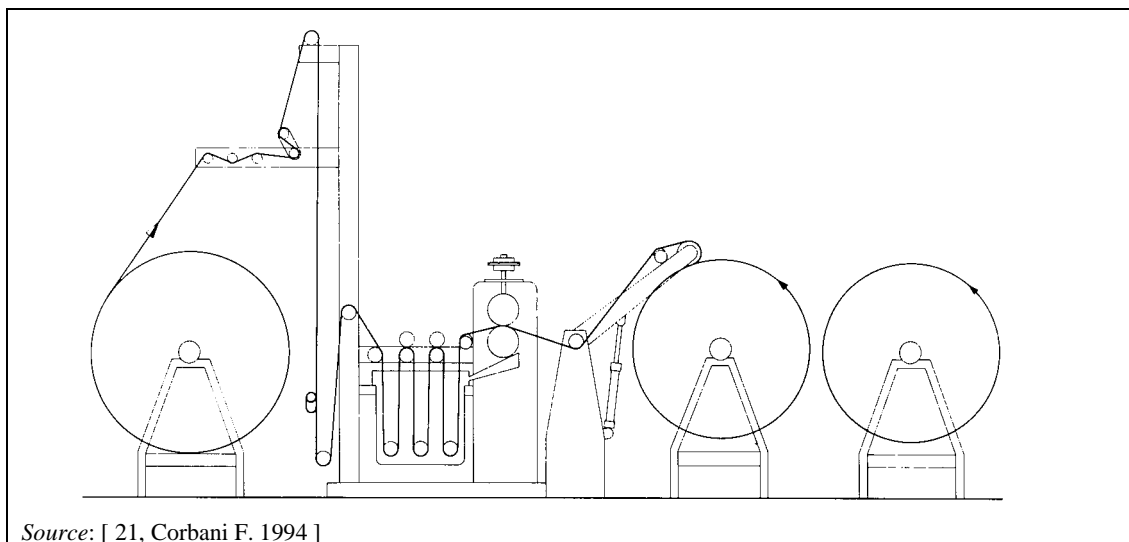
Figure 8.25: Illustration of some of the most important dye/finish applicators

#### 8.3.4.2.1 (Cold) Pad-batch process (semi-continuous)

This process includes an impregnation step on a padding machine.

After being squeezed, the fabric is wound onto a roll and stored at room temperature. The roll is kept in slow rotation until the desired chemical processes (e.g. fixation of the dyestuffs, etc.) are complete. At the end the fabric is washed in an open-width washing machine. Because rotation and reaction process is done at the room temperature the process is also called ‘cold’ pad-batch.

This process is commonly used for pretreatment (e.g. desizing) and dyeing (mainly with direct and reactive dyes). It is characterised by low water and energy consumption (about 50 – 80 % less than conventional systems) and good repeatability.



**Figure 8.26: Schematic layout of a pad-batch plant**

#### 8.3.4.2.2 Pad-roll process (semi-continuous)

This process is similar to pad-batch, but in this case the fabric, after padding, passes through an infrared oven. It is then rolled and kept in slow rotation in a hot steam chamber until fixation, or other chemical processes are complete. The fabric is then washed in an open-width washing machine.

#### 8.3.4.2.3 Pad-jig process (semi-continuous)

This process is generally used as a dyeing technique, mainly used for heavy weight fabrics with direct and reactive dyes.

In this process the fabric passes through a padding machine where it is impregnated with the dye bath, then the dyestuff is fixed on a jigger.

Sometimes the fabric can be dried in a hot-flue drier after padding, before entering the jigger.

The application of the dyestuff by padding allows for homogeneous dyeing and time saving when compared to traditional jigger dyeing processes.

#### 8.3.4.2.4 Pad-steam process (continuous)

This technique is mainly used for scouring woven fabric and dyeing. It is particularly suitable for the application of direct, vat, sulphur and reactive dyestuffs.

It includes the following steps:

- impregnation by padding
- steaming (at about 100 °C)
- additional impregnation of the fabric with developing agents (e.g. reducing agents in vat or sulphur dyeing)
- washing and rinsing.

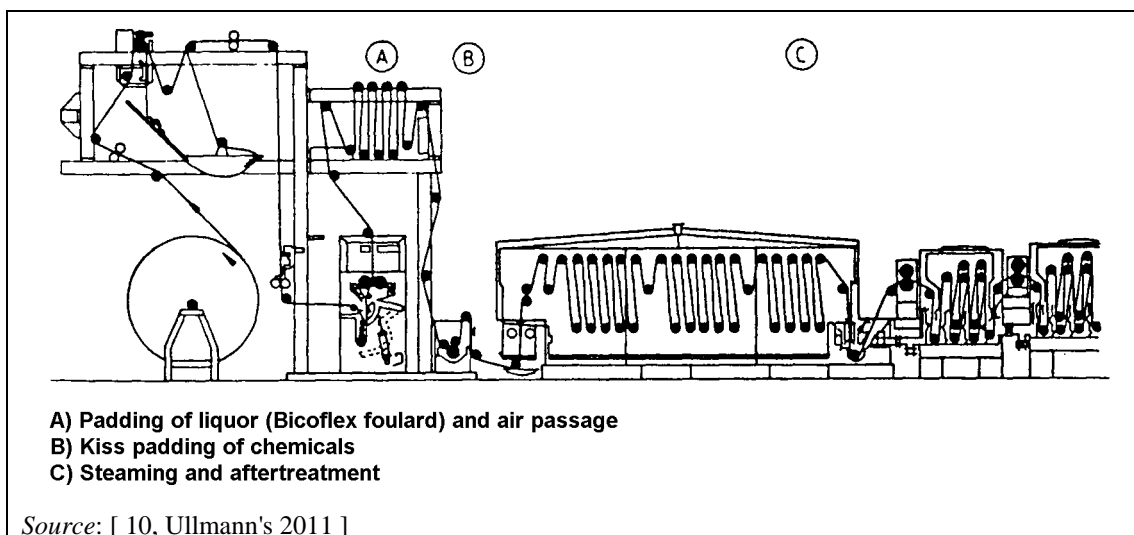


Figure 8.27: Schematic representation of a pad-steam plant (wet steam) for dyeing with vat dyes

#### 8.3.4.2.5 Pad-dry process (continuous)

This process includes the following steps:

- impregnation by padding
- intermediate drying (optional)
- fixation in hot-flue
- washing.

#### 8.3.4.2.6 Thermosol process (continuous)

This process is specific for dyeing with disperse dyestuffs polyester or cotton/polyester blends.

The process includes the following steps:

- impregnation in the dyeing liquor
- pre-drying in an infrared oven
- drying in hot-flue
- passage through a stenter frame for thermal fixation at 200 °C of the disperse dyes to the PES.

An alkaline reductive after-treatment is then carried out or, in the case of cotton/polyester blends, the second dye is developed according to the procedure typical of its class, using in general pad-steam, pad-jig or pad-batch processes.

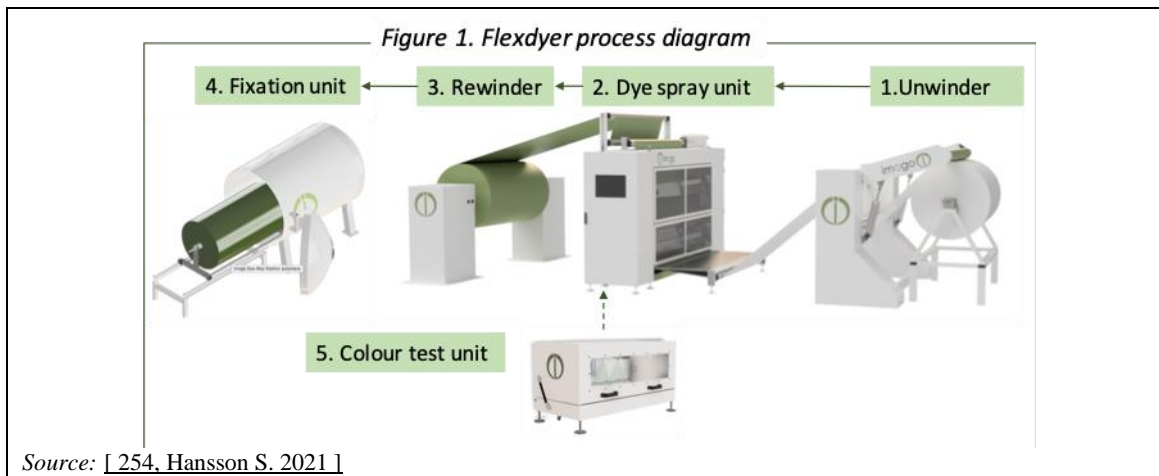
#### 8.3.4.2.7 Spraying process (semi-continuous)

Spray technology is widely used for impregnation of finishing chemicals as water repellences, antistatics, softeners and also preparation for digital printing in the textile industry.

The process allows to spray the exact amount of process bath (e.g. dye) that is needed to carry the dyestuff or chemicals onto the fabric/fibre, exactly where it is needed. The coverage of a textile substrate width is created by overlapping of multiple spray patterns. The nozzle design and placement are key to accomplish an even fluid distribution. The volume control is done by high frequency valves. By altering the frequency, the volume is automatically adjusted based on the substrate speed and volume settings. Depending on dye class and fibre present the fixation take place either in an autoclave, stenter or by rotating in room temperature.



This technology uses much less water, chemicals and energy and is also digitally controlled in a way that increases the reproducibility. There are different companies providing this technology [ 255, IMOGO 2019 ].



**Figure 8.28: Schematic representation of spray dyeing process**

In spray processing the aerosols and droplets may be formed through different physical mechanisms (e.g. through centrifugal forces on rotating plate or through pressure difference on passing the liquid jet through nozzle) [ 167, ROTASPRAY 2019 ].

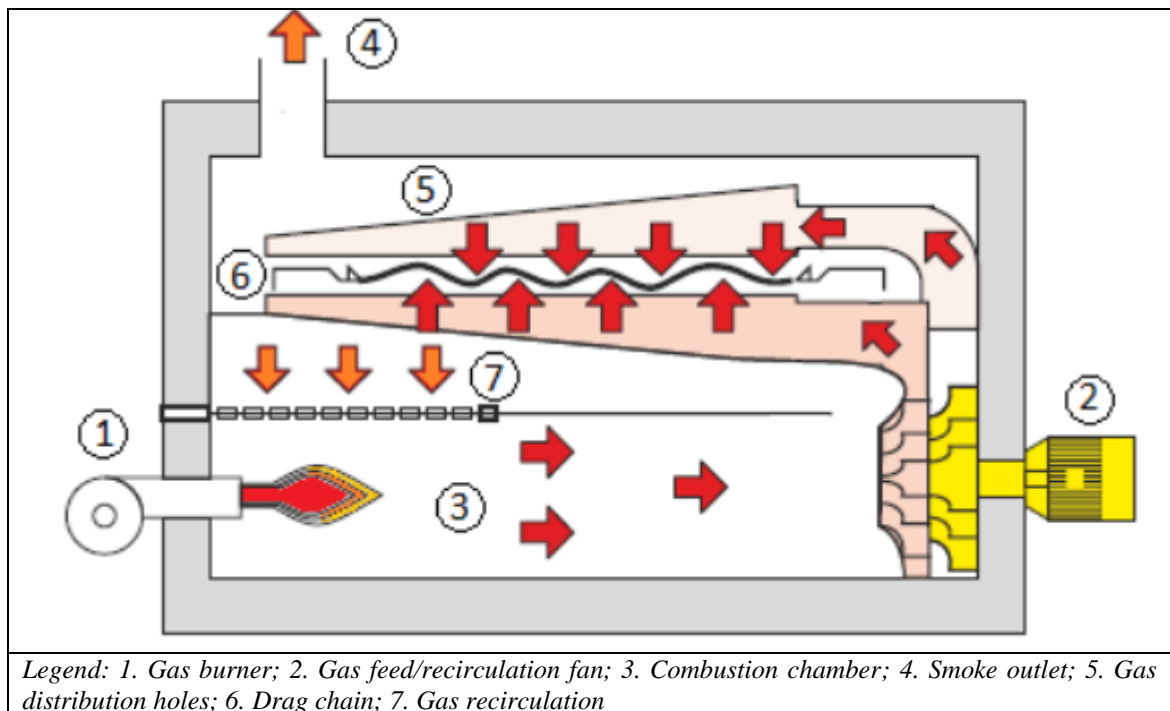
## 8.4 Stenters

[ 346, Pirobloc 2021 ]

Stenters are machines used for thermal (e.g. drying, curing, heat-setting) and mechanical (e.g. cross-stretching, widening and correcting distortions in the weft) treatments of the fabrics. The heat provided for their operation is either through direct heating via combustion gases from the gas burners, or indirect heating through thermal fluids, like steam. The advantages and disadvantages of these heating systems from both a technical and economic point of view are evaluated below.

### 8.4.1 Direct heating by gas burners

The operating scheme of stenter with direct heating by gas burners is shown in Figure 8.29.



**Figure 8.29: Stenter with direct heating by gas burner**

A burner (1) is inside a chamber (3) within the machine. The combustion gases are sucked by a fan (2) through a filter and distributed through pipes with distribution holes (5) to make the temperature on the fabric as uniform as possible and pulled through these pipes by chains (6). Some of the gas is recirculated (7), but most is evacuated at the smoke outlet (4). Stenters can have different by-passes to recirculate at different levels according to the machine production needs.

#### 8.4.1.1 Advantages and disadvantages of direct heating

##### Technical advantages

- Requires less space. No additional heat transfer pipes, boiler or auxiliary equipment needed.
- Quick start-up, as there is no intermediate exchange fluid to be heated beforehand.

Technical disadvantages

- The reduced energy efficiency/yields.

The combustion gases are filtered, since the presence of unburned products or ash must be avoided, as it would affect the quality of the finished product and the energy efficiency – incomplete burning of the fuel. This necessarily leads to the combustion with a high excess of air and substantial flow rate, leading to high amounts of energy expelled without being used, which results in lower energy efficiency/yield.

Although it is difficult to evaluate the overall yield reduction, indicative figures are shown in Figure 8.30. Thus, for a normal and proper excess of air in combustion with natural gas of 10-20%, the yield is of the order of 89-90%. For higher air excesses, to avoid unburned products, of at least 50-70% excess air, the yield is around 85-86%. For values of 80-100% excess air, the yield is 80-83%. Therefore, energy yield reductions of 5-8%, are to be expected in the indirect heating.

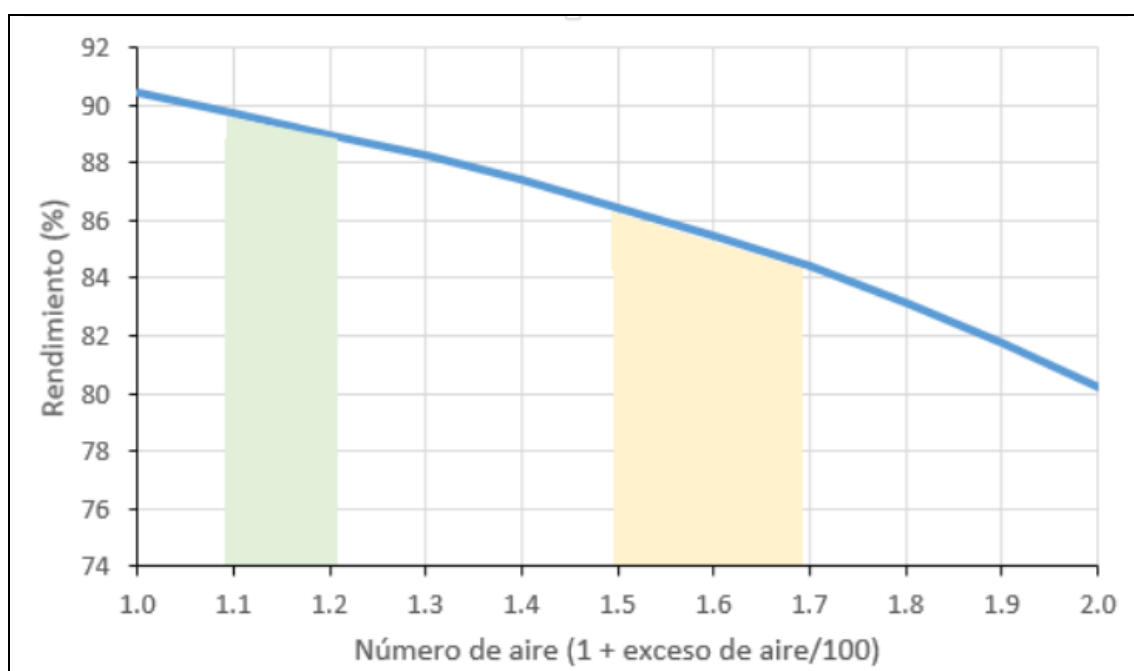


Figure 8.30: Energy yield vs excess air for a given exchange surface

The operation without high excess air is not the usual option since the energy efficiency of such operating mode, is even worse compared to excess air mode. In effect, low or no excesses of air result in a high flame temperature, (see Table 8.22) and a low coefficient of heat transmission due to the lower velocity/flow rates of the combustion gases. Furthermore, with such high gas temperature the exchange surface (e.g. textile substrate and inner convection surfaces) is typically too small to be able to absorb the energy properly. As a result, the temperature of the gases leaving the outlet is very high and therefore energy efficiency is much lower (if heat is not recovered from combustion gases – which involves higher investment costs).

Table 8.22: Flame temperature vs excess air for natural gas combustion

Excess air (%)	0	10	20	30	40	50	60	70	80	90	100
Flame temp (°C)	1 545	1 465	1 400	1 335	1 270	1 205	1 140	1 075	1 010	945	880

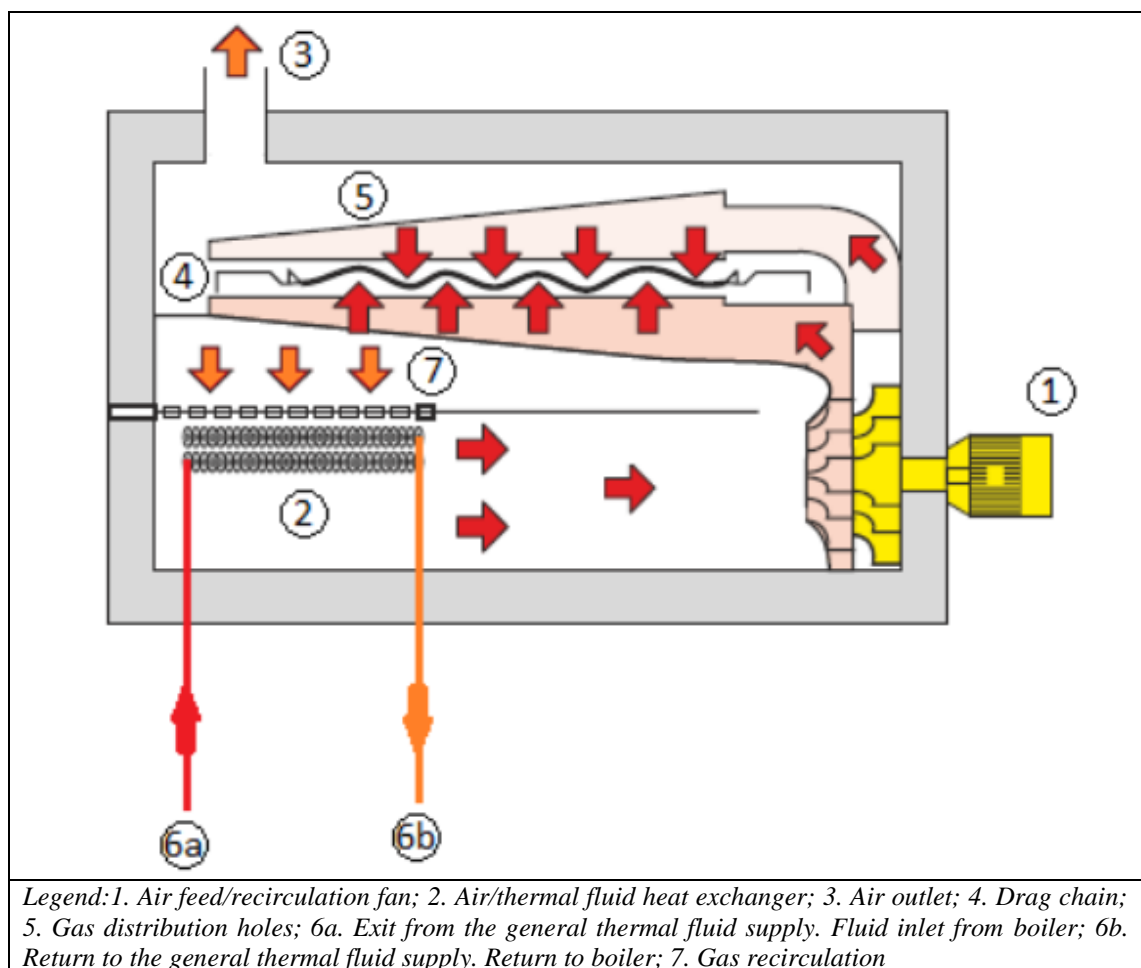
- Maintenance/readjustments of the gas burners  
Gas burners do not require large maintenance operations. However, there are usually a large number of burners installed in each stenter: one for each field. Therefore, ensuring proper combustion and its adequate adjustments is highly important, for ensuring reliability and quality of production. Also, a change of fabric or process conditions requires a change in the burner combustion parameters. Readjusting the burning parameters is generally overlooked and affects the final quality of the product. Finally, the maintenance is performed on equipment inside the stenter, which requires stopping the production.
- Possible yellowing of the textile.  
The combustion of natural gas produces NO<sub>x</sub> which can react with the fibre and cause yellowing. To prevent this, precisely adjusted, low NO<sub>x</sub> burners are required, which makes implementation of the equipment more expensive and affects the maintenance.

#### Economic considerations

- Gas supply and piping.  
The operation of stenter relies on the stable gas supply. Depending on the location of the stenters in the production area, the installation of gas piping may be complex and expensive.

### 8.4.2 Indirect heating by thermal fluids

The operating scheme of stenter with indirect heating by thermal fluids is shown in Figure 8.31.



**Figure 8.31: Stenter with indirect heating by thermal fluid**

Thermal fluid from a boiler (6a) passes through a heat exchanger (2) and heats air sucked by a fan (1) through a filter. As in the direct heating design, this is distributed through pipes with distribution holes (5) to make the temperature on the fabric as uniform as possible while being pulled through these pipes by chains (4). Some of the gas is recirculated (7), but most is evacuated at the smoke outlet (3). After the heat from the thermal fluid has been transferred to the air, it is returned (6b) to the general network of the boiler.

Stenters can have different by-passes to recirculate at different levels according to the machine production needs.

#### **8.4.2.1 Advantages and disadvantages of indirect heating**

##### Technical advantages

- Operating flexibility.  
Burner combustion parameters, following a change in fabric type or process, are easily adjusted and the operating mode of the stenter can be adapted quickly.
- Less maintenance of burners, which are fully centralized in the components (e.g. boiler) external to the machine. For continuous work, these components can have replacements on stand-by, so that production is not stopped.
- Auxiliary fuel. Different combustion systems and other fuels can be used apart from natural gas to ensure the stable supply and undisturbed production.

##### Technical disadvantages

- Time required to put into service.  
This disadvantage is exclusively for equipment that does not work continuously. It can be minimized by maintaining a moderate temperature in the boiler and piping, even if the machines are not in production mode. The energy losses with this mode of operation are minimal if the equipment and piping are properly insulated.

##### Economic considerations

Lower operating costs due to lower maintenance, less production stoppages, fewer critical components. However, investment costs are typically higher and space requirements greater compared to the direct heating (e.g. due to heat transfer piping, boiler and other auxiliary equipment).

#### **8.4.3 Selection of appropriate stenter**

Based on the above reasoning, the direct heating stenters are more suitable if the number of stenters is low, operation is non-continuous, with few variations in fabric type or process parameters, and there is a reliable gas supply.

The indirect (e.g. thermal fluid) heating stenters are more suitable for high capacity production processes, with numerous stenters in constant 16/24 hour operating times. These systems let production to continue without stopping for maintenance or adjustments. Also, operational parameters are easily adjusted to the different fabric types and practically immediate with no delays in start-up. Furthermore, having the facilities in constant operation maximizes its energy efficiency and low maintenance.

For more information on minimisation of energy consumption of stenter frames see Section 4.1.4.5.

## 8.5 Typical recipes (with some associated emission factor) in the textile sector

The following information is based on [ 5, UBA 2001 ] with reference to [ 23, Schönberger H. 1994 ]

### 8.5.1 Pretreatment

#### 8.5.1.1 Cotton and cotton blends

##### WOVEN FABRIC

##### Enzymatic desizing

Table 8.23: Standard recipe for enzymatic desizing of woven fabric consisting of CO and CO blends

Chemicals	(g Telquel/kg textile substrate)	Remarks
Enzyme	5	
Complexing agent	1	
Surfactant	1 - 8	For discontinuous processes, e.g. desizing in a winch with liquor ratio of 1:20, up to 30 g Telquel/kg textile substrate are applied
Water consumption (l/kg textile substrate)	4 - 6	

##### Removal of water-insoluble sizing agents by cold oxidative desizing

It is a semi-continuous process. The liquor for oxidative desizing is added at room temperature in a paddler with a pick-up of 70 – 80 %. Reaction takes place with a retention time of 16 - 24 h (max. 72 h). The fabric is then thoroughly rinsed.

**Table 8.24: Standard recipe for the desizing of woven fabric consisting of CO and CO blends sized with water-insoluble sizing agents**

Chemicals	(g Telquel/kg textile substrate)		Remarks
	Continuous and optimised process	Discontinuous process	
NaOH (100 %)	10 - 20		Usually applied as 33 % or 50 % solution
H <sub>2</sub> O <sub>2</sub> (100 %)	15 - 25		Usually applied as 33 % or 50 % solution
Surfactants	1.5 - 3		As surfactants a mixture of non-ionic (about 70 % average, e.g. ethoxylated fatty alcohol) and anionic surfactants (about 30 %, especially alkylsulphonates but also alkyl sulphates and linear alkylbenzene-sulphonates) are applied
Complexing agents	2 - 4		As complexing agents polyacrylates and phosphonates are applied but not EDTA or DTPA
MgSO <sub>4</sub> (100 %)	0.15 - 0.3		Usually applied as 40 % solution
Water glass (100 %)	5 - 8		Usually applied as 40 % solution
Na-peroxodisulphate (100 %)	3 - 6		Usually applied as 20 % solution
Water consumption (l/kg textile substrate)	4 - 6 or 8 - 12		4 - 6 l/kg in case of multi-usage of water or high efficient washing compartments; otherwise 8 - 12 l/kg

## Removal of water-soluble sizing agents

Table 8.25: Standard recipe for the desizing of woven fabric consisting of CO and CO blends sized with water-soluble sizing agents

Chemicals	(g Telquel/kg textile substrate)		Remarks
	Continuous and optimised process	Discontinuous process	
Complexing agent	1	3 – 15	As complexing agents polyacrylates and phosphonates are applied but not EDTA or DTPA
Surfactant	1 – 3	4 – 20	As surfactants a mixture of non-ionic (about 70 % average, e.g. ethoxilated fatty alcohol) and anionic surfactants (about 30 %, especially alkylsulphonates but also alkyl sulphates and linear alkylbenzene-sulphonates) are applied; also to a minor extent alkylether sulphates and alkylethoxy-phosphoric esters. For recovery of sizing agents desizing is carried out without surfactants; but then more washing compartments are needed in order to stay under a residual content of sizing agents of 1.2 %. Very often surfactant formulations already contain defoaming agents (0.1 – 1 g/kg); if not dosage of defoaming agents is needed. Usually polysiloxanes are used (very low dosage) and to a minor extent hydrocarbons (higher dosage) and trialkyl phosphoric esters
Soda or NaOH (100 %)	0 - 3 0 - 2	0 – 3 0 – 2	
Water consumption (l/kg textile substrate)	4 – 6 or 8 - 12	ca. 50 (winch)	4 - 6 l/kg for multi-usage of water otherwise 8 - 12 l/kg; in continuous processes washing water from bleaching and/or scouring is used for desizing



## Scouring

Table 8.26: Standard recipe for scouring of woven fabric consisting of CO and CO blends

Chemicals	(g Telquel/kg textile substrate)		Remarks
	Continuous and optimised process	Discontinuous process	
NaOH (100 %)	20 – 80	20 - 80	The quantity depends both on the percentage of cotton in blends and on the applied processes.
Complexing agents	1 – 6	3 - 30	<p>Some suppliers for complexing agents do not recommend more than 2 g/kg for continuous processes. The application of complexing agents is necessary to extract calcium. For this purpose NTA is not efficient enough. Normally a mixture of different complexing agents such as phosphonates, gluconates, polyphosphates, NTA, polyacrylates (in some cases are still in use EDTA and DTPA).</p> <p>The use of complexing agents can be reduced significantly if an acidic treatment is carried out prior to scouring (in Germany this possibility is very seldom practised).</p> <p>In some cases combinations of complexing agents and reducing agents are used.</p>
Surfactant	5 - 6	5 - 30	Some suppliers recommend 2 – 4 g/kg for continuous processes. The composition concerns the one which is given for desizing of water-soluble sizing agents (see Table 3)
Water consumption (l/kg textile substrate)	8 - 10	ca. 50	Rinsing is included for continuous processes the consumption can be lower if water-recycling is practised.

## Bleaching

**Table 8.27: Standard recipe for bleaching of woven fabric consisting of CO and CO blends**

Chemicals	(g Telquel/kg textile substrate)		Remarks
	Continuous and optimised process	Discontinuous process	
H <sub>2</sub> O <sub>2</sub> (100 %)	5 - 15	5 - 15	Stabilised by phosphoric acid and organic stabilisers
NaOH (100 %)	4 - 10	4 - 30	At the beginning of the bleaching process the phosphoric acid is neutralised and loses its stabilising effect
Complexing agents <sup>(1)</sup>	0 - 2	0 - 2	For complexing calcium and heavy metal ions the same compounds are used as for scouring; magnesium may not be complexed because it is needed for the stabilisation of H <sub>2</sub> O <sub>2</sub>
Organic stabiliser <sup>(1)</sup>	0 - 10	0 - 20	For the stabilisation of H <sub>2</sub> O <sub>2</sub> , many products are available which contain complexing agents for calcium and heavy metal ions, such as gluconate, NTA/EDTA/DTPA, polyacrylates and phosphonates; in Germany DTPA is no longer applied and EDTA only to a minor extent
Surfactant	2 - 5	2 - 10	The same compounds are applied as for desizing and scouring (see Tables 3 and 4)
Sodium silicate <sup>(1)</sup>	8 - 20		Sodium silicate acts as pH buffer, alkali supplier, anti-catalyte and stabiliser
Water consumption (l/kg textile substrate)	6 - 12	ca. 50	Rinsing is included

<sup>(1)</sup> The consumption of complexing agents, organic and inorganic (silicate) stabilisers vary in total from 0 - 20g/kg. As for scouring, the consumption can be significantly reduced by acidic pretreatment.

## Mercerisation

**Table 8.28: Standard recipe for mercerisation of woven fabric consisting of CO and CO blends**

Chemicals	(g Telquel/kg textile substrate)	Remarks
NaOH (100 %)	200 - 300	
Wetting agent	0 - 10	A wetting agent is only applied in case of dry-in-wet-mercerisation (raw mercerisation). They consist of short chain anionic compounds such as alkylsulphates
Complexing agent	2	Only for raw mercerisation. The same chemicals are used as for scouring (see Table 4)

## Alkali treatment

**Table 8.29: Standard recipe for alkali treatment of woven fabric consisting of CO and CO blends**

Chemicals	(g Telquel/kg textile substrate)	Remarks
KOH (100 %) or NaOH (100 %)	200 - 300 60 - 230	
Sandoflex A	60 - 80 ml	The product is a liquid formulation with a concentration of active compounds of 50 %. It consists of sulphuric acid esters, a fatty acid derivate and an alkylsulphonate
Wetting agent	5	

## KNIT FABRIC

Pretreatment of knitted fabric does not need desizing because sizing agents are not present.

“Light scouring” is applied if bleaching is not needed; i.e. it is applied for fabric to be dyed in dark shades (black, brown, dark marine or turquoise etc.). “Light scouring” is also called “alkali pre-washing”; a precise definition is not available.

Usually bleaching is only applied for full bleach qualities which are not dyed subsequently or which are dyed in light and medium shades. However, because of logistics some mills bleach all kind of qualities. In the case of continuous processes bleaching is usually performed in a single stage. There are exceptional cases in which the combined bleaching process with peracetic acid/hydrogen peroxide/optical brightener is applied.

In many cases so-called combination bleaching, consisting of a two-stage bleaching with sodium hypochlorite and hydrogen peroxide has been replaced by two-stage hydrogen peroxide bleaching and one-stage bleaching with reducing agents. An acidic pretreatment, which requires a lower dosage of complexing agents in the subsequent bleaching stage is usually carried out in one-stage, similarly to woven cotton fabric or cotton blends.

The consumption of chemicals for pretreatment of knitted fabric is similar to that for woven fabric.

### Neutral/acetic demineralisation

**Table 8.30: Standard recipe for neutral/acidic demineralisation of knitted fabric consisting of CO and CO blends**

Chemicals	(g Telquel/kg textile substrate)	Remarks
Inorganic or organic acid	0 - 2	
Complexing agents	1 - 3	The same chemicals are applied as for scouring of woven fabric (see Table 4)
Surfactant	1 - 3	The same chemicals are applied as for desizing of water-soluble sizing agents (see Table 3)
Water consumption (l/kg textile substrate)	n.d.	

### “Light scouring” process (alkali pre-wash)

**Table 8.31: Standard recipe for “light scouring” of knitted fabric consisting of CO and CO blends**

Chemicals	(g Telquel/kg textile substrate)	Remarks
Soda or NaOH (as 100 %)	ca. 50 ca. 50	There is a wide range of alkali quantities applied
Surfactant	1 - 3	
Water consumption (l/kg textile substrate)	n.d.	

### Bleaching with hypochlorite

**Table 8.32: Standard recipe for bleaching with hypochlorite of knitted fabric consisting of CO and CO blends**

Chemicals	(g Telquel/kg textile substrate)		Remarks
	Continuous and optimised process	Discontinuous process	
NaOCl (as active chlorine)	5 – 6	ca. 30	
NaOH (100 %)	1 – 3	5 - 15	
Surfactant	2 – 5	2 - 10	
Water consumption (l/kg textile substrate)	n.d.	n.d.	

### Bleaching with hydrogen peroxide

**Table 8.33: Standard recipe for bleaching with hydrogen peroxide of knitted fabric consisting of CO and CO Blends**

Chemicals	(g Telquel/kg textile substrate)		Remarks
	Continuous and optimised process	Discontinuous process	
H <sub>2</sub> O <sub>2</sub> (100 %)	5 - 15	5 – 15	
NaOH (100 %)	4 – 10	4 - 30	Usually the lower dosage is applied because for knitted fabric seed shells are already removed to a high extent
Complexing agents	0 - 2	0 - 2	See Table 5
Organic stabiliser	0 – 10	0 - 20	See Table 5
Surfactant	2 – 5	2 - 10	See Table 5
Sodium silicate	8 – 20	0 - 20	See Table 5
Water consumption (l/kg textile substrate)	n.d.	n.d.	

#### 8.5.1.2 Viscose

##### WOVEN FABRIC

Usually viscose is treated with alkali. Only exceptionally is subsequent bleaching with hydrogen peroxide carried out. Thereby the applied quantities of chemicals are lower than for cotton because viscose does not contain natural by-products which need to be removed.

##### Alkali treatment

**Table 8.34: Standard recipe for alkali treatment of woven fabric consisting of viscose**

Chemicals	(g Telquel/kg textile substrate)	Remarks
NaOH (100 %)	40 – 60	Normally strength of applied caustic soda lye is 6°Bé
Surfactant	3 – 20	
Water consumption (l/kg textile substrate)	n.d.	

## Scouring

**Table 8.35: Standard recipe for scouring of woven fabric consisting of viscose**

Chemicals	(g Telquel/kg textile substrate)	Remarks
NaOH (100 %)	ca. 30	When the scouring process is applied as a single stage
Surfactant	3 - 20	
Water consumption (l/kg textile substrate)	ca. 10	

## KNITTED FABRIC

Knitted fabric consisting of viscose is not a common product. The standard recipe for bleaching concerns cotton. However the dosage of caustic soda and hydrogen peroxide is reduced to 40 - 70 %.

### 8.5.1.3 Man-made fibres (woven and knitted fabric)

Woven fabric and knitted fabric consisting of man-made fibres are usually washed in order to remove sizing agents and preparation agents which are normally water-soluble. Scouring is not carried out. The application of bleaching of PES and PAN with chlorite is no longer common.

## STANDARD RECIPES FOR WASHING (CONTINUOUS AND DISCONTINUOUS PROCESSES)

### Woven fabric

**Table 8.36: Standard recipe for washing of woven fabric consisting of man-made fibres**

Chemicals	(g Telquel/kg textile substrate)	Remarks
Alkali	0 – 2	For pH-adjustment depending on the kind of sizing agents; normally NaOH, soda or ammonia hydroxide are used, seldom sodium phosphate
Complexing agents	0.5 – 15	
Surfactant	0.5 – 30	
Water consumption (l/kg textile substrate)	4 – 8	In case of micro fibres up to 60 l/kg

### Knitted fabric

**Table 8.37: Standard recipe for washing of knitted fabric consisting of man-made fibres**

Chemicals	(g Telquel/kg textile substrate)	Remarks
Complexing agents	0 – 10	Polyacrylates are predominantly applied, less often polyphosphates
Surfactant	2 – 20	
Water consumption (l/kg textile substrate)	n.d.	

## BLEACHING

### Reductive bleaching of polyamide

**Table 8.38: Standard recipe for reductive bleaching and optical brightening of polyamid**

Chemicals	(g Telquel/kg textile substrate)	Remarks
Sodium dithionite containing formulation	10 – 30	
Optical brightener	5 – 15	
Surfactant	1 – 2	
Water consumption (l/kg textile substrate)	n.d.	

### Bleaching of PES or PAN with sodium chlorite

**Table 8.39: Standard recipe for the bleaching of PES and PAN with sodium chlorite**

Chemicals	(g Telquel/kg textile substrate)	Remarks
NaClO <sub>2</sub> (100 %)	5 – 15	
Formic acid pH 2.5 – 3.5 or oxalic acid pH 2.5	n.d.	Additionally contains buffer salts and stabilisers
Corrosion inhibitor (Chemistry = ?)	10 – 20	
Water consumption (l/kg textile substrate)	n.d.	

#### 8.5.1.4 Wool

##### Raw wool scouring

**Table 8.40: Standard recipe for the raw wool scouring**

Chemicals	(g Telquel/kg textile substrate)	Remarks
Soda	n.d.	
Surfactant	n.d.	Non-ionic types
Water consumption (l/kg textile substrate)	ca. 4	For optimised continuous process

##### Carbonising

**Table 8.41: Standard recipe for wool carbonising**

Chemicals	(g Telquel/kg textile substrate)	Remarks
H <sub>2</sub> SO <sub>4</sub> (100 %)	35 – 70	
Surfactant	1 - 3	
Water consumption (l/kg textile substrate)	ca. 3	For optimised continuous process

## Washing and felting

**Table 8.42: Standard recipe for wool washing and felting**

Chemicals	(g Telquel/kg textile substrate)	Remarks
Soda or ammonia (100 %)	0 – 5 ca. 2.5	
Surfactant	3 – 20	
Water consumption (l/kg textile substrate)	n.d.	

## Bleaching

For full bleach qualities, the standard process for wool bleaching is the application of a combination of oxidation (hydrogen peroxide) with subsequent reductive bleaching (3 g/l reducing agent, e.g. stabilised sodium dithionite and 0.5 g/l surfactant). For wool pre-bleaching either hydrogen peroxide or reducing agents can be used. With regard to the standard recipe for wool bleaching it has to be stressed that the dosage of chemicals can vary considerably depending on time and temperature of the process.

**Table 8.43: Standard recipe for bleaching of wool**

Chemical	(g Telquel/kg textile substrate)	Explanations
H <sub>2</sub> O <sub>2</sub> (100 %)	50 - 75	Because of high dosage the process is often carried out on standing bath
Complexing agents (stabiliser)	5 - 30	
Ammonia (100 %)	0 - 20	pH 8 – 9 with buffer system (usually on base of sodium tripolyphosphate)
Water consumption (l/kg textile substrate)	n.d.	

In some cases acidic hydrogen peroxide bleaching is applied. Then an activator instead of a stabiliser is used. After bleaching rinsing takes place and reductive bleaching (40 – 80 g reducing agents/kg wool) at 60 °C for 30 minutes is carried out. Finally optical brighteners can be added.

In general, especially for bleaching of yarn and knitted fabric with hydrogen peroxide, stabilisers based on protein derivatives and modified phosphoric esters (lecithine types) are used. These stabilisers also act as dispersing agents. Also fatty acid amides are in use; they do not stabilise the bleaching bath only but also serve as a softening agent.

## Hercosett-anti-felt-finishing

**Table 8.44: Standard recipe for Hercosett-anti-felt-finishing of wool**

Chemicals	(g Telquel/kg textile substrate)	Remarks
NaOCl (as active chlorine)	n.d.	
H <sub>2</sub> SO <sub>4</sub> (100 %)	n.d.	
Surfactant	n.d.	
Soda	n.d.	
Na <sub>2</sub> SO <sub>3</sub>	n.d.	

Polyamide resin	n.d.	
Softening agent	n.d.	
NaHCO <sub>3</sub>	n.d.	
Water consumption (l/kg textile substrate)	n.d.	

### Pretreatment for printing

#### Pretreatment with chlorine-containing substances

**Table 8.45: Standard recipe for the pretreatment for printing of wool with chlorine-containing substances**

Chemicals	(g Telquel/kg textile substrate)	Remarks
Dichloroisocyanurate (1.2 – 3.8 % active chlorine)	20 - 60	
Formic/acetic/sulphuric acid	10 - 30	
Sodium disulphites or dithionite	20 – 40	
Surfactant	2 – 5	
Polymers (100 %)	10 – 30	Mainly cationic products
Water consumption (l/kg textile substrate)	n.d.	

#### Pretreatment without chlorine-containing substances

**Table 8.46: Standard recipe for the pretreatment for printing of wool without chlorine-containing substances**

Chemicals	(g Telquel/kg textile substrate)	Remarks
Peroxomonosulphates	20 - 60	
Sodium sulphite or dithionite	20 - 60	
Surfactant	2 - 5	
Polymers (100 %)	10 - 30	Mainly cationic but padding with anionic polymers is also common. Cationic and anionic polymers are also applied without pre-oxidation
Water consumption (l/kg textile substrate)	n.d.	

## 8.5.2 Dyeing

**Table 8.47: Typical recipe for padding liquors for cold pad-batch dyeing of cellulosic fibres (CO and CV) with reactive dyestuffs**

Component	(ml/l)	Remarks
Reactive dyestuffs	x (g/l)	
NaOH 38° Bé	20 - 40	
Water glass 37/40° Bé	30 - 50	Today, there are recipes available without water glass, using alkali only
Wetting agent	1 - 2	
Complexing and sequestering agents	1 - 3	Mainly phosphonates and polyacrylates in order to minimise silicate deposits
Urea (45 %)	about 200 g/l	Applied for reactive dyestuffs with comparatively low water solubility



**Table 8.48: Typical recipe for padding liquors for the application of sulphur dyestuffs (for dyeing of celluloses (CO and CV))**

Component	(g/l)
Sulphur dyestuffs	x
NaOH 38°Bé	20 - 30
Anti-foaming agent	1 - 2
Wetting agent	1.5 - 3
Reducing agent (liquid)	20 - 30

**Table 8.49: Typical recipe for padding liquors for the application of vat dyestuffs (for dyeing of celluloses (CO and CV))**

Component	(g/l)
Vat dyestuffs	x
Wetting agent	1 - 2
Sequestering agents	1 - 3
Anti-migration agent	10 - 15
<u>For reduction</u>	
NaOH 38°Bé	60 - 120
Na-dithionite	60 - 100
Wetting agent	1 - 2

**Table 8.50: Typical recipe for padding liquors for the application of vat and disperse dyestuffs (for dyeing of celluloses/PES blends with one padding liquor)**

Component	(g/l)
Vat and disperse dyestuffs	x
Wetting agent	1 - 2
Sequestering agents	1 - 3
Anti-migration agent	10 - 15
Acetic acid (60 %)	0.5 - 1

### 8.5.3 Printing

**Table 8.51: Typical composition of printing pastes with reactive dyestuffs (COD: ca. 55000 g/kg)**

Component	Composition %
Reactive dyestuff liquid	7
Alginate thickener	2
Ludigol	1
NaHCO <sub>3</sub>	3
Water	88

**Table 8.52: Typical composition of printing pastes with vat dyestuffs (COD: ca. 160000 g/kg)**

Component	Composition %
Vat dyestuff liquid	4.3
Thickener	5.0
Rongalit C	10.6
K <sub>2</sub> CO <sub>3</sub>	11
Urea	2
Sorbit	5
De-aerating agent	0.2
Water	61.9

**Table 8.53: Typical composition of pigment printing pastes (COD: ca. 300000 g/kg)**

Component	Composition %
Pigment dough	4
Acrylate thickener	3
Emulsifier	1
Binder	12
Cross-linking agent	1
Softening agent	1
Water	78

**Table 8.54: Typical composition of printing pastes with disperse dyestuffs**

Component	Composition %
Disperse dyestuff	2.6
Tamarinds thickener	7.0
Dispersing agents	0.5
Monosodium phosphate	2.8
Water	87.1

## 8.5.4 Finishing

Typical recipes for padding liquors in textile finishing are summarised in Table 8.55, while Table 8.56 to Table 8.71 report the substrate emission factors to air for some common auxiliary formulations listed in the “Textile Auxiliaries Buyers’ Guide” [ 358, TEGEWA 2000 ].

**Table 8.55: Typical recipes in textile finishing**

Effect	Substrate	Process temperature (°C)	Recipe
Softening	PES/CV/CO	150	Softening agent: 130 g/l Foaming agent: 15 g/l
Softening	PES	170	Softening agent: 40 g/l
Softening	CO/PES	160	Softening agent: 20 g/l
Softening	PES/WO	130	Softening agent: 5 g/l
Softening, optical brightener, antielectrostatic	PES	185	Softening agent: 5 g/l Optical brightener: 19 g/l Antielectrostatic agent: 6 g/l Wetting agent: 2 g/l Levelling agent: 2 g/l
Softening, stiffening	CO	120	Starch: 50 g/l Softening agent 1: 30 g/l Softening agent 2: 15 g/l Wetting agent: 2 g/l
Hydrophobic, conditioning	PES	160 - 190	Hydrophobic agent: 52 g/l Conditioning agent: 27 g/l
Hydrophobic	PES	160 - 190	Hydrophobic agent: 90 g/l
Hydrophobic	PAC/PES	180	Hydrophobic agent: 40 g/l Acetic acid: 2 g/l
Non-slip	PAC	160	Non-slip agent: 50 g/l
Non-slip	PES/WO	130	Non-slip agent: 30 g/l
Easycare	CO/PES	130 - 170	Crosslinking agent: 50 g/l Catalyst: 7 g/l Acid: 0.5 g/l
Easycare	PES	155	Non-creasing agent (formaldehyde-free): 25 g/l Additive for easycare: 10 g/l Dispersing agent: 1 g/l Levelling agent: 5 g/l
Easycare, softening, optical brightening	CO	100 - 150	Softening agent: 35 g/l Condition agent: 10 g/l Optical brightener: 25 g/l Crosslinking agent: 50 g/l
Easycare, softening, dyeing after-treatment	CO/EL	170	Softening agent: 30 g/l Crosslinking agent: 20 g/l Dyeing after-treatment: 10 g/l Catalyst: 8 g/l Acetic acid: 1 g/l
Easycare, softening, optical brightening	CO	150	Crosslinking agent: 100 g/l Softening agent 1: 40 g/l Softening agent 2: 40 g/l Catalyst 1: 30 g/l Catalyst 2: 5 mg/l Optical brightener: 2 g/l
Easycare, softening	CV/PA 6	180	Crosslinking agent: 65 g/l Catalyst 1: 20 g/l Catalyst 2: 0.2 g/l Softening agent 1: 50 g/l Softening agent 2: 15 g/l
Easycare, softening, anti-slip	LI/CO	180	Crosslinking agent: 70 g/l Catalyst: 40 g/l Anti-slip agent: 35 g/l Softening agent 1: 10 g/l Softening agent 2: 40 g/l Deaeration agent: 2 g/l
Anti-electrostatic, anti-slip	PES	100	Anti-slip agent: 90 g/l Anti-electrostatic agent: 5 g/l

Anti-electrostatic, optical brightening	PES	190	Optical brightener: 9 g/l Anti-electrostatic agent: 7 g/l
Flame retardant	CO	145	Flame retarder: 160 g/l

#### 8.5.4.1 Typical substance specific emission factors of textile auxiliaries

Volatility of textile auxiliaries can be characterised by using some basic substance emission factors.

The tables below give an overview on the main textile auxiliary classes and their emission factors or potential to release Organic-C or specific substances like formaldehyde during thermal processes in finishing. Only auxiliaries listed in the „Textile Auxiliaries Buyers' Guide“ [ 358, TEGEWA 2000 ] are mentioned. All emission factors mentioned in the tables below are measured according to German regulation on air emission.

Due to the different chemical composition and different content of active ingredients, by-products and impurities, considerable differences in the emission behaviour of auxiliaries which belong to the same class of auxiliaries are observed.

However it is evident that especially:

- conventional preparation agents based on mineral oils and fatty acid esters;
- some antifoaming agents;
- some wetting agents;
- some conditioning agents;
- carriers;
- and some flame retardants;
- and some antimicrobials are auxiliaries with a high emission potential concerning Organic-C. However exceptions have to be regarded carefully.

Formaldehyde is released mainly from auxiliaries based on cross-linking compounds (esp. crosslinking agents and reactive flame retardants). Regarding easy-care finishing formaldehyde emission potential of melamine derivatives is in most cases higher compared to auxiliaries based on Dimethyloldihydroxyethen urea derivatives (Table 8.57, Table 8.58 and Table 8.63)

Antifoaming agents which contains highly volatile hydrocarbons as main active compound have a very high emission potential compared to silicon based types (Table 8.59)

For wetting agents on the basis of tributylphosphate, which is characterized by a high vapour pressure substance specific emission factors up to approx. 340 g Organic-C/kg are observed. Due to the fact that various additives/by-products which are not specified in the Material Safety Data Sheets are used and the amount of active ingredients can differ in a great range the emission factors of the other wetting agents mentioned in Table 8.60 vary in a great range.

Softening agents based on fatty acid derivatives are characterized by emission factors between 1 and 5 g Organic-C/kg. Polysiloxane based types show higher values. The highest mentioned value in Table 8.61 is caused by a fatty acid type with an additive of a high volatile wax.

Carriers are highly volatile substances; emission factors above 300 g Organic-C/kg are observed (Table 8.62).

Levelling agents used in dyeing can – like carriers - be transferred to heating steps and cause considerable amounts of off-gas loads. However, due to missing data they are not mentioned here.

Differences in the emission potential of flame retardants are mainly caused by the different types of active substances and various amounts of by-products/additives (alcohols (esp. methanol in case of reactive types), glycols, glycol ethers) (Table 8.63).

Regarding repellents (Table 8.64) also a wide range of emission factors is observed. This is mainly caused by a different kind and quantity of solvents used for fluorocarbon resins (e.g. buthyl/ethyl acetate, methylethyl/isobutylketone, ethandiol, propanediol) and different amounts of active ingredients if paraffine based types are regarded.

In the case of conditioning agents it is clearly to be seen that products based on paraffines (which have a relatively high volatility) have a higher emission potential than fatty acid derivatives (Table 8.65).

For optical brighteners and antielectrostatic agents emission potential vary due to different active ingredients and differences in the formulations of the auxiliaries (Table 8.66 and Table 8.67).

Filling and stiffening agents based on natural or synthetic polymers have a low emission potential (Table 8.68).

Emission levels for aftertreatment agents are low (Table 8.69).

Biocides can contain aromatic hydrocarbons; this leads to increased emission factors (Table 8.70).

Emission potential of silicic acid based non-slip agents is very low (Table 8.71).

**Table 8.56: Textile substrate specific emission factors of different compounds in preparation agents at certain conditions**

	Active ingredients	Organic-C (g/kg)	Testing conditions (Curing temperature (°C); Curing time (min)); Substrate
A	Mineral oils	500 - 800	190 °C, 2 min (PES)
B	Conventional fatty acid esters	100 - 250	190 °C, 2 min (PES)
C	Steric hindered fatty acid esters	50 - 100	190 °C, 2 min (PES)
D	Polyolesters	20 - 200	190 °C, 2 min (PES)
E	Polyester- /polyethercarbonates	10 - 50	190 °C, 2 min (PES)

**Table 8.57: Substance specific emission factors to air (organic carbon and formaldehyde) of easycare finishing agents based on dimethyloldihydroxyethen urea derivatives**

	Organic-C (g/kg)	Formaldehyde (g/kg)	Testing conditions Curing temperature (°C); Curing time (min); Substrate
A	14	4	170 °C; 4 min (CO)
B	15	5	170 °C; 3 min (CO/PES)
C	2	6	180 °C; 1.5 min (CO)
D	15	4	170 °C; 3 min (CO/PES)
E	20	4	170 °C; 3 min (CO)
F	5	15	190 °C; 1.5 min (PES)
G	23	3	150 °C; 2 min (CO)
H	5	3	170 °C; 3 min (CO)

**Table 8.58: Substance specific emission factors to air (organic carbon and formaldehyde) of easycare finishing agents based on melamine derivatives**

	Organic-C (g/kg)	Formaldehyde (g/kg)	Testing conditions Curing temperature (°C); Curing time (min); Substrate
A	13	6	160 °C; 1 min (PES)
B	33	19	190 °C; 1.5 min (PES)
C	24	31	170 °C; 1.5 min (CO)
D	21	51	170 °C; 3 min (CO)
E	7	5	150 °C; 3 min (CO)
F	11	4	170 °C; 3 min (CO)

**Table 8.59: Substance specific emission factors to air of anti-foaming agents**

	Active ingredients	Organic-C (g/kg)	Testing conditions Curing temperature (°C); Curing time (min); Substrate
A	Fatty acid ethoxylate, hydrocarbons	112	190 °C; 1.5 min (PES)
B	Silicone	22	160 °C; 2 min (PES)
C	Hydrocarbons (80 %)	573	170 °C; 4 min (CO)
D	Hydrocarbons	737	190 °C; 1.5 min (PES)

**Table 8.60: Substance specific emission factors to air of wetting agents**

	Active ingredients	Organic-C (g/kg)	Testing conditions Curing temperature (°C); Curing time (min); Substrate
A	Fatty alcohol ethoxylate	64	150 °C; 2 min (WO)
B	Fatty alcohol derivative	31	190 °C; 1.5 min (PES)
C	Tributylphosphate	239	170 °C; 4 min (CO)
D	Tributylphosphate	228	170 °C; 4 min (CO)
E	Tributylphosphate	335	190 °C; 1.5 min (PES)
F	Phosphoric acid esters	45	170 °C; 4 min (BW)
G	Fatty alcohol ethoxylate	81	190 °C; 1.5 min (PES)
H	Fatty alcohol ethoxylate	294	190 °C; 1.5 min (PES)
I	Alkansulphonates	142	150 °C; 1.5 min (PES)

**Table 8.61: Substance specific emission factors to air of softening agents**

	Active ingredients	Organic-C (g/kg)	Testing conditions Curing temperature (°C); Curing time (min); Substrate
A	Polysiloxane	19	170 °C; 4 min (CO)
B	Polysiloxane	10	170 °C; 4 min (CO)
C	Polysiloxane	3	170 °C; 3 min (CO)
D	Polysiloxane	17	160 °C; 0.5 min (CO)
E	Polysiloxane, polyethylene	0.6	170 °C; 4 min (CO)
F	Polysiloxan	17	170 °C; 4 min (CO)
G	Fatty acid derivative	1.9	170 °C; 3 min (CO)
H	Fatty acid derivative	4	170 °C; 4 min (CO)
I	Fatty acid derivative	5	170 °C; 2 min (CO)
K	Fatty acid derivative	2	170 °C; 3 min (CO)
L	Fatty acid derivative	1	170 °C; 4 min (CO)
M	Fatty acid derivative, waxes	38	180 °C; 1.5 min (PES)

Table 8.62: Substance specific emission factors to air of carriers

	Active ingredients	Organic-C (g/kg)	Testing conditions Curing temperature (°C); Curing time (min); Substrate
A	Aromatic carboxylic acid derivative	357	150 °C; 4 min (PES)
B	Aromatic esters	219	190 °C; 1 min (PES)
C	o-phenylphenol	354	190 °C; 1.5 min (PES)

Table 8.63: Substance specific emission factors to air of flame retardants

	Active ingredients	Organic-C (g/kg)	Testing conditions Curing temperature (°C); Curing time (min); Substrate
A	Phosphonic acid derivative	124	190 °C; 1.5 min (PES)
B	Phosphonic acid derivative	37	100 °C; 1 min (PES)
C	Inorganic salts	2	170 °C; 3 min (CO)
D	Organic-P-compound	19; formaldehyde: 30 g/kg	160 °C; 3.5 min (CO)
E	Organic P-compound	0.2; formaldehyde: 3.6 g/kg	120 °C; 2 min (CO)
F	Alkylphosphate	109	150 °C; 2 min (PES)
G	Inorganic/organic salts salts	12	110 °C; 2 min (PES)
H	Organic P-compound	24	175 °C; 1 min (PES)
I	N-and P-containing compound	0.2	150 °C; 3 min (CO)
K	Inorganic/organic salts	3	110 °C; 2 min (PES)
L	N-and P-containing compound	30	190 °C; 1.5 min (PES)

Table 8.64: Substance specific emission factors to air of repellents

	Active ingredients	Organic-C (g/kg)	Testing conditions Curing temperature (°C); Curing time (min); Substrate
A	Fluorocarbon resin	43	190 °C; 1.5 min (PES)
B	Fluorocarbon resin	47	190 °C; 1.5 min (PES)
		42	170 °C; 4 min (CO)
C	Fluorocarbon resin	23	150 °C; 4 min (CO)
D	Fluorocarbon resin	19	150 °C; 3 min (CO)
		9	170 °C; 3 min (PES)
E	Fluorocarbon resin	22	150 °C; 3 min (PES)
G	Various. Fluorocarbon resins (same producer)	13; 15; 5; 7 22; 8; 13; 37	170 °C; 4 min (CO) 190 °C; 1.5 min (PES)
H	Paraffin, inorganic salt	43	120 °C; 2 min (CO)
I	Paraffin, Zr-salt	15	150 °C; 4 min (CO)
K	Paraffin	29	170 °C; 3 min (CO)
L	Polysiloxane	37	150 °C; 3 min (CO)
M	Polyurethane derivative	25	170 °C; 3 min (CO)
N	Melamine derivative	19; formaldehyde: 2 g/kg	140 °C; 4 min (CO)

Table 8.65: Substance specific emission factors to air of conditioning agents

	Active ingredients	Organic-C (g/kg)	Testing conditions Curing temperature (°C); Curing time (min); Substrate
A	Paraffin, polyethylene	75	190 °C; 1.5 min (PES)
B	Fatty acid ester	13	170 °C; 4 min (CO)
C	Wax	67	190 °C; 1.5 min (PS)
D	Paraffin	79	190 °C; 1.5 min (PES)
E	Wax	172	190 °C; 1.5 min (PES)
F	Fatty acid derivative	5	170 °C; 1.5 min (CO)
G	Fatty acid derivative	2	140 °C; 2 min (CO)
H	Fatty acid derivative	3	190 °C; 1.5 min (PES)

Table 8.66: Substance specific emission factors to air of optical brighteners

	Active ingredients	Organic-C (g/kg)	Testing conditions Curing temperature (°C); Curing time (min); Substrate
A	Diaminostilbene disulphonic acid	2	170 °C; 3 min (BW)
B	Pyrazoline derivative	32	190 °C; 1.5 min (PES)
C	Diaminostilbene disulphonic acid	3	170 °C; 3 min (BW)
D	Benzoxazol derivative	2	190 °C; 1.5 min (PS)
E	Distyrylbenzene derivative	18	190 °C; 1.5 min (PS)
F	Pyrene and oxazol derivatives	22	190 °C; 1.5 min (PS)
G	Benzoxazol derivative	11	190 °C; 1.5 min (PS)

Table 8.67: Substance specific emission factors to air of anti-electrostatic agents

	Active ingredients	Organic-C (g/kg)	Testing conditions Curing temperature (°C); Curing time (min); Substrate
A	Org. salt	72	150 °C; 3 min (PES)
B	Alkylphosphate	27	190 °C; 1.5 min (PES)
C	Polyglykolether	7	150 °C; 3 min (PES)
D	Org. P-compound	14	170 °C; 1 min (PES)
E	Quaternary ammonium compound	4	190 °C; 1.5 min (PES)
F	Alkylphosphate	5	190 °C; 1.5 min (PES)
G	Quaternary ammonium compound	24	190 °C; 1.5 min (PES)



Table 8.68: Substance specific emission factors to air of filling and stiffening agents

	Active ingredients	Organic-C (g/kg)	Testing conditions Curing temperature (°C); Curing time (min); Substrate
A	Polyvinyl alcohol	3	170 °C; 1.5 min (CO)
B	Starch derivative	1	160 °C; 4 min (CO)
C	Polyacrylate	2	170 °C; 1.5 min (CO)

Table 8.69: Substance specific emission factors to air of after-treatment agents for fastness improvement

	Active ingredients	Organic-C (g/kg)	Testing conditions Curing temperature (°C); Curing time (min); Substrate
A	Quaternary ammonia compound	3	170 °C; 1.5 min (CO)
B	Quaternary ammonia compound	3	170 °C; 4 min (CO)
C	Quaternary ammonia compound	< 1	180 °C; 1 min (CO)
C	Quaternary ammonia compound	17	190 °C; 1.5 min (PES)

Table 8.70: Substance specific emission factors to air of antimicrobials

	Active ingredients	Organic-C (g/kg)	Testing conditions Curing temperature (°C); Curing time (min); Substrate
A	Heterocyclic compounds	5	170 °C; 4 min (CO)
B	Aromatic compounds	47	170 °C; 4 min (CO)
		241	190 °C; 1.5 min (PES)
C	Isothiazolinone	55	190 °C; 1.5 min (PES)
D	Isothiazolinone	46	170 °C; 4 min (CO)
		302	190 °C; 1 min (pES)

Table 8.71: Substance specific emission factors to air of non-slip, ladder-proof agents

	Active ingredients	Organic-C (g/kg)	Testing conditions Curing temperature (°C); Curing time (min); Substrate
A	Silicic acid	0.6	100 °C; 0.5 min (CO)
		3.7	170 °C; 3 min (PES)
B	Silicic acid	1.3	170 °C; 3 min (CO)
		2.8	170 °C; 1.5 min (PES)

## 8.6 Typical pollutants (and potential sources) in air emissions from textile processes

**Table 8.72: Chemical compounds with less dangerous properties which may be present in waste gas**

Substance	Possible Source
Aliphatic hydrocarbons (C1-C40)	Preparation agents, wetting agents, printing
Aromatic hydrocarbons	Carriers, Machine cleaning
Ketones	Various products
Alcohols (low molecular)	Various products
Esters (low molecular)	Various products
Siloxanes	Softening agents
Carboxylic acids (e.g. acetic acid)	pH-adjustment
Fatty acids	By-product in surfactants
Fatty alcohols	By-product in surfactants
Fatty esters	By-product in surfactants
Fatty amines	By-product in surfactants
Aminoalcohols	By-product in surfactants
Dioles, polyoles	By-product in surfactants
Glycolether	By-product in surfactants
Aliphatic, aromatic ethers	Various products
<i>Source: [ 5, UBA 2001 ]</i>	

Table 8.73: Substances with more dangerous properties which may be present in waste gas

Substance	Possible source
Acetaldehyde	Polyvinylacetate, acetic acid
Acroleine	Decomposition of glycerol
Acrylates (methyl, ethyl, butyl)	Coating agents and binders for non-wovens
Acrylic acid	Polymers, thickeners
Aliphatic amines	Polymers (esp. polyurethanes)
Ammonia	Foaming agents, thickeners
2- aminoethanol	Wetting agents, softeners
Benzylalcohol	Carriers
Biphenyl	Carriers
Bis (2-aminoethyl)-1,2-ethanediamine, N, N	Softeners
Butine-1,4 diol	Fluorocarbon resins
Caprolactam	Polyamide 6 powder/textiles
Chloromethane (methylchloride)	Quaternary ammonium compounds
Chlorinated aromatic hydrocarbons	Carriers
Chloroethanol	Decomposition of flameretardants (chlorinated P-ester)
Chloroparaffins	Flame retardants
Dichloroethene	Polyvinylidenechloride
Dichloromethane	Solvent cleaning
Diethylenetriamine	Softeners
Di(ethylhexyl)phtalate	Dyeing auxiliaries/polymerdispersinons
Diglycidylether	Epoxide resins
Diisocyanatetoluene, 2,4-	Fluorocarbon resin-extender
Diisocyanatetoluene, 2,6-	Fluorocarbon resin-extender
N,N-dimethylacetamide	Fibre solvent (polyamide 6.6, metaramide)
Dimethylethylamine, 1,1-	Rare
Dioxane, 1,4-	Surfactants (ethoxilate)
Diphenylmethane-2,4 diisocyanate	Extender, polyurethanes
Diphenylmethane-4,4' diisocyanate	Extender, polyurethanes
Dipropylenetriamine	Softeners
Epoxy-1-propanol, 2,3-	Some antistatics
Acetic acid-(2-ethoxyethyl)-ester	Softeners/fluorocarbon resins
Ethoxyethanol	Softeners/fluorocarbon resins
Ethanedialdehyde (glyoxal)	Crosslinkers
Ethylenediamine	Softeners
Fluoroorganics, low molecular	Fluorocarbon resins
Formaldehyde	Crosslinkers, conservation agent, stenter off-gas
Formic acid	Various recipes
Hexamethylenediamine	Polycondensationproducts
Hexamethylenediisocyanate	Fluorocarbon resins, polyurethane
Hexanone, 2-	Fluorocarbon resins
Hydrogen chloride	Catalyst
Isocyanatomethyl-3,5,5-trimethylcyclohexyl-Isocyanate,3	Fluorocarbon resins, polyurethane
Methoxy-1-propanol, 2-	Rare
Methoxypropylacetate	Rare
Monochloroacetic acid, Na-salt	Rare
Monochloroacetic acid, 1-methylethylester	Rare
Monochloroacetic acid, ethylester	Rare
Monochloroacetic acid, methylester	Rare
N-alkylmorpholine	Non wovens coating
Sodiumtrichloroacetate	Rare
Oxalic acid	Bleaching auxiliary
Tetrachloroethene	Dry cleaning
Thiourea	Dyeing auxiliary
Trichloroacetic acid	Rare
Triethylamine	Special crosslinkers

Trikresylphosphate (ooo, oom, oop, omm, omp, opp)	Flame retardants
Trimethylphosphate	Flame retardants
tin derivatives, organic, inorganic	Fluorocarbon resins, Hydrophobing agents biocides
Vinylacetate	Polyvinylacetate
<i>Source: [ 5, UBA 2001 ]</i>	

**Table 8.74: Substances with cancerogenic properties which may be present in waste gas**

Substance	Possible source
Polycyclic aromatic hydrocarbons	Crackproducts in off-gass (very low)
PCDD/PCDF (Br, Cl, F)	Crackproducts in off-gass (very low)
Bischloromethylether	Strongest synthetic carcinogenic, spontaneous formation when working with formaldehyde and hydrogenchloride (very low)
Arsenictrioxide/antimonytrioxide	Flame retardants
Dimethylsulphate	Quaternary ammonium compounds
Ethylenimine	Flame retardants
Acrylonitrile	Polymer dispersions
1,3-butadiene	Polymer dispersions
2-vinylcyclohexen	Polymer dispersions
Epichlorohydrin	Polycondensation products
1,2-epoxypropane (propyleneoxide)	Surfactants (propoxilate)
Ethyleneoxide	Surfactants (ethoxilate)
Vinylchloride	Polymer dispersions (PVC)
Acrylamide	Reactive polymers, flame retardants
Butanoneoxime	Fluorocarbon resins, polyurethanes
Pentachlorophenol	Pesticide
Propyleneimine	Flame-retardant and polyurethane crosslinker
N-vinylpyrrolidon	Polyvinylpyrrolidone dispersions
<i>Source: [ 5, UBA 2001 ]</i>	

## 8.7 List of European Textile plants that participated in the data collection

Plant code	Name of the textile plant	City	Country	Process carried out
AT001	Feinjersey Colours Gmbh & Cokg	Rankweil	Austria	Dyeing, Functional finishing
AT002	Fussenegger Textil	Dornbirn	Austria	Bleaching, Dyeing , Printing
AT003	Getzner Textil Ag	Bludenz	Austria	Mercerising, Dyeing , Desizing, Bleaching, Singeing, Functional finishing
AT004	Sattler Ag, Production Thondorf	Goessendorf	Austria	Washing synthetic fibre, Functional finishing
AT005	Schoeller Gmbh & Cokg Hard	Hard	Austria	Dyeing
AT006	Textilveredelung Gmuend Gmbh	Gmünd	Austria	Bleaching, Dyeing , Functional finishing
BE007	Balta Oudenaarde Nv	Oudenaarde	Belgium	Dyeing, Coating and laminating, Thermal treatment, Fabric production
BE008	Denderland Martin Nv	Gijzegem (Aalst)	Belgium	Dyeing, Printing, Thermal treatment
BE009	Ideal Floorcoverings Wielsbeke Nv	Wielsbeke	Belgium	Printing, Fabric production, Coating and laminating, Thermal treatment, Functional finishing
BE010	Maes Dyeing And Finishing	Zwevegem	Belgium	Dyeing , Bleaching, Scouring, Functional finishing, Thermal treatment, Fabric production, Shrink-proof finishing
BE011	Tarkett	Dendermonde	Belgium	Dyeing, Spinning, Functional finishing, Thermal treatment, Coating and laminating
BE013	Veramtex	Brussel	Belgium	Mercerising, Thermal treatment, Functional finishing
BE014	Ververijen Escotex	Deinze	Belgium	Bleaching, Dyeing , Thermal treatment, Functional finishing
CZ015	Adient Strakonice S.R.O.	Strakonice	Czech Republic	Dyeing, Fabric production, Printing, Functional finishing, Coating and laminating, Thermal treatment
CZ016	Nejdecká Česárna Vlny A.S.	Nejdek	Czech Republic	Raw wool scouring, Shrink-proof finishing, Thermal treatment
CZ017	Nová Mosilana, A.S.	Brno	Czech Republic	Dyeing, Spinning, Fabric production, Singeing, Functional finishing, Shrink-proof finishing, Thermal treatment, Other
CZ018	Toray Textiles Central Europe S.R.O.	Prostějov	Czech Republic	Desizing, Dyeing , Fabric production, Functional finishing, Coating and laminating, Thermal treatment
CZ019	Velveta - Upravna	Varnsdorf	Czech Republic	Bleaching, Dyeing , Desizing, Printing, Functional finishing, Singeing
CZ020	Vlanp A.S.	Nejdek	Czech Republic	Dyeing, Spinning
DE021	Amann & Soehne Gmbh & Co. Kg; Plant Augsburg	Augsburg	Germany	Dyeing , Scouring, Bleaching, Washing synthetic fibre
DE022	Textilveredlung Drechsel Gmbh	Selb	Germany	Raw wool scouring, Washing synthetic fibre, Desizing, Scouring, Bleaching, Dyeing , Coating and laminating, Thermal treatment, Functional finishing

DE023	Dreiländereck Textilveredelungs Gmbh	Wehr	Germany	Washing synthetic fibre, Mercerising, Bleaching, Dyeing , Functional finishing, Thermal treatment, Other
DE024	Eratex	Herford	Germany	Desizing, Dyeing , Scouring, Singeing, Functional finishing, Coating and laminating, Thermal treatment
DE025	Blanke Textech Gmbh	Bad Salzuflen	Germany	Washing synthetic fibre, Dyeing , Printing, Functional finishing, Thermal treatment, Coating and laminating
DE026	G. Van Clewe Gmbh & Co. Kg	Hamminkeln	Germany	Washing synthetic fibre, Desizing, Bleaching, Dyeing , Singeing, Functional finishing, Printing, Thermal treatment, Coating and laminating
DE029	Hanns Glass Paderborn	Paderborn	Germany	Dyeing, Fabric production, Thermal treatment, Coating and laminating
DE030	Hch. Kettelhack Gmbh & Co. Kg	Rheine	Germany	Washing synthetic fibre, Desizing, Mercerising, Dyeing , Bleaching, Singeing, Functional finishing, Thermal treatment
DE031	Hermann Biederlack Gmbh & Co.Kg	Greven	Germany	Dyeing, Spinning, Fabric production
DE032	Eing Textilveredlung Und Handelsgesellschaft Mbh & Co. Kg	Gescher	Germany	Washing synthetic fibre, Desizing, Bleaching, Dyeing , Singeing, Printing, Functional finishing, Coating and laminating, Thermal treatment, Other
DE034	Kob Medical Devices Deutschland Gmbh	Wolfstein	Germany	Washing synthetic fibre, Desizing, Bleaching, Dyeing , Spinning, Fabric production, Functional finishing, Thermal treatment, Other
DE039	Main Site	Schüttorf	Germany	Desizing, Mercerising, Bleaching, Dyeing, Washing synthetic fibre, Fabric production, Singeing, Functional finishing, Thermal treatment, Shrink- proof finishing
DE041	Sanders.Eu	Bramsche	Germany	Desizing, Bleaching, Dyeing , Singeing, Functional finishing, Thermal treatment
DE042	Schmitz Textiles Gmbh + Co. Kg	Emsdetten	Germany	Washing synthetic fibre, Desizing, Bleaching, Dyeing, Fabric production, Printing, Functional finishing, Coating and laminating, Other, Thermal treatment
DE044	Schümer Textil Gmbh	Schüttorf	Germany	Desizing, Mercerising, Bleaching, Dyeing, Singeing, Functional finishing, Thermal treatment
DE045	Setex-Textil-Gmbh	Greven	Germany	Washing synthetic fibre, Desizing, Bleaching, Dyeing , Singeing, Functional finishing, Thermal treatment, Coating and laminating
DE046	Texra Gmbh	Radevormwald	Germany	Washing synthetic fibre, Dyeing , Functional finishing, Coating and laminating, Thermal treatment
DE047	Textilveredlung An Der Wiese Gmbh	Lörrach	Germany	Desizing, Mercerising, Bleaching, Dyeing, Singeing, Other, Thermal treatment, Functional finishing

DE049	Bierbaum Unternehmensgruppe GmbH & Co. Kg	Borken	Germany	Desizing, Bleaching, Dyeing , Scouring, Singeing, Printing, Functional finishing, Coating and laminating
DE050	Thorey Gera Textilveredelung GmbH	Gera	Germany	Washing synthetic fibre, Desizing, Bleaching, Functional finishing, Thermal treatment
DE051	Tvu Textilveredlungsunion GmbH	Leutershausen	Germany	Washing synthetic fibre, Scouring, Bleaching, Dyeing , Functional finishing, Other
DK054	Ege	Herning	Denmark	No information
ES058	Textil Santanderina, S.A.	Cabezón De La Sal	Spain	Mercerising, Bleaching, Dyeing , Desizing, Spinning, Fabric production, Printing, Functional finishing, Thermal treatment, Singeing
FR130	Etablissement Samuel Roche	La Ricamarie	France	Dyeing, Fabric production
FR131	Crouvezier Developpement	Gerardmer	France	Washing synthetic fibre, Desizing, Bleaching, Dyeing , Printing, Functional finishing, Coating and laminating, Thermal treatment
FR132	Decoster Caulliez	La Gorgue	France	Bleaching, Dyeing
FR133	Union Textile De Tourcoing Industrie	Tourcoing	France	Dyeing
FR134	Feutrie Sas	Sailly Sur La Lys	France	Washing synthetic fibre, Desizing, Mercerising, Bleaching, Dyeing , Singeing, Functional finishing
FR135	Dickson Constant	Wasquehal	France	Washing synthetic fibre, Functional finishing, Coating and laminating, Thermal treatment, Fabric production
FR136	Tdv Industries	Laval	France	Desizing, Scouring, Bleaching, Mercerising, Dyeing , Spinning, Fabric production, Singeing, Functional finishing, Thermal treatment
IT059	Beste Spa	Cantagallo	Italy	Scouring, Mercerising, Bleaching, Dyeing, Singeing, Dry cleaning, Thermal treatment, Functional finishing
IT060	Candiani Spa	Robecchetto Con Induno	Italy	Dyeing , Desizing, Mercerising, Spinning, Shrink-proof finishing, Fabric production, Singeing, Coating and laminating
IT061	Carbonizzo Cocci S.P.A.	Prato	Italy	Scouring, Wool Carbonising
IT063	Eurojersey Spa	Caronno Pertusella	Italy	Dyeing, Fabric production, Dry cleaning, Thermal treatment, Printing, Functional finishing
IT064	Fit Finissaggio Industriale Toscano S.R.L.	Montemurlo	Italy	Desizing, Mercerising, Bleaching, Dyeing, Washing synthetic fibre, Scouring, Singeing, Functional finishing, Thermal treatment, Other
IT065	F.Lli Ciampolini & C. S.P.A.	Prato	Italy	Desizing, Mercerising, Bleaching, Dyeing, Singeing, Functional finishing, Thermal treatment
IT067	Finissaggio E Tintoria Ferraris S.P.A. - Benna	Benna	Italy	Dyeing, Shrink-proof finishing, Printing, Other

IT068	Finissaggio T.R.T. S.R.L. / Ou Via Strobino	Prato	Italy	Washing synthetic fibre, Desizing, Scouring, Bleaching, Dyeing , Functional finishing, Thermal treatment, Other
IT069	Finissaggio T.R.T. S.R.L. / Ou Via Galvani	Prato	Italy	Desizing, Mercerising, Scouring, Bleaching, Singeing, Functional finishing, Thermal treatment, Other
IT070	Tintoria F.Lli Pratesi S.R.L.	Prato	Italy	Dyeing , Washing synthetic fibre, Bleaching, Scouring, Functional finishing, Thermal treatment
IT071	Gruppo Colle S.R.L.	Cantagallo	Italy	Scouring, Bleaching, Dyeing , Thermal treatment, Other, Other, Functional finishing
IT072	Gruppo Colle S.R.L. - Colorfibre Division	Agliaia (Pistoia)	Italy	Scouring, Bleaching, Dyeing , Thermal treatment, Other, Other
IT073	Jersey Mode S.P.A.	Prato	Italy	Dyeing, Functional finishing
IT074	Lavatura Industriale La Fonte S.P.A.	Prato	Italy	Washing synthetic fibre, Scouring, Desizing, Functional finishing, Dry cleaning, Thermal treatment, Other
IT075	Pettinatura Di Verrone S.R.L.	Verrone	Italy	Raw wool scouring, Spinning, Other
IT076	Pettinatura Lane Di Romagnano Sesia S.P.A.	Romagnano Sesia	Italy	Raw wool scouring, Spinning, Other
IT077	Rifinitone Alan S.P.A.	Prato	Italy	Desizing, Mercerising, Scouring, Bleaching, Dyeing , Singeing, Wool Fulling, Functional finishing, Thermal treatment, Other
IT078	Cambi Luigi & C S.R.L.	Prato	Italy	Desizing, Washing synthetic fibre, Bleaching, Scouring, Dyeing , Singeing, Functional finishing, Thermal treatment, Other, Wool Fulling, Dry cleaning
IT079	Ellevu Rifinitone S.R.L.	Prato	Italy	Scouring, Wool Fulling, Functional finishing, Thermal treatment, Other
IT082	Successori Reda S.P.A	Valdilana	Italy	Dyeing, Spinning, Fabric production, Singeing, Functional finishing, Thermal treatment, Wool Fulling, Other
IT083	Ti.F.A.S. S.P.A.	Lurate Caccivio (Co)	Italy	Scouring, Dyeing , Functional finishing, Thermal treatment, Singeing
IT084	Ti.Bel Spa	Brentino Belluno	Italy	Bleaching, Dyeing , Thermal treatment, Other
IT085	Tintalana S.R.L. - Sagliano Micca (Bi)	Sagliano Micca	Italy	Dyeing, Printing, Other
IT087	Tintoria Di Verrone S.R.L.	Verrone	Italy	Dyeing, Shrink-proof finishing, Other
IT088	Tintoria Fiordiluce Srl	Prato	Italy	Dyeing , Bleaching, Thermal treatment
IT089	Tintoria Martelli & C. S.R.L.	Vaiano	Italy	Scouring, Dyeing , Bleaching, Thermal treatment, Other
IT090	Tintoria Martelli & C. S.R.L.	Vaiano	Italy	Scouring, Dyeing , Bleaching, Thermal treatment, Other
IT091	Tintoria Rifinitone Banelli S.R.L.	Prato	Italy	Scouring, Dyeing , Functional finishing, Thermal treatment, Other
IT092	Tollegno 1900 S.P.A. - Via Roma 9	Tollegno	Italy	Dyeing, Spinning, Other
IT094	Rifinitone Vignali Spa	Montemurlo (Prato)	Italy	Dyeing , Desizing, Scouring, Bleaching, Functional finishing, Thermal treatment, Coating and laminating



IT096	Zanolo Spa	Arborio	Italy	Dyeing, Other
IT097	Zegna Baruffa Lane Borgosesia S.P.A. - Borgosesia	Borgosesia	Italy	Dyeing , Bleaching, Shrink-proof finishing, Spinning, Printing, Other
IT137	Tessilquatro S.P.A.	Rovetero	Italy	Dyeing
PT098	A Penteadora - Sociedade Industrial De Penteação E Fiação De Lãs, S. A.	Unhais Da Serra	Portugal	Dyeing, Spinning, Fabric production, Wool Fulling, Functional finishing, Thermal treatment
PT099	Acatel - Acabamentos Têxteis S.A	Barcelos	Portugal	Dyeing, Printing, Functional finishing
PT102	Domingos De Sousa & Filhos S.A.	Guimarães	Portugal	Scouring, Bleaching, Dyeing , Spinning, Functional finishing, Fabric production
PT104	Fabrica De Tecidos De Viuva De Carlos Da Silva Areias & C <sup>a</sup> , Sa	Vizela	Portugal	Dyeing, Bleaching
PT105	Faria & Coelho, Lda	Vila Nova De Famalicão	Portugal	Dyeing , Bleaching, Thermal treatment
PT108	Lameirinho - Indústria Têxtil, S.A.	Guimarães	Portugal	Washing synthetic fibre, Desizing, Mercerising, Scouring, Bleaching, Dyeing, Fabric production, Printing, Functional finishing
PT109	Mgc Acabamentos Têxteis, S.A.	Ronfe	Portugal	Desizing, Mercerising, Scouring, Bleaching, Dyeing , Singeing, Functional finishing, Shrink-proof finishing, Thermal treatment
PT110	Mundotêxtil - Indústrias Têxteis, Sa.	Vizela	Portugal	Dyeing, Fabric production
PT111	Paulo De Oliveira Sa	Covilhã	Portugal	Desizing, Dyeing , Spinning, Fabric production, Wool Fulling, Functional finishing, Thermal treatment, Shrink-proof finishing, Dry cleaning
PT113	Riler- Indústria Têxtil, S.A.	Vizela	Portugal	Dyeing , Washing synthetic fibre, Bleaching, Functional finishing
PT114	Riopele Têxteis, Sa	Vila Nova De Famalicão	Portugal	Mercerising, Dyeing , Washing synthetic fibre, Desizing, Scouring, Bleaching, Thermal treatment, Dry cleaning
PT115	Somelos Acabamentos Têxteis Sa	Guimarães	Portugal	Dyeing
PT117	Têxteis Luís Simões	Barcelos	Portugal	Dyeing , Bleaching, Functional finishing
SE118	Almedahls	Kinna	Sweden	Washing synthetic fibre, Scouring, Bleaching, Dyeing , Singeing, Printing, Functional finishing, Shrink-proof finishing, Coating and laminating, Thermal treatment
SE119	Fov Fabrics Ab	Borås	Sweden	Washing synthetic fibre, Desizing, Dyeing, Fabric production, Thermal treatment, Functional finishing
SE120	Sjuhäradsbygdens Färgeri Ab	Kinna	Sweden	Dyeing , Washing synthetic fibre, Desizing, Bleaching, Singeing, Functional finishing, Coating and laminating, Shrink-proof finishing, Thermal treatment, Other
UK121	Brintons Carpets Ltd. Package Dye	Kidderminster	United Kingdom	Dyeing
UK123	Dewsbury Mills	Dewsbury	United Kingdom	Scouring, Dyeing , Other
UK124	Heathcoat Fabrcs Ltd	Tiverton	United Kingdom	Washing synthetic fibre, Dyeing , Functional finishing, Thermal treatment

UK126	Beech Hill Plant	Gtr Manchester	United Kingdom	Dyeing, Fabric production, Coating and laminating
UK127	Pincroft	Chorley	United Kingdom	Desizing, Mercerising, Bleaching, Dyeing, Scouring, Singeing, Printing, Functional finishing, Thermal treatment, Other
UK128	Standard Wool Uk Ltd	Dewsbury	United Kingdom	Raw wool scouring
UK129	Cashmere Works	Bradford	United Kingdom	Raw wool scouring

## 8.8 ECHA's Methodology to prioritise chemicals for prevention or control of emissions

[ 347, Pillet et al. 2020 ]

This Annex gives more details about the methodology to priorities chemicals for prevention or control of emissions in the process of chemicals selection as introduced in Section 4.1.6.1.

### 8.8.1 Objective and scope

The methodology described below aims to support site managers [operators] in the identification of process chemicals for which (additional) emission prevention and control measures may be required as a priority. The method is based on the chemicals inventory information (see Section 4.1.6.2) and supports risk based identification of priority substances (see Section 4.1.6.1).

Figure 8.32 provides an overview on the methodology and the steps to carry out. The inventory of hazardous chemical products<sup>5</sup> used onsite should contain the information necessary to identify those that need to be addressed as a priority with regard to prevention and control of emissions.

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<sup>5</sup> Hazardous chemical refers to substances or mixtures that are classified and labelled according to the CLP regulation. A mixture is composed of two or more ingredient substances.

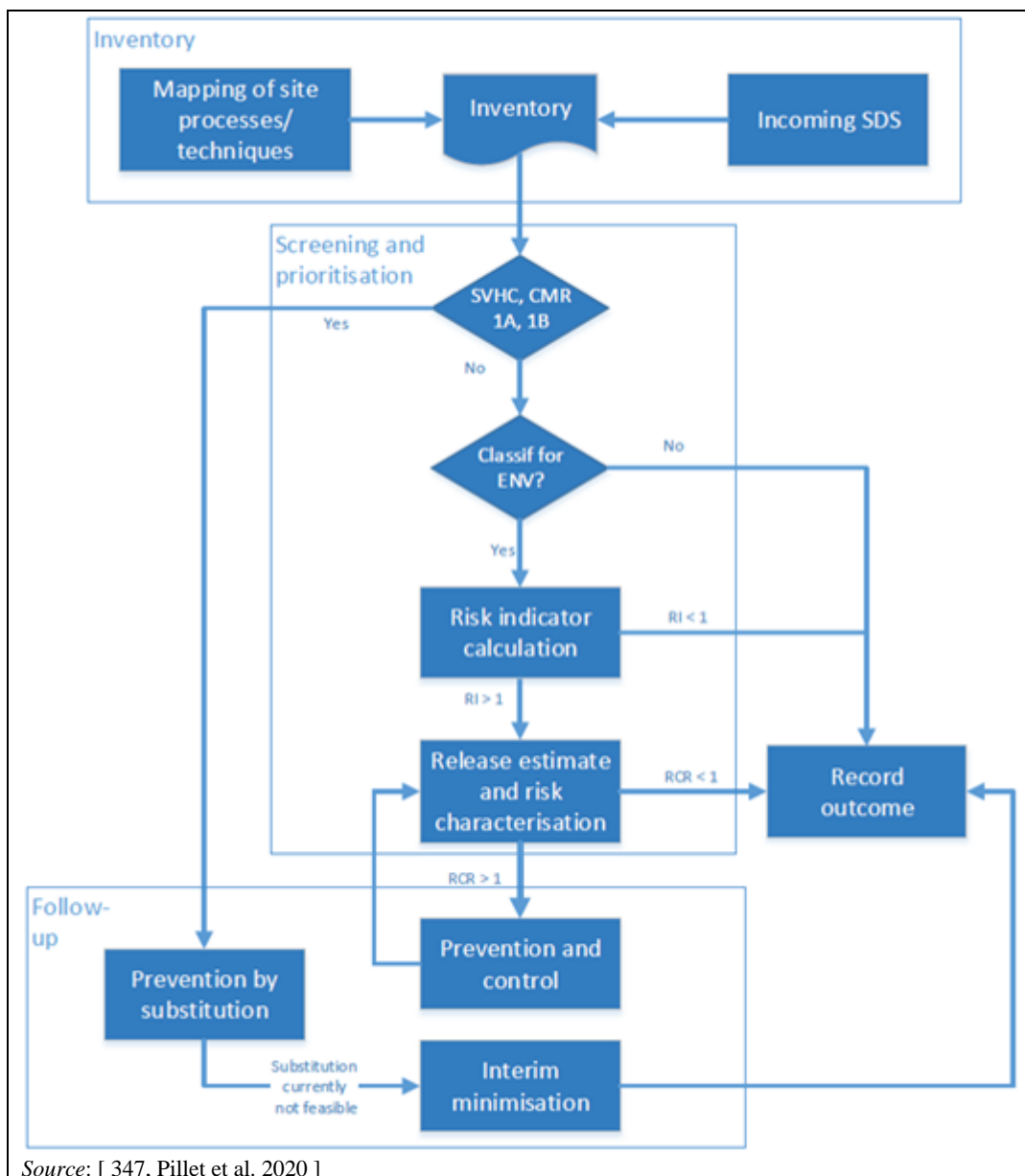


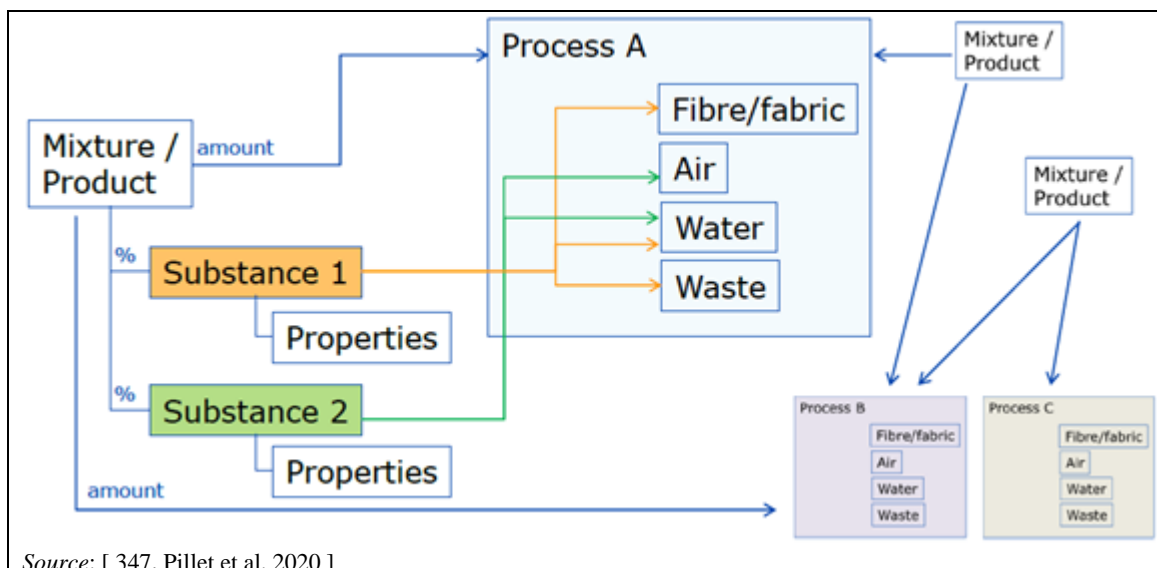
Figure 8.32: The overall workflow of the methodology

## 8.8.2 Description of the methodology

### 8.8.2.1 The inventory - mapping of site processes and chemical products (mixture and substances as such) used

The purpose of the inventory is to combine chemicals-related information (such as identity, composition and amount of each purchased hazardous chemical product) and site-related information (such as different processes used and abatement techniques in place). The inventory should be structured in a way that allows to track in which processes the chemical products are used.

In order to identify the potential source of release from the site to the different environmental compartments, the fate of the ingredient substances during the different processes where they are used will need to be identified and recorded in the inventory. For example: does substance 1 used in process A attach to the fibre, remain in waste water, is released to air or is disposed-off as waste. This is illustrated in Figure 8.33 below.



Source: [ 347, Pillet et al. 2020 ]

**Figure 8.33: Function of inventory**

The supplier's safety data sheet (SDS) should be the first source of information on the chemical product and its ingredient substances. However, the operator can also use ECHA website to cross-check the information for certain substances. For instance, substances identified as SVHCs can be found on the Candidate list: <https://echa.europa.eu/candidate-list-table>.

Based on up-to-date SDS for the hazardous chemical products used on site, the operator populates the inventory with the necessary information from the SDS. He also maps the hazardous chemicals to the processes in which they are used as well as of the type of emission control measures in place. This mapping should be reviewed at regular intervals and updated whenever an updated SDS is received or when a change in the site takes place that is relevant to the content of the inventory.

If the chemical product is a mixture (i.e. composed of two or more substances), the operator should report in the inventory the identity and classification of each ingredient substance, its properties and the concentration in the mixture. This is important, because most steps of the methodology should be carried out at substance level, taking into account the aggregated amount of the individual substances used.

As illustrated in Figure 8.32, the methodology is carried out stepwise. At the beginning, a low amount of information for each substance is needed. For substances that cannot be deprioritised on this basis, additional information is collected before undertaking the next step. For example specific quantification of release of the ingredient-substances, is only entered after the identification of and initial screening for a limited number of substances that need further assessment. At the end, those substances that need follow up action are identified.

An example with the full content of the inventory is given in the appendix to this document.

### 8.8.2.2 Screening and prioritisation

The different steps as illustrated in Figure 8.32 are described here below.

#### 8.8.2.2.1 Screening for specific hazard properties

Substances with specific hazard properties should be prioritised by default, regardless the amount used or the potential release from the site. These are:

- Substances identified as substances of very high concern SVHC and included in the Candidate List<sup>6</sup> (PBT, CMR 1A or 1B, equivalent concern such as concern for endocrine disruption).
- Substances classified as CMR 1A or 1B (Annex VI of the CLP Regulation<sup>7</sup>), even if not yet identified as SVH.

The release of these substances should be prevented. The most efficient way to do this is substitution by less hazardous substances or by processes where these substances are not needed. As interim solution until substitution becomes feasible, the releases from the site to the environment should be minimised as far as technically and practically possible.

After the screening for SVHC and/or CMR substances, the operator would focus on the environmental hazard profile of the substances. Substances that are not classified hazardous to the aquatic environment can be considered of low priority. The operator can record this outcome and no further action is needed for these substances.

All other substances that are classified hazardous to the aquatic the environment (either chronic or acute, hazard statement H400, H410, H411, H412 or H413 in section 3.1 or 3.2 of the SDS) should be assessed further.

#### 8.8.2.2.2 Risk indicator

As a first step, a ranking can be done using a risk indicator, assuming worst case release to water. Note that substances which adsorb and may end in the soil, are not yet taken into account in this methodology. If a hazardous substance has a  $Kow > 5$ , it may have to be considered separately<sup>8</sup>.

The risk indicator takes into consideration the aggregated amount of the substance used on site (from different chemical products), the predicted no-effect-concentration (PNEC) for the water compartment, the biodegradability of the substance (assuming that the wastewater is treated in a biological sewage treatment plant before final release to the environment), and a default dilution factor in the environment.

The risk indicator expresses the relation of the substance amount potentially released and diluted in the environment with the concentration of the substance causing adverse effects on the aquatic ecosystems (PNEC).

The risk indicator can be calculated as follow:

$$RI = [DA \times BF / CF] / PNEC \text{ water}$$

**Table 8.75: Input and output for risk indicator calculation per substance**

Acronym	Definition	Source	Value
RI (-)	Risk indicator	-	Outcome of the calculation

<sup>6</sup> The full list of these substances is published on the ECHA website: <https://echa.europa.eu/candidate-list-table>

<sup>7</sup> <https://echa.europa.eu/information-on-chemicals/annex-vi-to-clp>

<sup>8</sup> This methodology could be extended in the future to also include this type of substances.

DA (kg/d)	Daily amount used at the site for the substance	Inventory Note: the amount of substance is to be aggregated across the different mixtures in which it may be contained. It is assumed in this first step that 100% of the amount is released to water.	Based on the amount of chemical product used at the site and the concentration of each specific ingredient substance in that product
BF (-)	Biodegradation factor based biodegradability screening tests	SDS section 12 Note: biodegradation factor for substances readily biodegradable, based on biodegradability screening tests. The use of such factor assumes that the waste water is biologically treated (onsite or of site) before release to surface water. If there is no biological treatment plant, then this factor should be set to 1.	If the substance is readily biodegradable set to 0.15 If not readily biodegradable, this factor should be set to 1
CF (-)	Conversion factor from amount into concentration (mg/l)	Note: takes into account the dilution into a default effluent flow rate (2000 m <sup>3</sup> /d), with further default dilution into a river (10) and a unit conversion factor of 1000 (g/kg)	20 (fixed value)
PNEC <sub>water</sub> (mg/l)	Predicted No Effect Concentration (PNEC)	SDS section 8	PNEC for freshwater

- Substances getting a risk indicator below 1 are considered of low priority, as even 100% emission of the substance into waste water would not lead to adverse effects. The operator can record the outcome of the screening and no further action is needed.
- For substances getting a risk indicator above 1, a more detailed assessment needs to be conducted (see next section).

### 8.8.2.2.3 Release estimate and risk characterisation

The more detailed assessment follows in a simplified way the methodology set in Annex I of the REACH Regulation<sup>9</sup> and is focussed on emissions to water only.

This step of the assessment includes more realistic assumptions on releases of the substance from the site, information about any off-site abatement measures (such as municipal biological treatment plant) and information about the potential for dilution in the environment via the flow of the receiving water compartment. This information is used to model the predicted environmental concentration (PEC) of the substance in the receiving water and other compartments (sediment and soil), and calculating the corresponding risk characterisation ratios (RCR). The RCR expresses the ratio between the predicted environmental concentration (PEC) and the predicted no-effect concentration (PNEC).

The tool commonly used to estimate the PEC is EUSES. The ECHA tool for Chemical Safety Assessment, Chesar (<https://chesar.echa.europa.eu/>) contains the EUSES model, is publically available and can be already used for this purpose<sup>10</sup>.

<sup>9</sup> Annex I of the REACH Regulation sets the provisions for assessing substances and preparing chemical safety reports.

<sup>10</sup> ECHA considers whether there may be a need for a simplified version of the tool supporting operators of sites in performing their assessments.

The release estimate and risk characterisation step follows an iterative approach. An initial assessment is first conducted with conservative default assumptions. If the risk characterisation ratio of the substance is above 1, a second more refined release estimate and risk characterisation can be undertaken.

The following information (substance and process/use condition related) is needed for iterating the exposure assessment, and should be added to the inventory:

**Table 8.76: Substance properties**

Acronym	Definition	Source / reference
MW (g/mol)	Molecular weight	ECHA dissemination*
S (mg/l)	Solubility	Section 9 SDS
VP (Pa)	Vapour Pressure	Section 9 SDS
Log Kow <sup>11</sup>	Partition coefficient octanol water	Section 9 SDS
Log Koc	Sorption coefficient for organic carbon	Section 12 SDS
Biodegradability	Biodegradability screening tests	Section 12 SDS
PNECs (mg/l)	Predicted No Effect Concentration for water, sediment and soil.	Section 8 SDS

\* Search with substance name or EC/CAS number at <https://echa.europa.eu/information-on-chemicals>. In future this info will become available in the SDS.

**Table 8.77: Use conditions and releases**

Parameter	Source / Value (default)
DA (kg/day)	Daily amount used at the site for the substance (kg/d), see Table 8.75
Biological STP	Is the substance sent to a biological treatment plant (on site or off site)? Default: Yes
Release factor to water (fraction)	This parameter <b>can be iterated</b> (see below). Note that for the calculation of the Risk Indicator, 1 was used for any substance)
Release rate (water) (kg/day)	Daily Amount (kg/d) x Release factor (water) The release rate <b>can, in the iteration</b> , be replaced by measured release of the substance (if available, see below)
Dilution to surface water (-)	The dilution in the receiving environment is by default set to 10, with the following assumptions: effluent flow rate 2.000 m <sup>3</sup> /d and river flow rate 18.000 m <sup>3</sup> /d - It <b>can be iterated</b> using site specific data, river and effluent flow rate (m <sup>3</sup> /d); Note that a maximum dilution factor (river flow divided by effluent flow) of 1.000 is allowed

The exposure assessment is based on a pre-determined scenario, where the releases to water are distributed, directly (from the site) or indirectly (from the biological treatment plant), among different environmental compartments (water, soil, sediments).

Environmental exposure concentrations for these different compartments, the PECs, are estimated according to this fixed scenario, for example using EUSES or Chesar. At the end, the PECs (PEC freshwater, PEC FW sediments, PEC agricultural soil) are compared to the PNECs (threshold values for environment) to calculate the RCR.

- Substances getting a risk characterisation ratio (RCR) below 1 for all compartments are considered of low priority. The operator can record the outcome of the assessment and no further action is needed.

<sup>11</sup> If a hazardous substance has a Kow>5, it may have to be considered separately. This methodology could be extended in the future to also include this type of substances.



- For substances getting a risk characterisation ratio above 1 (even after further refinement of the release/exposure estimate) follow-up actions are needed.

The initial assessment based on conservative default assumptions can be refined with local information regarding i) release factors/release rates for the individual substances<sup>12</sup> (based on knowledge on losses/releases from the processes and/or efficiency of abatement techniques (put) in place) or ii) local dilution factor to surface water (see Table 8.77).

### Release factors

For the release factors, the following source of information can be used to iterate the estimation of exposure and RCR.

- Release factors for textile processes set based on the technical fate of the substance<sup>13</sup>:
  - 1 for substance not intended to fix to the fibre of the textile (e.g. surfactants)
  - 0.5 for substances intended to remain on the fibre of the textile (e.g. dyes)
  - 0 (no release) in case of very volatile substances used in dry process only
- Fixation rates as provided by the supplier. The fraction of chemical not fixing to the fibre (calculated as 1 - fixation rate), can be used as a proxy for the release factor from the process.
- Emission factors sourced from literature, in particular the OECD Emission Scenario Document on Textile finishing and Textile Dyeing<sup>14</sup> (generic factors summarised in Table 8.78).
- Emission factors provided by downstream user sector organisations in the framework of use-maps set up under REACH. The emission factors provided in this source are usually called Specific Environmental Release Factors (SPERCs)<sup>15</sup>.

**Table 8.78: Typical release factors to water for different kinds of textile chemicals**

Type of textile chemical	Process	Typical release factor to water or waste
Basic chemicals	Pre-treatment	1
Auxiliaries	Pre-treatment	1
Textile auxiliaries not intended to fix to the fibre	Exhaust process	1
Textile auxiliaries expected to fix to the fibre	Exhaust process	0.2
Functional finishing agents	Padding	0.1
Dye stuff	Padding	0.1
Dye stuff	Printing	0.25
Finishing, printing paste	Coating	0.01

<sup>12</sup> The different ingredient substances in the pre-treatment, dyeing, finishing, printing or coating chemical may have different functions and thus may behave differently. A chemical product intended for dyeing for example, may nevertheless contain substances serving as processing aid and not fixing to the fibre. Thus the information on the fate may need to be differentiated per ingredient substance.

<sup>13</sup> Those release factors are worst case realistic assumption used in the context of REACH See Appendix 1 in Guidance on information requirements and Chemical Safety Assessment Chapter R.16: Environmental exposure assessment [https://echa.europa.eu/documents/10162/13632/information\\_requirements\\_r16\\_en.pdf/b9f0f406-ff5f-4315-908e-e5f83115d6af](https://echa.europa.eu/documents/10162/13632/information_requirements_r16_en.pdf/b9f0f406-ff5f-4315-908e-e5f83115d6af)

<sup>14</sup> <http://www.oecd.org/chemicalsafety/risk-assessment/emissionscenariodocuments.htm>

<sup>15</sup> See also ECHA's use-map library <https://echa.europa.eu/csr-es-roadmap/use-maps/use-maps-library>. Please note: For textile dyeing and finishing products, the relevant sector organisation have not published a use-map up to now.

### Release rate

Alternatively the release rate may be iterated based on i) measured concentration of residual substance in the waste water stream coming from the process and ii) waste water amount. Note: Those parameters should refer to the same time-frame for calculating a reliable emission rate.

#### 8.8.2.3 Follow-up

Chemicals containing SVHC, CMR 1A or 1B should be substituted either by alternative less hazardous substances or different processes. Where substitution is currently not feasible, the operator should minimise the releases to the environment as far as technically and practically possible with the view to minimising the likelihood of adverse effect. In addition, the operator should actively search for potential alternatives (substance or processes). Once the operator identifies an alternative, he should set a substitution plan and implement it. The operator should keep a record of these activities and of their outcome.

For all other substances, a risk characterisation ratio above 1 indicates that significant adverse impacts on the environment cannot be excluded, and hence additional action to prevent and control the emissions is needed.

The operator can consider a number of actions:

- Process efficiency: review the processes where the substance is used to see whether the loss of substance to waste water or air can be reduced.
- Abatement: introduce additional abatement measure to decrease the amount released.
- Substitution: replace the substance either by alternative less hazardous substance or different process.

After the implementation of any corrective action, the operator should review his assessment and verify if the risk characterisation ratio has gone below 1.

When this is the case, the operator can record the outcome of the assessment and no further action is needed.

#### 8.8.2.4 Record outcome

The overall aim of the methodology is to prioritise the chemicals used at the site for prevention or control of emissions. When the operator records the outcome of the different steps of the process, he will be able to sort the chemicals into the following categories:

- Chemicals products containing SVHC and CMRs 1A/1B for which prevention of releases via a substitution plan is needed as a priority;
- Chemicals products containing environmentally classified substances for which the risk characterisation ratio is  $> 1$ , and hence measures for emission prevention and control (abatement plan) should be considered as a priority.
- Chemicals products which composition doesn't seem to raise major concern at present. The hazard profile of the substances in the products (sometimes combined with information on amount used and process/fate) seem to suggest that prevention and control of emissions for these chemicals are of no particular priority.

The operator should ensure that his overall assessment of the chemicals he uses stays up to date. The assessment should be reviewed at regular intervals and updated whenever an updated SDS is received or when a relevant change in the site takes place (e.g. changes in chemicals used, in amounts used, in processes, etc.).

## 8.9 Materials Restricted Substance List of Zero Discharge of Hazardous Compounds collaboration (ZDHC MRSL)

This Annex is an extract from the Materials Restricted Substance Lists [ 153, ZDHC 2020 ] as introduced in Section 4.1.6.3.

Category of chemicals	Additional information
Alkylphenol (AP) and Alkylphenol Ethoxylates (APEOs) including all isomers	APEOs can be used as or found in: detergents, scouring agents, spinning oils, wetting agents, softeners, emulsifier/dispersing agents for dyes and prints, impregnating agents, de- gumming for silk production, dyes and pigment preparations, polyester padding and down/feather fillings.
Anti- Microbials & Biocides	These substances have biocidal properties, making it useful for multiple preservation applications.
Chlorinated parafins	These are used occasionally as flame retardants in certain industries. In leather formulations, these are also used as fat liquoring agents.
Chlorobenzenes and Chlorotoluenes	Chlorobenzenes and chlorotoluenes (chlorinated aromatic hydrocarbons) can be used as carriers in the dyeing process of polyester or wool/polyester fibres. They can also be used as solvents.
Chlorophenols	Chlorophenols are polychlorinated compounds used as preservatives or pesticides. Pentachlorophenol (PCP) and tetrachlorophenol (TeCP) have been used in the past to prevent mould when storing/transporting raw hides and leather. They are now regulated and should not be used.
Dyes – Azo (forming restricted amines)	Azo dyes and pigments are colourants that incorporate one or several azo groups (-N=N-) bound with aromatic compounds. Thousands of azo dyes exist, but only those that degrade to form the listed cleavable amines are restricted. Azo dyes that release these amines are regulated and should no longer be used for the dyeing of textiles.
Dyes – Carcinogenic or equivalent concern	Most of these substances are regulated and should no longer be used for the dyeing of textiles.
Dyes – Disperse (Sensitising)	Disperse dyes are a class of water-insoluble dyes that penetrate the fibre system of synthetic or manufactured fibres and are held in place by physical forces without forming chemical bonds. Disperse dyes are used in synthetic fibre (e.g. polyester, acetate, polyamide). Restricted disperse dyes are suspected of causing allergic reactions and should no longer be used for dyeing of textiles.
Dyes – Navy Blue Colourant	Navy blue colourant is regulated and should no longer be used for the dyeing of textiles.
Flame retardants	Flame retardant chemicals are rarely used to meet flammability requirements in children's clothing and adult products. They should no longer be used in apparel and footwear. All halogenated flame retardants are banned from intentional use that means including but not exclusive the list below;
Glycols/Glycol Ethers	In apparel and footwear, glycols have a wide range of uses including as solvents for finishing/cleaning, printing agents, and dissolving/diluting fats, oils, and adhesives (e.g. in degreasing or cleaning operations).
Halogenated Solvents	In apparel and footwear, halogenated solvents are used as finishing/cleaning and printing agents, for dissolving/diluting fats, oils and adhesives (e.g. in degreasing or cleaning operations).
Organotin Compounds	Organotins are a class of chemicals combining tin and organics such as butyl and phenyl groups. Organotins are predominantly found in the environment as antifoulants in marine paints, but they can also be used as biocides (e.g. antibacterials), catalysts in plastic and glue production and heat stabilisers in plastics/rubber. In textiles and apparel, organotins are associated with plastics/rubber, inks, paints, metallic glitter, polyurethane products and heat transfer material.
Other/Miscellaneous Chemicals	These are other chemicals/substances/process with a usage ban.

Perfluorinated and Polyfluorinated Chemicals (PFCs)	Durable water, oil and stain repellent finishes based on long-chain PFC's are banned from intentional use. There are two methods of manufacture of PFCs referred to as electrofluorination and telomerisation. PFC's made by the electrofluorination method have by-products associated with them called perfluoroalkyl sulphonates with the most common being the C8 species Perfluorooctane sulphonate (PFOS). The deliberate use of any PFCs made by electrofluorination with a chain length of C6 or above is not permitted. The detection of any PFOS analogue as where the chain length is 6 units or longer will trigger a failure (i.e. PFHS and above). These types of PFCs are typically used in home textiles. PFC's made by the telomerisation method have by-products associated with them called perfluorocarboxylic acid with the most common being the C8 species perfluorooctanoic acid (PFOA). The deliberate use of any PFCs made by telomerisation with a chain length of C8 or above is restricted. ZDHC plans to further restrict the use of PFCs in future revisions and details can be found in the candidate list is not permitted. The detection of any PFOA analogue as where the chain length is 8 units or longer will trigger a failure (i.e. PFOA and above). These types of PFCs are typically used in clothing and footwear PFOA and PFOS may be present as unintended by-products in long-chain commercial water, oil and stain repellent agents. PFOA also may be in used in the production for polymers like polytetrafluoroethylene (PTFE).
Phthalates – including all other esters of ortho-phthalic acid	Esters of ortho-phthalic acid (phthalates) are a class of organic compounds commonly added to plastics to increase flexibility. They sometimes are used to facilitate moulding of plastic by decreasing its melting temperature. Phthalates can be found in: <ul style="list-style-type: none"> <li>• Flexible plastic components (e.g. PVC)</li> <li>• Print pastes</li> <li>• Adhesives</li> <li>• Plastic buttons</li> <li>• Plastic sleeveings</li> <li>• Polymeric coatings</li> </ul>
Polycyclic Aromatic Hydrocarbons (PAHs)	Oil containing PAHs are added to rubber and plastics as a softener or extender and may be found in rubber, plastics, lacquers, and coatings. Within the footwear producing industry, PAHs are often found in the outsoles of footwear and in printing pastes for screen prints. PAHs can be present as impurities in carbon black dyestuffs.
Total Heavy Metals	In the list below the formulation limit for As, Cd, Hg, Pb and Cr VI apply to all types of formulation. Where there is a specific limit for pigments that that is different to the general limit this is shown in brackets. The formulation limits for Sb, Cr, Ba, Se, Sn, Ni, Cu, Co and Ag only apply to dye and/or pigment formulations. Any differences between limits for dyes and pigments are indicated in the formulation limit column. The limits for the heavy metals do not apply to colourants containing a listed metal as an inherent compositional part (e.g. metal-complex colorants, the double salts of certain cationic colourants or extenders like barium sulfate). When using any colourant with listed metals as an inherent compositional part, wet processors need to be aware of the need to comply with brand RSL limits with respect to extractable metals from dyed materials and they also need to be aware of the metal limits in the ZDHC wastewater guidelines. Where RSL and/or wastewater issues are observed wet processors should discuss this with supply chain partners. For the listed exceptions, laboratory tests to determine separately metal contaminants that are not bound into a colourant (free metals) are under development. Although typically associated with leather tanning, chromium VI also may be used in the dyeing of wool (after the chroming process).
UV absorbers	These are frequently used in formulations to be stable to the influences of light and UV.
Volatile Organic Compounds (VOC)	These Volatile Organic Compounds (VOC) should not be used in textile auxiliary chemical preparations. They are associated with solvent-based processes like solvent-based polyurethane coatings and glues/adhesives. They should not be used for any kind of facility cleaning or spot cleaning.



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## 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 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
<i>Member States (*)</i>	
AT	Austria
BE	Belgium
CZ	Czech Republic
DE	Germany
DK	Denmark
ES	Spain
FR	France
IT	Italy
PT	Portugal
SE	Sweden
<i>Non-member countries</i>	
NO	Norway
UK	United Kingdom
US	United States
(*) 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 <sup>(1)</sup>	Country/territory	Currency
<i>Member State currencies</i>		
EUR	Euro area <sup>(2)</sup>	euro (pl. euros)
DKK	Denmark	Danish krone (pl. kroner)
SEK	Sweden	Swedish krona (pl. kronor)
<i>Other currencies</i>		
AUD	Australia	Australian dollar
USD	United States	US dollar
<p><sup>(1)</sup> ISO 4217 codes.  <sup>(2)</sup> Includes Austria, Belgium, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Portugal, Slovakia, Slovenia and Spain.</p>		



### 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 ~ is the notation used to indicate approximation.

The symbol Δ is the notation used to indicate a difference.

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
h	hecto	$10^2$	Hundred	100
da	deca	$10^1$	Ten	10
-----	-----	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
n	nano	$10^{-9}$	Billionth	0.000 000 001

## IV. Units and measures

Unit symbol	Unit name	Measure name (measure symbol)	Conversion and comment
atm	normal atmosphere	Pressure (P)	1 atm = 101 325 N/m <sup>2</sup>
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 <sup>2</sup>	square metre	Area	
m <sup>3</sup>	cubic metre	Volume	
mg	milligram	Weight	1 mg = 10 <sup>-3</sup> g
mm	millimetre		1 mm = 10 <sup>-3</sup> m
min	minute		
MW <sub>e</sub>	megawatts electric (energy)	Electric energy	
MW <sub>th</sub>	megawatts thermal (energy)	Thermal energy Heat	
nm	nanometre		1 nm = 10 <sup>-9</sup> m
Nm <sup>3</sup>	normal cubic metre	Volume	at 101.325 kPa, 273.15 K
ouE	European odour unit	Odour	
Pa	pascal		1 Pa = 1 N/m <sup>2</sup>
ppb	parts per billion	Composition of mixtures	1 ppb = 10 <sup>-9</sup>
ppm	parts per million	Composition of mixtures	1 ppm = 10 <sup>-6</sup>
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 <sup>6</sup> g
t/d	tonnes per day	Mass flow Materials consumption	
t/yr	tonnes per year	Mass flow Materials consumption	
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 <sup>-6</sup> m

**V. Chemical elements**

Symbol	Name	Symbol	Name
Ag	Silver	He	Helium
Al	Aluminium	Hg	Mercury
Ar	Argon	I	Iodine
As	Arsenic	K	Potassium
B	Boron	Mg	Magnesium
Ba	Barium	Mn	Manganese
Br	Bromine	N	Nitrogen
C	Carbon	Na	Sodium
Ca	Calcium	Ni	Nickel
Cd	Cadmium	O	Oxygen
Cl	Chlorine	P	Phosphorus
Co	Cobalt	Pb	Lead
Cr	Chromium	S	Sulphur
Cu	Copper	Sb	Antimony
F	Fluorine	Si	Silicon
Fe	Iron	Sn	Tin
H	Hydrogen	Ti	Titanium
		Zn	Zinc

## VI. Chemical formulae commonly used in this document

Chemical formula	Name (explanation)
CH <sub>2</sub> Cl <sub>2</sub>	Dichloromethane or methylene chloride
Cl <sub>2</sub>	Chlorine
ClO <sub>2</sub>	Chlorine dioxide
CO	Carbon monoxide
CO <sub>2</sub>	Carbon dioxide
H <sub>2</sub> O <sub>2</sub>	Hydrogen peroxide
H <sub>2</sub> S	Hydrogen sulphide
H <sub>2</sub> O	Water
H <sub>2</sub> O <sub>2</sub>	Hydrogen peroxide
H <sub>2</sub> SO <sub>4</sub>	Sulphuric acid
HCl	Hydrochloric acid
NaClO	Sodium hypochlorite
NaClO <sub>2</sub>	Sodium chlorite
NaOH	Sodium hydroxide. Also called caustic soda
NH <sub>3</sub>	Ammonia
NO <sub>x</sub>	Nitrogen oxides ( NO or NO <sub>2</sub> )
O <sub>2</sub>	Oxygen
SO <sub>2</sub>	Sulphur dioxide
Sb <sub>2</sub> O <sub>3</sub>	Antimony trioxide
TiO <sub>2</sub>	Titanium dioxide

## VII. Acronyms

Acronym	Full phrase
AE	Alcohol ethoxylates
AMS	Automated measuring system
APEO	Alkyl phenol ethoxylates
AOX	Adsorbable organically bound halogens
ASTM	American Society for Testing and Materials
BAT	Best Available Techniques
BAT-AEL	Best Available Techniques - associated emission level
BAT-AEPL	Best Available Techniques - associated performance emission level
BFW	Boiler feed-water
BF	Bag filter
BOD	Biochemical oxygen demand
BREF	BAT reference document
BSI	British Standards Institution
BTEX	Benzene, toluene, ethylbenzene, xylene
BTX	Benzene, toluene, xylene
CAS	Chemical abstracts service (chemicals registry number)
CEFIC	Conseil Européen de l'Industrie Chimique (European Chemical Industry Council)
CEMS	Continuous emissions monitoring system
CEN	Comité Européen de Normalisation (European Committee for standardisation)
C.I.	Colour index
CMC	Carboxymethyl cellulose
CMR	Carcinogenic, mutagenic, reprotoxic
CMS	Chemicals management system
CO	Cotton
COD	Chemical oxygen demand
CPI	Corrugated plate interceptor
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CT	Cellulose triacetate
CTO	Catalytic thermal oxidiser
CU	Cupro
CV	Viscose
DAF	Dissolved air flotation
DEFRA	Department for Environment, Food and Rural Affairs (UK)
DIN	Deutsches Institut für Normung (German national organisation for standardisation)
DOC	Dissolved Organic Carbon
DTPA	Diethylenetriaminepentaacetic acid
DTPMP	Diethyletriamine penta(methylenephosphonic acid)
EA	Environment Agency (England and Wales)
EDTA	Ethylenediaminetetraacetic acid
EDTMP	Ethylenediamine tetra(methylenephosphonic acid)
EEA	European Environment Agency
E-Fac	Emission factor
EFTA	European Free Trade Association (established on 3 May 1960)
EIA	Environmental impact assessment
EL	Elastane
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)
EO/PO	Ethylene oxide/propylene oxide (group of copolymers)
EOP	End-of-pipe (measure)
EOX	Extractable organic halogens

EPA	Environmental Protection Agency (US)
ESP	Electrostatic precipitator
EQS	Environmental quality standard
ETAD	Ecological and Toxicological Association of Dyes and Organic Pigments Manufacturers
EURATEX	The European Apparel and Textile Confederation
EVA	Ethylene vinylacetate
EWL	European waste list (from the European Waste Framework Directive 2008/98/EC)
FID	Flame ionisation detector
FR	Flame retardant
HC	Hydrocarbons
HCH	Hexachlorocyclohexane (pesticide)
HP	High pressure
HT	High temperature (process, machine)
IED	Industrial Emissions Directive (2010/75/EU)
IGR	Insect growth regulators (group of pesticides)
IK	Indanthren cold (group of vat dyes)
IN	Indanthren normal (group of vat dyes)
IPPC	Integrated pollution prevention and control
IR	Infrared
ISO	International Organisation for Standardisation
IW	Indanthren warm (group of vat dyes)
LCP	Large combustion plant
LP	Low pressure
L.R.	Liquor ratio
MBR	Membrane bioreactor
MEL	Minimum Effect Level
MF	Microfiltration
MP	Medium pressure
MS	(European Union) Member State
MSW	Municipal solid waste
N	Normal – refers to volume of gases under normal operating conditions with a temperature of 273.15 K and pressure of 101.325 kPa
NA	Not applicable
ND	Not determined / Not detectable
NFR	Nitrogen flame-retardant
NGO	Non-governmental organisation
NMVO	Non-Methane Volatile Organic Compound
NOC	Normal operating conditions
NPE	Nonyl phenol ethoxylates
NRA	National Registration Authority (Australia)
OC	Organochlorines (group of pesticides)
OECD	Organisation for Economic Co-operation and Development
OEL	Observable Effect Level
OP	Organophosphates (group of pesticides)
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
OTNOC	Other than normal operating conditions
o.w.b	On the weight of the bath
o.w.f	On the weight of the fibre
PA	Polyamide fibres
PAC	Polyacrylonitrile fibres
PAH	Polycyclic aromatic hydrocarbons
PAN	Acrylonitrile
PBT	Polybutylene terephthalate
PCDD/Fs	Polychlorinated dibenzodioxins/dibenzofurans
PCP	Pentachloro phenol
PE	Polyethylene
PES	Polyester fibres

PET	Polyethylene terephthalate
PFAS	Per- and polyfluoroalkyl compounds
PFC	Perfluorocarbon, containing 8 atoms of carbon (C8) or less (C6 or C4)
PFR	Phosphorus flame-retardant
ROI	Return on investment
PP	Polypropylene
PPE	Personal protective equipment
PTT	Polytrimethylene terephthalate
PU	Polyurethane
PVA	Polyvinyl alcohol
PVC	Polyvinyl chloride
RTO	Regenerative thermal oxidiser
SBR	Styrene butadiene rubber
SEC	Specific energy consumption
SI	Silk
SP	Synthetic pyrethroids (group of pesticides)
SS	Suspended solids
TDS	Total dissolved solids
TEF	Toxic equivalency factor
TEGEWA	Verband der Textilhilfsmittel-, Lederhilfsmittel-, Gerbstoff- und Waschrohstoff-Industrie e.V. (Industry Association)
TEQ	Toxicity equivalents (iTEQ: international toxicity equivalents)
TFI	Textile finishing industry
THPC	Tetrakis(hydroxymethyl)phosphonium chloride
TKN	Total Kjeldahl nitrogen
TO	Thermal oxidiser
TOC	Total organic carbon
TS	Total solids
TSS	Total suspended solids
TVOC	Total volatile organic carbon
TWG	Technical Working Group
UF	Ultrafiltration
UBA	Umweltbundesamt – Federal Environment Agency, i.e. from Germany or Austria
ULLR	Ultra-Low Liquor Ratio
UV	Ultraviolet
UWWT(P)	Urban waste water treatment (plant)
VOC	Volatile organic compound
WEA	Whole effluent assessment
WESP	Wet electrostatic precipitator
WFD	Waste Framework Directive (2008/98/EC)
WHO	World Health Organisation
WO	Wool
WW	Waste water
WWT(P)	Waste water treatment (plant)
x-SBR	Carboxylated SBR

## VIII. Definitions

<b>Absorption</b>	A volume process in which one substance permeates another (soaking up).
<b>Accreditation</b>	Formal recognition that a testing laboratory is competent to carry out specific tests or specific types of tests. Laboratory accreditation uses criteria and procedures specifically developed to determine technical competence based on the international standard ISO/IEC 17025.
<b>Accuracy</b>	Associated with measured values. It is the degree of how close a measurement is to the actual (true) value.
<b>Acidification</b>	Raising the acidity (lowering the pH) of a fluid by the addition of an acid.
<b>Acidity</b>	Measure of the capacity of a solution to neutralise a strong base.
<b>Activated sludge process</b>	A biological process for treating municipal and industrial waste waters by the use of microorganisms under aerobic conditions.
<b>Acute effect</b>	An adverse effect on any living organism in which severe symptoms develop rapidly but often subside after the exposure stops.
<b>Acute pollution</b>	Pollution arising from infrequent events, unplanned events or accidents (see also: chronic pollution).
<b>Acute toxicity</b>	Toxicity which is severe enough to produce a response rapidly (typically a response observed in 48 or 96 hours). Acute toxicity studies in animals aim to assess the human risk from single exposure to high doses.
<b>Adsorption</b>	The adhesion of molecules of a gas, liquid or dissolved substance to a solid surface resulting in the formation of a thin film on the surface of the solid.
<b>Aerobic processes</b>	Biological processes that occur in the presence of oxygen.
<b>Air-to-textile ratio</b>	The ratio of the total exhaust gas volume flow (expressed in Nm <sup>3</sup> /h) from the emission point of a textile treatment unit (e.g. stenter) to the corresponding throughput of the textile to be treated (dry textile, expressed in kg/h).
<b>Alkalinity</b>	The acid-neutralising capacity of solutes in a water sample. This capacity is a result of carbonate, bicarbonate, hydroxide and occasionally borate, silicate and phosphate content of the water. It is equivalent to the stoichiometric sum of the basis in solution. It is expressed in milliequivalents per litre.
<b>Ammoniacal nitrogen</b>	Nitrogen present as ammonia and ammonium ions in liquid effluents.
<b>Anaerobic processes</b>	Biological processes that occur in the absence of oxygen and other electrons accepting substances except carbon dioxide/carbonate.
<b>Anodising</b>	Anodic oxidation – an electrolytic process in which the surface layer of a metal, such as aluminium, magnesium or zinc is converted to a coating, usually an oxide, having protective, decorative or functional properties.
<b>Anoxic denitrification</b>	Bacterial process by which nitrate nitrogen is converted to inert nitrogen gas in the absence of oxygen.
<b>A/O process</b>	Process used for combined carbon oxidation and phosphorus removal from waste waters. It is a suspended-growth system similar to the activated sludge process that combines anaerobic (10-20 % total reactor volume) and aerobic (oxic) sections in sequence.
<b>AOX</b>	Adsorbable organically bound halogens in water; the most frequently used measurement standard is EN ISO 9562. The AOX measurements are expressed in mg Cl/l of water or mg Cl/g of substance.



<b>Aquatic toxicity</b>	A measure of the adverse effects of a given pollutant on aquatic life. The most common parameters are given below. IC <sub>10</sub> – inhibition concentration of bacterial growth (10 % inhibition). Concentrations above the IC <sub>10</sub> value may strongly affect the efficiency of a biological treatment plant or even completely poison the activated sludge. LC <sub>50</sub> – lethal concentration (the concentration which is lethal to 50 % of the test organisms).
<b>Assimilative capacity</b>	The capacity of a natural body of water to receive waste waters or toxic materials without harmful effects and without damage to aquatic life or humans who consume the water.
<b>Auxiliaries</b>	See Chemical Auxiliaries.
<b>Base case</b>	The existing situation. The projection of the base case is sometimes referred to as ‘business as usual’ or the ‘baseline’ scenario.
<b>Base year</b>	In the context of processing time-dependent data such as costs or emissions, the base year is the first of the years for which data have been assembled.
<b>BFW</b>	Boiler feed-water. Water used to supply (‘feed’) a boiler to generate steam or hot water.
<b>BHF</b>	Bag house filter. Also fabric filter (FF). Abatement equipment used for the removal of particulate matter from gases. The gases are forced to pass through removable filter bags, and the particulate matter collected by the bag filters is normally periodically removed by shaking or the application of a reverse airflow.
<b>Biodegradability</b>	A measure of the ease with which a substance will degrade as a result of biological metabolism.
<b>Bioeliminability</b>	A measure of the ability of an organic substance to be removed from the effluent as a consequence of all elimination mechanisms that can take place in a biological plant (including biodegradation). It is measured by the bio-elimination test OECD 302 B, which determines the total effect of all elimination mechanisms in a biological treatment plant: <ul style="list-style-type: none"> <li>- biodegradation (measured over a long period - up to 28 days - in order to account for the biodegradation of substances that necessitate the development of specially acclimatised bacteria capable of digesting them);</li> <li>- adsorption on activated sludge;</li> <li>- stripping of volatile substances;</li> <li>- hydrolysis and precipitation processes.</li> </ul> It is usually expressed in % (of the substance).
<b>Biological nutrient removal</b>	The removal of nitrogen and/or phosphorus from aqueous effluents in biological treatment processes.
<b>Biomass</b>	The biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste (Directive 2009/28/EC on the promotion of the use of energy from renewable sources).
<b>Bioremediation</b>	The use of living organisms, e.g. bacteria, to remove pollutants from contaminated sites.
<b>Bleaching agent</b>	The active substance providing the bleaching effect. The bleaching agent is formed/produced by activating the bleach.
<b>Bleach</b>	The formulation used in the bleaching process.
<b>BOD</b>	Biochemical oxygen demand – the quantity of dissolved oxygen required by microorganisms in order to decompose organic matter in a given water sample at a certain temperature over a specific time period. The unit of measurement is mg O <sub>2</sub> /l. In Europe, BOD is usually measured after 3 (BOD <sub>3</sub> ), 5 (BOD <sub>5</sub> ) or 7 (BOD <sub>7</sub> ) days using EN 1899-1 and 1899-2.

<b>By-product</b>	A substance or object, resulting from a production process, the primary aim of which is not the production of that item and which is not regarded as being waste, and which meets the requirements of Article 5 of Directive 2008/98/EC on waste.
<b>Cake</b>	Solid or semisolid material remaining on a filter after pressure filtration.
<b>Calibration</b>	Set of operations that establishes, under specific conditions, the systematic difference that may exist between the values of a parameter to be measured and those indicated by a measuring system (with the corresponding values given in reference to a specific 'reference' system, including reference materials and their accepted values).
<b>Campaign monitoring</b>	(Also referred to as spot measurements): Measurements made in response to a need or an interest to obtain further fundamental information than that which routine/conventional monitoring provides. Examples are campaign monitoring during a special time period for estimating uncertainties, estimating variations in emissions patterns or for evaluating the chemical content or the ecotoxicological effects of the emissions by more advanced analyses.
<b>Carcinogen</b>	Any substance that is capable of causing cancer in humans or animals or a substance that promotes or aggravates cancer.
<b>Carding</b>	Reduction of entangled mass of fibres into a filmy web which is done by working between two closely spaced and relatively moving surface clothed with the sharp wire points.
<b>CAS</b>	Chemical abstracts service (registry number). A division of the American Chemical Society holds registries of chemical substances; providing a unique numerical identifier for chemical compounds, polymers, biological sequences, mixtures and alloys which designates only one substance.
<b>Cellulosic materials</b>	Cellulosic materials include cotton and viscose.
<b>Certification</b>	Procedure by which a third party gives written assurance that a product, process or service conforms to specified requirements. Certification can apply to instruments, equipment and/or personnel.
<b>Chalk</b>	Amorphous type of calcium carbonate.
<b>Chamber filter press</b>	Equipment for dewatering waste water or product sludges.
<b>Channelled emissions</b>	Emissions of pollutants to air through any kind of duct, pipe, stack, etc.
<b>Chelating agent</b>	A compound capable of chelation with metal ions.
<b>Chelation</b>	The formation of a closed ring of atoms by the attachment of compounds or radicals to a central polyvalent metal ion (occasionally non-metallic) (see also: sequestration, complexing agent).
<b>Chemical auxiliaries</b>	Process chemicals except: <ul style="list-style-type: none"> <li>- dyestuff and pigments;</li> <li>- "basic chemicals" such as inorganic chemicals, organic reducing and oxidising agents and aliphatic organic acids.</li> </ul>
<b>Chronic pollution</b>	Pollution occurring from regular or continuous events, such as effluent discharge (see also: acute pollution).
<b>Chronic toxicity</b>	The toxicity due to regular or continuous exposure over a long period of time, such as years, to a toxin that can have irreversible effects (see also: acute toxicity).
<b>COD</b>	Chemical oxygen demand - indicating the amount of organic matter in waste waters susceptible to oxidation by a strong chemical oxidant (normally referring to analysis with dichromate oxidation) according to ISO 15705:2002 (see 'hard COD').
<b>Coagulation</b>	A process in which dispersed colloidal particles agglomerate by the addition of a chemical reagent called a coagulant.
<b>Combustible material</b>	Solids, liquids and gases capable of igniting and burning in the presence of ignition source.

<b>Comparability</b>	A process for identifying and/or assessing differences and/or common characteristics between two (or more) samples, measurements, monitoring results, etc. Comparability is related to uncertainty, traceability to the specified reference, averaging time and frequency.
<b>Complexing agent</b>	See chelating agent.
<b>Compliance assessment</b>	Process to compare actual emissions of pollutants from an installation (manufacturing unit) with the permitted emission limit values, within a defined degree of confidence.
<b>Component</b>	Substance embedded in a mixture, e.g. in waste water, waste gas, solid waste.
<b>Composite sample</b>	Sample prepared by an operator or by an automatic device and that has been obtained by mixing several spot samples.
<b>Containment, contained area</b>	(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. May also refer to remediation measures put in place in order to prevent contaminant spreading from primary sources of pollution.
<b>Continuous measurement</b>	Measurement with an automated measuring system (AMS) permanently installed on site.
<b>Continuous monitoring</b>	Two types of continuous monitoring techniques are considered: <ul style="list-style-type: none"> <li>• Fixed in-situ (or in-line) continuous reading instruments. The measuring cell is placed in the duct, pipe or stream itself. These instruments do not need to withdraw any sample to analyse it and are usually based on optical properties.</li> <li>• Fixed on-line (or extractive) continuous reading instruments. This type of instrumentation extracts a sample of the emissions along a sampling line, which is driven to a measurement station, where the sample is then analysed continuously. The measurement station may be remote from the duct, and therefore care must be taken so that the sample integrity is maintained.</li> </ul>
<b>Continuous sampling</b>	Sampling on a continuous basis, and without interruption, of a portion of an effluent, which itself can be continuous or discontinuous. An aliquot of the flow is taken at any time when there is a discharge. Two formats can be identified: <ul style="list-style-type: none"> <li>• continuous flow-proportional sampling - where a continuous sample is taken from a partial flow ratio of the sample volume to the effluent flow rate;</li> <li>• continuous sampling at fixed time intervals - where equal volumes are taken at fixed time intervals.</li> </ul>
<b>Control of emissions</b>	Techniques used to limit, reduce, minimise or prevent emissions.
<b>Cooling water</b>	Water used for energy transfer (heat removal from components and industrial equipment), which is kept in a network separated from industrial water and which can be released back to receiving waters without further treatment.
<b>Co-product</b>	Any of two or more products coming from the same unit process or product system.
<b>Corrosion</b>	Surface chemical reaction, especially on metals by the action of moisture, air or chemicals.
<b>Corrosive material</b>	A material that, in contact with the skin, can have a destructive effect on living tissue. Corrosives can also damage or even destroy metal.

<b>CMR</b>	Carcinogenic, mutagenic or toxic for reproduction. This includes CMR substances of categories 1A, 1B and 2, as defined in Regulation (EC) No 1272/2008 and amended, i.e. with hazard statement codes: H340, H341, H350, H351, H360 and H361.
<b>CPI</b>	Corrugated plate interceptor – oil/water separation device utilising inclined corrugated plates to separate free non-emulsified oil and water based on their density difference.
<b>Decommissioning</b>	The shutdown of an installation including decontamination and/or dismantling.
<b>Denitrification</b>	Biological process by which nitrite is converted to nitrogen through a series of intermediate gaseous nitrogen oxide products.
<b>Desizing</b>	Pre-treatment of textile materials to remove sizing chemicals.
<b>Diffuse emissions</b>	Non-channelled emissions to air
<b>Digestate</b>	The solid residue remaining after anaerobic digestion.
<b>Dilution factor</b>	Final volume/aliquot volume (is the measure of subvolume of the original sample).
<b>Dioxins</b>	Polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs).
<b>Direct discharge</b>	Discharge to a receiving water body without further downstream waste water treatment.
<b>Direct measurements</b>	Specific quantitative determination of the emitted compounds at source.
<b>Discharge</b>	Physical release of a pollutant through a defined outlet, (i.e. channelled), system, (e.g. sewer, stack, vent, curbing area, outfall).
<b>Discrete</b>	Not continuous, i.e. having gaps between all possible values.
<b>Drainage</b>	Natural or artificial removal of surface and subsurface water from an area, including surface streams and groundwater pathways.
<b>Draining</b>	Emptying the liquid contents of a system to a collection system or other storage system, creating a possible liquid waste stream.
<b>Dry cleaning</b>	Cleaning of textile materials with an organic solvent.
<b>Dry matter percentage</b>	The ratio between the initial weight of a defined substance and the final (constant) weight, obtained after a defined drying procedure.
<b>Dust</b>	Solid particles with a size ranging from submicroscopic to macroscopic of any shape, structure or density, dispersed in the gas phase. Also includes particulate matter (PM).
<b>Dye</b>	The formulation (commercial product) containing the dyestuff together with other dyeing auxiliaries
<b>Dyestuff</b>	The colouring agent in the dye formulation: a planar molecule which contains chromophoric group(s) capable of interacting with light.
<b>Emissions factor</b>	Emission factors are representative values that attempt to relate the quantity of a substance emitted to a process associated with the emission of that substance. Emission factors are derived from emission measurements according to a predefined protocol considering the textile materials and the reference processing conditions. They are expressed as the mass of a substance emitted divided by the mass of textile materials treated at the reference gas flow (e.g. grams of organic carbon emitted per kg of textile materials treated at a waste gas flow of 20 m <sup>3</sup> /h).
<b>Emissions pattern</b>	Type of variation of emissions over time; for example, emissions can be stable, cyclic, random peaking, random variable, erratic.
<b>Emissions to air</b>	<ul style="list-style-type: none"> <li>• Concentration: mass of emitted substance related to the volume of waste gas under standard conditions (273.15 K, 101.325 kPa), after deduction of water vapour content, expressed in the units g/Nm<sup>3</sup>, mg/Nm<sup>3</sup>, µg/Nm<sup>3</sup> or ng/Nm<sup>3</sup>.</li> <li>• Mass flow: mass of emitted substances related to time, expressed in the units kg/yr, kg/h, g/h or mg/h.</li> <li>• Specific emission: ratio of mass of emitted substances to the mass of products generated or processed (consumption or emissions factors), expressed in the units kg/t, g/t or mg/t or µg/t.</li> </ul>

<b>Emissions to water</b>	<ul style="list-style-type: none"> <li>• Mass of emitted substances related to the volume of waste water, expressed in the units g/m<sup>3</sup>, g/l, mg/l or µg/l.</li> <li>• Mass flow: mass of emitted substances related to time, expressed in the units kg/yr, kg/h, g/h or mg/h.</li> <li>• Specific emission: ratio of mass of emitted substances to the mass of products generated or processed (consumption or emissions factors), expressed in the units kg/t, g/t or mg/t or µg/t.</li> </ul>
<b>EOP</b>	<ul style="list-style-type: none"> <li>• End-of-pipe, device or treatment system applied to waste water or channelled exhaust or flue gas at the outlet of a collection system prior to release into the environment.</li> <li>• Extraction bleaching stage using sodium hydroxide with the subsequent addition of oxygen and hydrogen peroxide solution as a reinforcing agent.</li> </ul>
<b>Eutrophication</b>	The excessive growth of algae as a result of the pollution of a body of water by sewage, fertilisers washed from the land, or industrial wastes; containing plant nutrients (principally inorganic nitrates and phosphates). Dead algae decomposing reduce the oxygen content in the water and so kill animals with a high oxygen requirement.
<b>EWL</b>	European waste list from the European Waste Framework Directive (Directive 2008/98/EC on waste) – hierarchical list of waste descriptions. This list classifies waste materials and categorises them by: <ul style="list-style-type: none"> <li>• the activity from which they are produced, and</li> <li>• their characteristics.</li> </ul>
<b>Exhaust gas (or exhaust air)</b>	Gas/air stream coming from a combustion or extraction process; it may contain gaseous or particulate components. There is no link to exhausting through a stack. (See also flue-gas, off-gas, waste gas.)
<b>Existing plant</b>	A plant that is not a new plant.
<b>Fabric production</b>	Production of fabric, e.g. by weaving or knitting.
<b>Finishing</b>	Physical and/or chemical treatment aiming at giving the textile materials end-use properties such as visual effects, handling characteristics, waterproofness or non-flammability.
<b>Fixation rate</b>	Ratio of the dye fixed on the fibre to the total dye applied.
<b>Fixation efficiency</b>	Ratio of the dye fixed on the fibre to the dye exhausted from the bath.
<b>Flame lamination</b>	Bonding of fabrics using a thermoplastic foam sheet exposed to a flame located before the laminating rolls.
<b>Flammable material</b>	Any solid, liquid, vapour or gas material that will ignite easily and burn rapidly.
<b>Flocculation</b>	Agglomeration of destabilised particles into microfloc, and afterwards into bulky floccules which can be settled called floc. The addition of another reagent called a flocculant or a flocculant aid may promote the formation of the floc.
<b>Flotation</b>	A water treatment process that clarifies waste waters by the removal of suspended matter such as oil or solids; a specific example is dissolved air flotation (DAF).
<b>Flue-gas</b>	A mixture of combustion products and air leaving a combustion chamber and that is directed up a stack to be emitted.
<b>Fouling</b>	A process of becoming dusty or clogged, e.g. by undesirable foreign matter, such as dirt and other material, accumulating and clogging pores and coating surfaces.
<b>Free CN</b>	The cyanide not combined in complex ions, both the molecular HCN and the cyanide ion.
<b>Fugitive emissions</b>	Emissions that leave a process because of lack of containment, or failure of containment. Note: fugitive emissions are a subset of diffuse emissions.

<b>Groundwater</b>	All water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil (Article 2 of Directive 2000/60/EC on establishing a framework for Community action in the field of water policy). Note: groundwater is distinct from surface water.
<b>Halogenated organic compound</b>	An organic compound which contains one or more halogen atoms of bromine, chlorine, fluorine or iodine per molecule.
<b>Hard COD</b>	Total residual COD, including the inert non-treatable fraction and that part beyond the capacity of a particular treatment (see COD).
<b>Hazardous substance</b>	Hazardous substance as defined in point 18 of Article 3 of Directive 2010/75/EU.
<b>Hazardous waste</b>	Hazardous waste as defined in point 2 of Article 3 of Directive 2008/98/EC.
<b>Heavy metals</b>	Metals with a density greater than 4.5 g/ml, according to the 1998 Aarhus Protocol on Heavy Metals.
<b>Highly flammable substance</b>	Flammable liquids, gases and aerosols as covered by Annex I to Regulation (EC) No 1272/2008 on the classification, labelling and packaging of substances and mixtures).
<b>IED</b>	Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control (Recast). Under the framework of the Industrial Emission Directive (see IED Art. 13), a consultation body, the IED Forum (IEDF), is regularly convened by the Commission.
<b>Indirect discharge</b>	Discharge that is not a direct discharge.
<b>IPCC</b>	Intergovernmental Panel on Climate Change.
<b>IPPC Directive</b>	Directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control (IPPC Directive) that has been replaced by Directive 2010/75/EU on industrial emissions (→IED).
<b>Leachate</b>	Solution obtained by leaching. The solution consists of liquid that, in passing through matter, extracts solutes, suspended solids or any other component of the material through which it has passed.
<b>Leakage</b>	Gaseous or liquid spills out of system/equipment due to system/equipment failure.
<b>Liquor ratio</b>	For a batch process, weight ratio between the dry textile materials and the process liquor used.
<b>Major plant upgrade</b>	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.
<b>Make-up</b>	Generic term used in the textile industry to name the different forms in which a textile material can exist. Examples are floc, yarn, woven and knitted fabric.
<b>Make-up water</b>	Water added to a process or a circuit to replace water that is lost by leakage or evaporation for example.
<b>Mass flow</b>	The mass of a given substance or parameter which is emitted over a defined period of time.
<b>Measurement uncertainty</b>	Non-negative parameter characterising the dispersion of the values attributed to a measured quantity. The uncertainty has a probabilistic basis and reflects incomplete knowledge of the quantity.
<b>MF</b>	Microfiltration (membrane process). A filtration process which removes contaminants from a liquid by passage through a microporous membrane (pore size 0.1-10 µm).
<b>Monitoring</b>	Systematic surveillance of the variations of a certain chemical or physical characteristic of emissions, discharges, consumptions, equivalent parameters or technical measures, etc.
<b>Mother liquor</b>	Saturated solution remaining after crystallisation or precipitation.
<b>Nanofiltration</b>	A membrane filtration process using typical pore sizes of the membrane of about 1 nm.

<b>Nanomaterial</b>	A natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50 % or more of the particles in the number size distribution, one or more external dimensions is in the size range 1-100 nm.
<b>NCV</b>	Net calorific value or lower heat value (LHV) (see also: UHV).
<b>New plant</b>	A plant first permitted at the site of the installation following the publication of the BAT conclusions or a complete replacement of a plant following the publication of the BAT conclusions.
<b>Nitrification</b>	A biological process by which ammonia is converted first to nitrite and then to nitrate.
<b>Normal operating conditions (NOC)</b>	Conditions during which the plant is operating normally and discharging emissions into the air and/or water, excluding other than normal operating conditions (see OTNOC below).
<b>n-octanol/water partition coefficient</b>	The ratio of the equilibrium concentrations of a dissolved substance in a two-phase system consisting of the largely immiscible solvent octanol and water.
<b>N-total or TN, total Nitrogen</b>	The sum of organic nitrogen, ammonia, nitrite and nitrate in the chemical analysis of soil, water or waste water (see also TKN, total Kjeldahl nitrogen).
<b>Nylon</b>	Generic name for polyamide fibres.
<b>O</b>	Oxygen bleaching stage.
<b>Odour concentration</b>	Conventionally defined (EN 13725) as the dilution factor to be applied to an effluent in order to be no longer perceived as odorant by 50 % of people in a sample of population.
<b>Off-gas</b>	General term for gas/air resulting from a process or operation (see exhaust gas, flue-gas, waste gas).
<b>Organic solvent</b>	Organic solvent as defined in Article 3(46) of Directive 2010/75/EU.
<b>ORP</b>	Oxidation reduction / redox potential. The electric potential required to transfer electrons from one compound or element (the oxidant) to another compound (the reductant).
<b>OSPAR</b>	Oslo and Paris Convention for the Protection of the Marine Environment of the North-East Atlantic ( <a href="http://www.ospar.org">www.ospar.org</a> ).
<b>Osmosis</b>	The passage of a liquid from a weak solution to a more concentrated solution across a semipermeable membrane that allows passage of the solvent (water) but not the dissolved solids. See reverse osmosis technique.
<b>Other than normal operating conditions (OTNOC)</b>	Conditions other than normal operating conditions, such as start-up and shutdown operations, leaks, malfunctions, momentary stoppages and definitive cessation of operations.
<b>Oxidant</b>	<ul style="list-style-type: none"> <li>• One of the elements of the transfer of electrons to another (the reductant) in the oxidation reduction chemical reaction.</li> <li>• Some of the primary constituents of photochemical smog, leading to tropospheric ozone.</li> </ul>
<b>Oxidiser</b>	An oxidising agent (e.g. peroxides) that can react highly exothermically when brought into contact with other materials, flammables in particular.
<b>Ozone (O<sub>3</sub>)</b>	Stratospheric ozone: natural form of oxygen that provides a protective layer shielding the earth from ultraviolet radiation. Tropospheric ozone: produced through complex chemical reactions of nitrogen oxides, hydrocarbons and sunlight; can seriously impair the respiratory system.
<b>PAH(s)</b>	Polycyclic aromatic hydrocarbons. Group of fused aromatic ring compounds, of which naphthalene is the simplest example. Regarding environmental impact and although individual health effects are not the same, 17 PAHs are considered as a group. Among them, benzo[a]pyrene was first listed as a carcinogen.

<b>Particulate matter (PM)</b>	Total particulate matter refers to all inorganic and organic solid and liquid materials (droplets and aerosols) that may be present in the flue-gas. Specific sizes of PM may be measured/distinguished, such as PM <sub>10</sub> , PM <sub>2.5</sub> , PM <sub>1</sub> , depending on the amount of particulate matter which passes through a size-selective inlet with a 50 % efficiency cut-off at 10 µm, 5 µm, 1 µm aerodynamic diameter, respectively. (See also dust.)
<b>PBB</b>	Polybrominated biphenyl - polyhalogenated compounds whose chlorine analogues are the PCBs.
<b>PCDD</b>	Polychlorinated dibenzo-p-dioxins. Organic polyhalogenated compounds. Members of this group have been shown to bioaccumulate due to lipophilic properties and are known human carcinogens. Usually named dioxins.
<b>PCDF</b>	Polychlorinated dibenzofurans. Organic polyhalogenated compounds. Tend to co-occur with PCDD. Usually named furans.
<b>Periodic measurement</b>	Measurement at specified time intervals using manual or automated methods.
<b>Periodic sampling</b>	Discrete / individual / separate / discontinuous / grab / spot sampling - individual samples taken in batch, time or effluent-volume-dependent. Three formats can be identified: <ul style="list-style-type: none"> <li>• periodic time-dependent sampling – discrete samples of equal volume are taken at equal time intervals;</li> <li>• periodic flow-proportional sampling – discrete samples are taken of variable volumes at equal time intervals;</li> <li>• periodic samples taken at fixed flow intervals – discrete samples of equal volume are taken after the passage of a constant volume.</li> </ul>
<b>Pesticide</b>	Biological, physical or chemical agent used to kill pests. The term pesticide is often applied only to chemical agents. Various pesticides are known as insecticides, nematicides, fungicides, herbicides and rodenticides. According to the Stockholm Convention on Persistent Organic Pollutants, 10 of the 12 most dangerous and persistent organic chemicals are pesticides.
<b>PFC</b>	Perfluorinated carbon or perfluorocarbons. Organofluorine compounds that contain only carbon and fluorine bonded together. They are potent greenhouse gases.
<b>Pick-up</b>	For a continuous process, weight ratio between the liquid taken up by the textile materials and the dry textile materials.
<b>PID</b>	Piping and instrumentation diagrams: diagrams which show the interconnection of process equipment and the instrumentation.
<b>Pigging</b>	In the maintenance of pipelines, the practice of using inspection gauges or ‘pigs’ to perform various operations on a pipeline without stopping the flow of the product in it. Operations include cleaning and inspection of the pipeline.
<b>PLC</b>	Programmable logic controller: digital computer used for the automation of industrial processes.
<b>PNEC</b>	Predicted no effect concentrations. Ecotoxicological measure for multiple species systems defined as the concentration below which a specified percentage of species in an ecosystem are expected to be protected.
<b>Pollution</b>	The direct or indirect introduction, as a result of human activity, of substances, vibrations, heat or noise into the air, water or land which may be harmful to human health or the quality of the environment, result in damage to material property, or impair or interfere with amenities and other legitimate uses of the environment (Directive 2010/75/EU).



<b>Pollution source</b>	The emissions source. Pollution sources can be categorised as: <ul style="list-style-type: none"> <li>• point, or concentrated sources;</li> <li>• dispersed sources;</li> <li>• line sources, including mobile (transport) and stationary sources</li> <li>• area sources.</li> </ul>
<b>POPs</b>	Persistent organic pollutants, as defined by protocol to the UNEP LRTAP convention: they are organic substances that: possess toxic characteristics that are likely to cause significant adverse human health or environmental effects; are persistent, i.e. remain intact for exceptionally long periods of time (many years); bioaccumulate in the fatty tissue of living organisms including humans, and are found at higher concentrations at higher levels in the food chain; and are prone to long-range transboundary atmospheric transport and deposition, i.e. become widely distributed throughout the environment as a result of natural processes involving soil, water and air.
<b>Post-combustion</b>	Ignition and burning of exhaust gas through the injection of air or the use of a burner (e.g. in order to reduce the amount of CO or other pollutants).
<b>PPI</b>	Parallel plate interceptor. A decantation device made with a series of plates parallel to the longitudinal axis of a separator (plates form a 'V' viewed along the axis) used to separate sediments from a liquid. (See also API, CPI.)
<b>Precision</b>	Refers to the ability of a measurement to be consistently reproduced.
<b>Preparation</b>	Mixture of chemicals.
<b>Process chemicals</b>	Substances or mixtures as defined in Article 3 of regulation EC/1907/2006 that are used in the process(es), including sizing chemicals, bleaching chemicals, dyes, printing pastes and finishing chemicals. Process chemicals may contain hazardous substances and/or substances of very high concern.
<b>Process liquor</b>	Solution and/or suspension containing process chemicals.
<b>Primary measure/technique</b>	A measure/technique that changes the way in which the core process operates thereby reducing raw emissions or consumption (see also the counterpart: end-of-pipe technique).
<b>Purging</b>	Replacement of the gaseous contents of a system by air or inert gases.
<b>Rayon</b>	A generic name for man-made continuous filament fibres, obtained from regenerated cellulose. The term rayon is used for fibres produced by both cupra-ammonium and viscose processes.
<b>Recovery</b>	Any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy (Waste Directive (2008/98/EC)).
<b>Recycling</b>	Any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations (Waste Directive (2008/98/EC)).
<b>Reuse</b>	Any operation by which products or components that are not waste are used again for the same purpose for which they were conceived (Waste Directive (2008/98/EC)).
<b>Reference conditions</b>	Conditions that are specified, e.g. in connection with operating a process, collecting samples.
<b>Release</b>	Actual discharge (routine, usual or accidental) of emissions into the environment.

<b>Remediation</b>	The containment and/or decontamination of contaminated environmental media such as soil, groundwater, sediment, or surface water from a contaminated site intended for further use. The area of the site may be larger than the fenced area.
<b>Reporting</b>	A process of periodic transmission of information about environmental performance, including emissions and compliance with permit conditions, to authorities or to the internal management of the installation and other agencies, such as the general public.
<b>Residual pick-up</b>	The remaining capacity of wet textile materials to take up additional liquid (after the initial pick-up).
<b>Residue</b>	A material that is not deliberately produced in a production process and may or may not be waste.
<b>Roving</b>	Prior to spinning, reduction of the sliver thickness by drafting.
<b>R-phrases</b>	R-phrases are standard phrases indicating the special risk arising from the dangers involved in using the dangerous substance. The wording of the R-phrases is laid down in Annex III to Directive 67/548/EEC on the approximation of laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances.
<b>Run-off</b>	Part of the precipitation and snowmelt that does not infiltrate but moves as overland flow.
<b>Sampling, sample</b>	Sampling is the process by which a portion of substance is collected to form a representative part (the sample) of the whole, for the purpose of examination of the substance or material under consideration. (See also continuous sampling, periodic sampling.)
<b>Sankey diagram</b>	A specific type of diagram used for displaying flows through a system, e.g. to show mass, energy, material, money flows.
<b>Scouring</b>	Pre-treatment of textile materials which consists of washing the incoming textile material. Removal of foreign impurities from textiles. In the case of wool, this term can address both the removal of the grease and dirt present on raw wool (wool scouring process) and the removal of spinning oils and residual contaminants from yarn or fabric in the wet treatments that are carried out before the dyeing process.
<b>Sequencing batch reactor</b>	A variation of the conventional activated sludge system to treat waste waters containing organic material whereby the aeration and settlement take place in the same vessel (no need for a secondary clarifier).
<b>Secondary measure/technique</b>	See EOP, end-of-pipe techniques.
<b>Slag</b>	A vitrified or partially vitrified residue.
<b>Sludge</b>	A suspension with a high solids content, such as the type precipitated by sewage treatment.
<b>Slurry</b>	A suspension of solid particles in a liquid but at a lower concentration than found in sludge.
<b>Specific emissions/consumption</b>	Emissions/consumption related to a reference basis, such as production capacity, or actual production.
<b>Spot measurement</b>	A measurement relating to a specific point in time – not a continuous measurement.
<b>Spot sample</b>	A sample related to a single point in time.
<b>Standard conditions</b>	Referring to a temperature of 273.15 K a pressure of 101.325 kPa and a specified oxygen content.
<b>Site</b>	Geographical area which may contain more than one installation, plant or facility.
<b>Singeing</b>	Removal of the fibres at the surface of the fabric by passing the fabric through a flame or heated plates.
<b>Sizing</b>	Impregnation of yarn with chemicals aiming to protect the yarn and provide lubrication during weaving.
<b>Sump</b>	A pit, well or hole used for collecting water or other liquid.

<b>Surrogate parameter</b>	Measurable or which can calculable quantities be closely related, directly or indirectly, to conventional direct measurements of pollutants, and which may therefore be monitored and used instead of the direct pollutant values for some practical purposes. Also called proxy parameter.
<b>Substances of very high concern</b>	Substances as defined in Article 57 and included in the Candidate List of Substances of Very High Concern, according to the REACH Regulation ((EC) No. /1907/2006).
<b>Synthetic materials</b>	Synthetic materials include polyester, polyamide and acrylic.
<b>TA Luft</b>	Technical Instructions on Air Quality Control. German Federal Regulation for the control of pollution to air.
<b>TDS</b>	Total dissolved solids - the concentration in liquid of the solids that remain after the liquid has passed through a filter with a defined pore size.
<b>TEQ</b>	Toxicity equivalent (also called TE or iTEQ – international toxicity equivalent) - dioxins and furans. The last revision of the equivalency methodology (WHO-TEQDFP) now also includes PCBs.
<b>Textile materials</b>	Textile fibres and/or textiles.
<b>Texturised fibres</b>	Filament yarns that have undergone a special treatment aimed at giving the fibre a greater volume and surface interest than the conventional yarn of the same fibre.
<b>Thermal treatment</b>	Thermal treatment of textile materials includes thermofixation, heat-setting or a process step (e.g. drying, curing) of the activities covered by these BAT conclusions (e.g. coating, dyeing, pre-treatment, finishing, printing, lamination).
<b>Thickening</b>	Liquid-solid separation process to increase the concentration of a suspension by sedimentation, accompanied by the formation of a clear solid.
<b>TKN</b>	Total Kjeldahl nitrogen - the sum of organic nitrogen, ammonia (NH <sub>3</sub> ) and ammonium (NH <sub>4</sub> <sup>+</sup> ) in the chemical analysis of soil, water or waste water.
<b>TOC</b>	Total organic carbon. The concentration in water of all organic compounds, measured according to EN 1484. The term TOC is also used for carbon in air.
<b>Top</b>	A continuous untwisted strand or sliver of wool fibres.
<b>TS</b>	Total solids (content). The sum of TDS and TSS.
<b>TSS</b>	Total suspended solids. The concentration in any liquid, usually water, of suspended particles that are trapped by a filter with a defined pore size. (See also SS.)
<b>UF</b>	Ultrafiltration is a variety of membrane filtration in which hydrostatic pressure (typically 0.1-5 MPa) forces a liquid against a semi-permeable membrane (typical pore size of 2-10 nm).
<b>Unit</b>	A part of the plant in which a specific processing operation is conducted.
<b>Waste gas</b>	Any gas leaving a process which is not a product (includes exhaust gas, off-gas and flue-gas).
<b>Waste hierarchy</b>	Priority order in waste prevention and management legislation and policy: (a) prevention; (b) preparing for reuse; (c) recycling; (d) other recovery, e.g. energy recovery; and (e) disposal (Waste Directive (2008/98/EC)).
<b>Waste treatment</b>	Waste recovery or waste disposal operations, including preparation prior to recovery or disposal (Waste Directive (2008/98/EC)).
<b>WEA</b>	Whole Effluent Assessment of the entire effluent using integrating parameters (e.g. acute and chronic toxicity, liability to bioaccumulate and to persist) in contrast to measuring individual substances.

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<b>WESP</b>	Wet electrostatic precipitator A WESP or wet ESP is an electrostatic precipitator (ESP) operating with saturated air streams (100 % relative humidity) which is often used to control particulate matter and acid mists and can provide incidental control of volatile organic compounds. Wet ESPs are used when the material to be collected is wet, sticky, flammable, explosive, or has a high resistivity.
<b>Zeolites</b>	Microporous, aluminosilicate minerals commonly used as commercial adsorbents.



## REFERENCES

- [1] EURATEX, *FACTS & KEY FIGURES OF THE EUROPEAN TEXTILE AND CLOTHING INDUSTRY - 2020 EDITION*, 2021.
- [2] EU, *NACE Rev. 2 - Statistical classification of economic activities in the European Community*, 2008.
- [3] Adinolfi R., *EURATEX: Statistics and trends of the EU technical textile production and international trade*, Press Conference *techtexsil-texprocess*, Frankfurt 15th May 2019, 2019.
- [4] EURATEX, *EURATEX - Contribution to the original BREF - Chapters 2 to 6*, 2000.
- [5] UBA, *BAT reference document - Germany*, 2001.
- [6] bluesign, *Attachment to comment DE#88: Typical consumption ranges of chemical products in textile dyeing and finishing*, 2020.
- [7] EU, '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)', *Official Journal of the European Union*, Vol. L 396, 30.12.2006, 2006, pp. 1-849.
- [8] EIIPCB, *Report of the Kick-off Meeting for the review of the TXT BREF*, 2018.
- [9] TWG, *Comments made by the Technical Working Group to the first draft of the original Textiles BREF*, 2001.
- [10] Ullmann's, *Ullmann's Encyclopedia of Industrial Chemistry*, 2011.
- [11] Beton et al., *Environmental Improvement Potential of Textiles (IMPRO-Textiles) (JRC scientific and policy reports)*, 2014.
- [12] TEGEWA, TEGEWA website, accessed on 04.12.2018, 2018.
- [13] TEGEWA, *TEGEWA nomenclature of textile auxiliaries*, 2018.
- [14] Danish EPA, *Environmental assessment of textiles (Environmental project n°369)*, 1997.
- [15] INTERLAINE, *INTERLAINE REPORT: Contribution for Wool Scouring Sector (Chapters 1 to 6)*, 1999.
- [16] EU, Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control), 2010.
- [17] Savage G., *The Residues Implications of Sheep Ectoparasiticides (report for the Woolmark company)*, 1998.
- [18] Peterson et al., 'Production and business methods in the integral knitting supply chain', *AUTEX Research Journal*, Vol. 8, No4, December 2007, 2007.
- [19] Jacobs et al., *VITO Document on BAT for textile industry*, 1998.
- [20] GuT/ECA, *Production process for textile floor-coverings (draft) - Contribution for the original TXT BREF (chapters 1-2)*, 2000.
- [21] Corbani F., *Nobilitazione dei tessili*, Prodiggi, 1994.
- [22] TWG, *Comments of the Technical Working Group on Draft 2 of the original BREF*, 2002.
- [23] Schönberger H., *Reduktion der Abwasserbelastung in der Textilindustrie*, UBA Texte 3/94, 1994.
- [24] Bettens L., 'Environmentally friendly bleaching of natural fibres by advanced techniques (SYNBLEACH EV5V-CT 94-0553). European Workshop on Technologies for Environmental Protection', 1995.
- [25] Bozzetto, *Servizio Informazioni Tecniche n°62: Tintura della lana.*, 1997.
- [26] Italy, *Information submitted about the pre-treatment of silk as attachment to comments on the first draft of the original BREF*, 2001.
- [27] VITO, *Information submitted by L. Bettens on behalf of VITO about spin finishes and lubricants.*, 2001.

- [28] GuT, Information submitted by L. Bettens on behalf of GuT about Carpet Manufacturing., 2001.
- [29] RIZA, *Dutch notes on BAT for the textile and carpet industry*, 1998.
- [30] US EPA, *Manual - Best Management Practices for Pollution Prevention in the Textile Industry*, US EPA, 1996.
- [31] Cotton Incorporated, *A World of Ideas: Technologies for Sustainable Cotton Textile Manufacturing*, 2009.
- [32] Bettens L., *Evolution in Chemical Use since 1992 within the Textile Processing Industry*, 1999.
- [33] BASF, *Products for Textile finishing: ecological evaluation*, 1994.
- [34] Tebodin, *Technical and economic aspects of measures to reduce water pollution from the textile finishing industry.*, 1991.
- [35] RICARDO, *Novel sustainable techniques in the textiles sector identified by the Innovation Observatory. Service Request 8 under Framework Contract ENV.C.4/FRA/2015/0042*, 2019.
- [36] Sinocolor, *Comparison between Direct-to-Textile and Heat Transfer Printing*, 2019.
- [37] Manich et al., *MIDWOR LIFE project LIFE14 ENV/ES/000670 - Deliverable B.6.1 "Recommendations to update the BREF for the Textile Industry"*, 2018.
- [38] EC, *Directive 2008/105/EC of the European Parliament and of the Council of 16 December 2008 on environmental quality standards in the field of water policy, amending and subsequently repealing Council Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC of the European Parliament and of the Council*, Official Journal of the European Union, 2008, pp. 84-97.
- [39] EU, *Regulation (EU) 2019/1021 of the European Parliament and of the Council of 20 June 2019 on persistent organic pollutants*, 2019.
- [40] COM, *Chemicals Strategy for Sustainability*, 2020.
- [41] FLAREX, *Recommendations for the textile sector with BREF review*, 2020.
- [42] LEITAT, *Report on proposal for updating the BREF for the Textiles Industry Sector - LIFE project ENV/ES/000667 (ECOTEX-NANO)*, 2016.
- [43] Johnson et al, *Advances in wool technology*, Textiel Institute/CRC Press/WOODHEAD PUBLISHING LIMITED, 2009.
- [44] ÖKOPOL, *BAT for the Textile Industry*, 2011.
- [45] Weydts et al., 'Centexbel comments on Hotmelt lamination', Personal Communication, 2019.
- [46] BSC, BSC Website <http://www.bbr-llc.com/index.html>, 2018.
- [47] CRIT, *IPPC - Italian wool textile industry*, 1999.
- [48] Carr et al., 'Drying of Textile Products', *Handbook of Industrial Drying*, Edited By Arun S. Mujumdar, Vol. Chapter 34, 2006.
- [49] Italy, *Information submitted by Italy for the original TXT BREF - Emission and consumption levels in Prato district*, 2000.
- [50] TWG, *Data collection for the review of the TXT BREF*, 2019.
- [51] Hansson. S, Swedish contribution to the issues specified on the list of actions which was agreed upon during the 1st and 2nd data assessment workshop, 2020.
- [52] Schönberger H., *Technique combinations to meet the ambitious ZDHC Wastewater Guidelines*, 2018.
- [53] EURATEX, EURATEX contribution to action 6: COD removal efficiency, 2020.
- [54] Viers S., France contribution to action 6: COD removal efficiency, 2021.
- [55] Patwary S.M., *Antimony diffusion from polyester textiles upon exhaust dyeing (Report no: 2017.14.10.)*, The Swedish School of Textiles, University of Borås, 2017.

- [56] EURATEX, *EURATEX\_Additional information*, 2021.
- [57] UBA, *Antimony measurements*, 2020.
- [58] EURATEX, *Information provided as follow up from the 2nd data assessment workshop (letter with contributions to various actions)*, 2020.
- [59] Zietlow B., *German contribution to action 9*, 2020.
- [60] Hoebeke L., *BE - BREF Textiles acute toxicity results and methodology (Lut Hoebeke, Flemish EPA)*, 2019.
- [61] ECHA, *Information note on restriction report for intentionally added microplastic particles.*, 2019.
- [62] Austrian EPA, *Plastik in der Donau - Report REP-0547*, 2015.
- [63] Danish EPA, *Microplastic in Danish wastewater - Sources, occurrences and fate - Environmental project 1906*, 2017.
- [64] Danish EPA, *Occurrence, effects and sources of releases to the environment in Denmark - Environmental project No. 1793*, 2015.
- [65] SVEREA IVF, *Investigation of the occurrence of microplastics in wastewater from five textile production facilities - Report 5170952*, 2018.
- [66] IVL, *Swedish sources and pathways for microplastics to the marine environment - Report C 183*, 2016.
- [67] Jönsson et al., 'Microplastics Shedding from Textiles—Developing Analytical Method for Measurement of Shed Material Representing Release during Domestic Washing (Sustainability 2018, 10, 2457; doi:10.3390/su10072457)', 2018.
- [68] STERLITECH, Sterlitech website, 2019.
- [69] Moser. G, *AT\_plant\_Getzner\_Infos\_bioeliminability*, 2021.
- [70] UBA, Germany contribution to action 5: monitoring of formaldehyde, 2020.
- [71] EURATEX, EURATEX contribution to action 5: monitoring of formaldehyde, 2020.
- [72] Viers S., France contribution to action 5: monitoring of formaldehyde, 2021.
- [73] Brinkmann et al., *JRC Reference Report on Monitoring of Emissions to Air and Water from IED Installations (ROM REF)*, European Commission, Joint Research Centre, Seville, *EUR 29261 EN*, doi: 10.2760/344197, 2018.
- [74] Danish EPA, *Method for measuring oil mist in flowing gas*, 2018.
- [75] IAF, International Accreditation Forum website, 2010.
- [76] EU, 'Regulation (EC) No 1221/2009 of the European Parliament and of the Council of 25 November 2009 on the voluntary participation by organisations in a Community eco-management and audit scheme (EMAS), repealing Regulation (EC) No 761/2001 and Commission Decisions 2001/681/EC and 2006/193/EC', *Official Journal of the European Union*, Vol. L 342, 22.12.2009, 2009, pp. 1-45.
- [77] COM, *Best Available Techniques (BAT) Reference Document for Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector (CWW BREF)*, European Commission, Joint Research Centre, Seville, *EUR 28112 EN*, doi:10.2791/37535, European Commission, JRC IPTS EIPPCB, 2016.
- [78] COM, DG Environment: What is Emas?, 2010.
- [79] ISO, EN ISO 14001:1996, 1996.
- [80] CEN, *EN ISO 14001:2015 Environmental management systems – Requirements with guidance for use*, 2015.
- [81] bluesign, *Fact Sheet - Environmental Key Performance Indicators (eKPIs) at manufacturing plants*, 2018.
- [82] Siemens, *Spectrum Textile - Innovative Solutions for the Textile Industry - October 2005*, 2005.
- [83] CITEVE, *SET (Save Energy in Textile SMEs) - Production Processes and Efficiency Measures*, 2014.



- [84] Hasanbeigi A., *Energy-Efficiency Improvement Opportunities for the textile industry*, ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY, 2010.
- [85] Veiga J., *Specific water and energy consumption*, 2021.
- [86] Shishoo, *Plasma technologies for textiles*, Woodhead Publishing Limited / The Textile Institute, 2007.
- [87] TextileLearner, *Application of Plasma Technology in Textiles*, 2019.
- [88] Swedish EPA, *List of Emerging Techniques related to the TXT BREF*, 2018.
- [89] EURATEX, *EURATEX\_action 8\_info on technique for separate treatment of finishing liquor*, 2019.
- [90] UK, *Good practice guide 168 - Cutting your energy costs - A guide for the textile dyeing and finishing industry*, 1997.
- [91] Ullah S., 'Water Efficiency in Textile Wet Processing Industries - A Case Study of Pakistan', *Colloquium on Textile Wastewater Management 2019-09-19; Minimisation of Wastewater Emissions from Textile Finishing Industries*, Vol. ISBN 978-3-8356-7434-9, Dr.-Ing. Harald Schönberger, 2019, Stuttgart.
- [92] Inayath Hussain et al., 'Innovative Approach for Reuse of Concentrate Brine in Textile Dyeing Zero Liquid Discharge Plants- the Arulpuram CETP, Tirupur Case Study', *Colloquium on Textile Wastewater Management 2018-09-19 "Integrated Best Available Wastewater Management in the Textile Industry"*, Vol. ISBN 978-3-8356-7411-0, Dr.-Ing. Harald Schönberger (Editor), 2018, Stuttgart, Germany.
- [93] Austrian EPA, *State of the art - Austrian Textile Industry*, 2016.
- [94] Wagaw et al., '*Optimization of Caustic Soda Concentration for Causticization of Cotton*', *Open Access Scientific Reports, Volume 1, Issue 9, pp. 1-6.*, 2012.
- [95] COM, *Best Available Techniques (BAT) Reference Document for Energy Efficiency (ENE BREF)*, European Commission, JRC-EIPPCB, 2009, 2009.
- [96] Pinasseau et al., *Best Available Techniques (BAT) Reference Document for Waste Treatment (WT BREF)*, JRC Seville. European Commission, 2018.
- [97] EfA, *Produktionsintegrierter Umweltschutz in der Textilindustrie*, 2004.
- [98] Lecomte et al., *Best Available Techniques (BAT) Reference Document for Large Combustion Plants (LCP BREF)*, European Commission - Joint Research Centre, 2017.
- [99] Kohla et al., 'Effizienzsteigerung in der Textilindustrie (Efficiency Increase in Textile Industry)', Erich Schmidt Verlag', 2008.
- [100] EfA, *Produktionsintegrierter Umweltschutz in der Textilindustrie*, 2003.
- [101] Kuesters, *Vacuum technology (technical brochure)*, 2019.
- [102] Cay et al., *Relation between fabric porosity and vacuum extraction efficiency: Energy issues*, *Journal of the Textile Institute*, 99:6, 499-504, DOI: 10.1080/00405000701556707, 2008.
- [103] Bellini V., 'Information submitted by Vincenzo Bellini - "Efficienza di asciugamento, ottimizzazione dell'aria di espulsione da un tipico asciugatoio e da una rameuse"', Personal Communication, 2001.
- [104] Brückner, *Best practices in energy efficiency in textile finishing sector - Presentation made on 28.06.2016.*, 2019.
- [105] Munir S., *Aamra Resrouces>> Innovation of RCR: a self-cleaning heat exchanger for the textile industry* (<https://www.textiletoday.com.bd/aamra-resrouces-innovation-of-rcr-a-self-cleaning-heat-exchanger-for-the-textile-industry>) , 2013.
- [106] Aspland J.R., '*Chapter 3/Part 2: Practical Application of Vat Dyes*', *American Association of Textile Chemists and Colorists*, Vol. 24, No. 4, p. 27-31., 1992.
- [107] Greenpeace, *Destination Zero: seven years of Detoxing the clothing industry*, 2018.
- [108] Derden et al., *VITO report 2010/TEM/R/111: BAT For the Textile Industry: reducing emissions of some micro-pollutants via wastewater*, 2010.
- [109] EA, *Nonylphenol ethoxylates (NPE) in imported textiles (EA report LIT 7721)*, 2013.

- [110] ECHA, *Compendium of analytical methods recommended by the Enforcement Forum to check compliance with Reach annex xvii restrictions March 2016 Version 1.0 (ECHA-15-R-18-EN)*, 2016.
- [111] bluesign, *Guidance sheet - Input stream management of non-chemical raw materials/intermediates at manufacturers - BSP | 2019-12*, 2019.
- [112] COM, COMMISSION DECISION 2014/350/EU of 5 June 2014 establishing the ecological criteria for the award of the EU Ecolabel for textile products, 2014.
- [113] AWTA, *Fact sheet - Pesticide residue analysis*, 2018.
- [114] IWTO, *Clean wool production and management of chemical residues in greasy wool (ag-research)*, 2021.
- [115] AWTA Ltd, *Raw Wool Testing Fees 2018–2019 (Effective 1st July 2018)*, 2018.
- [116] Russell I.M., "Wool as a natural renewable fibre", by I. M. Russell, CSIRO, Australia in *Woodhead Publishing in Textiles: Number 72, Advances in wool technology*, Edited by N. A. G. Johnson and I. M. Russell, Woodhead Publishing Limited, 2009, 2009.
- [117] Dodd et al., *JRC Technical Reports - Revision of the EU Green Public Procurement (GPP) Criteria for Textile Products and Services: Technical background and criteria proposals (Draft) Working Document (December 2014)*, 2014.
- [118] GOTS, *Global Organic Textile Standard (Version 5.0)*, 2017.
- [119] OEKO-TEX, *Standard 100 by OEKO-TEX®: Appendix 4 - Limit values and fastness, part 1*, 2017.
- [120] bluesign, *bluesign®system substances list(BSSL) Consumer safety limits Version 10.0/ July 1, 2019*, 2019.
- [121] Attallah et al., 'Monitoring of Pesticide Residues in some Cotton Products in Egypt using GCMS/MS and LC-MS/MS', *Middle East J. Appl. Sci.*, 2017, 7(1), p. 102-109, 2017.
- [122] bluesign, *Fact sheet - Antimony*, 2020.
- [123] TEIJIN, *Teijin Aramid Statement on the Absence of REACH- SVHC, POP, ODS, RoHS2 and California Prop 65 Substances in Teijinconex® Products*, 2020.
- [124] SpinDye, We are SpinDye (web page: <https://spindye.com/>), 2019.
- [125] Lenzing, Lenzing Modal® Color (web page: <https://www.lenzing.com/>), 2019.
- [126] Terinte et al., 'Environmental assessment of coloured fabrics and opportunities for value creation: spin-dyeing versus conventional dyeing of modal fabrics', *Journal of Cleaner Production* 72 (2014) p. 127-138, 2014.
- [127] TWD Fibres, *Technical brochure for DIOLEN® (Polyester) and TIMBRELLE® (Polyamid 6.6) fibre*, 2020.
- [128] CIRFS, *IFRF (Inherently Flame Retardant and Resistant Fibres) Brochure 2020*, 2020.
- [129] Centexbel, *CENTEXBEL presentation on FR (site visit 13.03.2019)*, 2019.
- [130] Lubrizol, *Technical brochure on X4zol™-J Fiber*, 2017.
- [131] VITO, *Information submitted by L. Bettens on behalf of VITO about Corterra PPT.*, 2001.
- [132] ECHA, *Communication in the supply chain*, 2019.
- [133] ECHA, *Q&As Support - Q: Which restrictions under REACH concern textiles and leather articles?*, 2019.
- [134] EU, *The European Union System for the Evaluation of Substances* (<https://ec.europa.eu/jrc/en/scientific-tool/european-union-system-evaluation-substances>), 2019.
- [135] ZDHC, *Chemical management system guidance manual*, 2015.
- [136] OEKO-TEX, *STeP standard*, 2019.
- [137] Rodríguez P.U., *Inditex: Waste water analysis report - Data update and assessment*, 2018.
- [138] ECHA, *ECHA website*, 2019.

- [139] ECHA, Candidate List of substances of very high concern for Authorisation, 2020.
- [140] Textilbündnis, Chemical Inventory Collection Template, 2019.
- [141] bluesign, *Chemical inventory (bluesign academy, web-based training)*, 2019.
- [142] HAZBREF, *Proposal of BAT candidates for prevention and reduction of emissions from hazardous chemicals.*, 2019.
- [143] Pillet et al., 'Proposal for the content of a chemical inventory', Personal Communication, 2019.
- [144] ECHA, Guide on safety data sheets and exposure scenarios, 2019.
- [145] EIPPCB, *Report of site visits in Biella province, Italy, carried out on 29-30 January 2019*, 2019.
- [146] ZDHC, ZDHC homepage - <https://www.roadmaptozero.com/>, 2019.
- [147] OEKO-TEX, OEKO-TEX® Association homepage - [https://www.oeko-tex.com/en/about\\_oeko\\_tex/association/association.xhtml](https://www.oeko-tex.com/en/about_oeko_tex/association/association.xhtml), 2019.
- [148] GOTS, Global Organic Textile Standard homepage - <https://www.global-standard.org/>, 2019.
- [149] bluesign, BLUESIGN® homepage - <https://www.bluesign.com/en>, 2019.
- [150] bluesign, bluesign FINDER tool, 2020.
- [151] AG AFIRM, AG AFIRM Group homepage - <https://www.afirm-group.com/>, 2019.
- [152] GUT, Gemeinschaft umweltfreundlicher Teppichboden - GUT homepage - [https://www.pro-dis.info/about\\_gut.html?&L=0](https://www.pro-dis.info/about_gut.html?&L=0), 2019.
- [153] ZDHC, *ZDHC Manufacturing Restricted Substance List\_V2.0*, 2020.
- [154] ZDHC, *ZDHC MRSL Conformance Guidance VI.1*, 2019.
- [155] ChemSec, ChemSec MARKETplace homepage - <https://marketplace.chemsec.org/>, 2019.
- [156] UBA, *Proposal for BREF (textile industry) revision 2020 - Selection of preferred chemicals from positive lists*, 2020.
- [157] Danish EPA, *Danish experiences: Best Available Techniques (BAT) in the clothing and textile industry*, 2001.
- [158] Germany, 'Lanaset TOP process', Personal Communication, 2002.
- [159] Germany, *First General Administrative Regulation Pertaining the Federal Immission Control Act (Technical Instructions on Air Quality Control - TA Luft 2002) of 24.07.2002*, 2002.
- [160] LAI, *Vollzugsempfehlung Formaldehyd*, 2015.
- [161] Schlachta R., *Presentation 1 Richard Schlachta*, 2020.
- [162] Schröder V., *Presentation 2 Volker Schröder*, 2020.
- [163] Sedlak D., *Presentation 3 Dieter Sedlak*, 2020.
- [164] Kohla M., *Presentation 4 Monika Kohla*, 2020.
- [165] TEGEWA, *TEGEWA Guidelines for determination of substance emission factors*, 2011.
- [166] Zietlow B., *Report of webinar on emission factor concept*, 2020.
- [167] ROTASPRAY, *Rotating atomizer for dyeing and finishing (presentation)*, 2019.
- [168] Swedish EPA, 'Information provided by the Swedish EPA on Emerging techniques', Personal Communication, 2019.
- [169] Danish EPA, *Replacing chemicals with enzymes*, 2019.
- [170] Saxena et al., *Challenges in Sustainable Wet Processing of Textiles*, Textiles and Clothing Sustainability, Textile Science and Clothing Technology, Springer Science & Business Media, Singapore, 2017.
- [171] Cotton Incorporated, *A World of Ideas: Technologies for Sustainable Cotton Textile Manufacturing (Volume 2)*, 2018.
- [172] Novozymes, Efficient, gentle textile manufacturing with enzymes (web page: <https://www.novozymes.com/en/advance-your-business/textiles>), 2019.

- [173] COM, *Best Available Techniques (BAT) Reference Document on Emissions from Storage (EFS BREF)*, European Commission, JRC IPTS EIPPCB, 2006.
- [174] HSE, Textile - Dyes and dyeing (<https://www.hse.gov.uk/textiles/dyes-dyeing.htm>), 2020.
- [175] Benninger et al., *Toolkit for Textile Finishing Industry published by the United Nations Industrial Development Organization (UNIDO)*, 2016.
- [176] Color Service, 'Information submitted by Color Service about "Application of automated dosing and dispensing systems for chemicals and dyes in IPPC companies"', Personal Communication, 2002.
- [177] Acir et al., 'Endocrine-disrupting metabolites of alkylphenol ethoxylates – A critical review of analytical methods, environmental occurrences, toxicity, and regulation', *Science of the Total Environment* 635 (2018) 1530–1546, 2018.
- [178] EU, *Regulation (EC) No 648/2004 of the European Parliament and of the Council of 31 March 2004 on detergents*, 2004.
- [179] ECHA, *Background document to the Opinion on the Annex XV dossier proposing restrictions on NONYLPHENOL and NONYLPHENOL ETHOXYLATES*, 2014.
- [180] Sasol, *Alcohol ethoxylates: Versatile alternatives for technical applications (technical brochure)*, 2019.
- [181] SUBSPORT, *SUBSPORT Specific Substances Alternatives Assessment – Nonylphenols and Nonylphenol ethoxylates* ([https://www.subsportplus.eu/subsportplus/\\_Downloads/SUBSPORT-Nonylphenols.pdf?\\_\\_blob=publicationFile&v=3](https://www.subsportplus.eu/subsportplus/_Downloads/SUBSPORT-Nonylphenols.pdf?__blob=publicationFile&v=3)), 2013.
- [182] ISO, *ISO/TR 15642:2006 - Water quality - Selection of tests for biodegradability*, 2006.
- [183] Spain, *Information submitted by Spain: "Posición Técnica Española en relación al 1 Draft of the BREF on Textiles" including "Nuevas Aportaciones a los Capítulos 4 Y 5 del Draft 1 Documento BREF"*, 2001.
- [184] ENco, *ENco REPORT - Contribution for Wool Yarn Carpet Wet Processing (final: Chapter 1-5)*, 2001.
- [185] Germany, *Comments made by Germany on the second draft of the original BREF*, 2001.
- [186] Bettens L., 'Comment about the "BAT Document" submitted by UBA - Germany', Personal Communication, 2001.
- [187] Zanaroli P., 'The Use of Fully Closed-Loop Solvent Treatment Installations for Continuous Textile Webs', Personal Communication, 2001.
- [188] Rott et al., *Organophosphonates biodegradability and removal in WWTP*, 2017.
- [189] Lanxess, *Baypure - technical brochure* ([http://www.aniq.org.mx/pqta/pdf/baypure%20DS%2010040%20\(HT\).pdf](http://www.aniq.org.mx/pqta/pdf/baypure%20DS%2010040%20(HT).pdf)), 2019.
- [190] Seaman S., Process description for the alkaline hydrolysis method of permethrin destruction UK Chapter 4.8.4, 2019.
- [191] TenCate, Salts, dyes and acid removal from textile production (TenCate Protective Fabrics) wastewater, 2015.
- [192] Paques, *BIOPAQ®IC: Anaerobic industrial effluent treatment (technical brochure)*, 2019.
- [193] US EPA, *Emerging technologies for wastewater treatment and in-plant wet weather management - Addendum (2013-08)*, 2013.
- [194] BDP Envirotech, *Simultaneous Nitrification / Denitrification: A Continuous Biological Wastewater Treatment Technology*, 2016.
- [195] BDP Envirotech, *BDP Project Reference: High Concentration Industrial Park Wastewater Treatment (dyeing and printing)*, 2016.
- [196] US EPA, *Emerging technologies for wastewater treatment and in-plant wet weather management (2013-03)*, 2013.
- [197] ZDHC, *2016 ZDHC Wastewater Guidelines*, 2016.

- [198] ZDHC, *ZDHC Wastewater Treatment Technologies for the Textile Industry*, 2019.
- [199] FR Ministry of Ecology, Sustainable Development and Energy , *Textile finishing sectors: branch study on hazardous substances in water*, 2016.
- [200] Zimpro, Zimpro® Wet Air Oxidation Systems (technical brochure) (<https://new.siemens.com/global/en.html>), 2019.
- [201] Telgmann et al., 'Wastewater, 2. Aerobic Biological Treatment', *Ullmann's Encyclopedia of Industrial Chemistry*, 2019.
- [202] Tamil Nadu PCB, *Best Practice – Zero Liquid Discharge (ZLD) System in Textile Processing units' CETP in Tamil Nadu*, 2019.
- [203] Vajnhandl et al., 'The status of water reuse in European textile sector (Review)', *Journal of Environmental Management* 141 (2014) 29-35, 2014.
- [204] ENEA, BATTLE - Best Available Technique for water reuse in TextiLE SMEs (LIFE05 ENV/IT/000846) ([http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n\\_proj\\_id=2872](http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=2872)), 2019.
- [205] Tecnotessile, PROWATER - Sustainable water management in the textile wet industry through an innovative treatment process for wastewater re-use (LIFE04 ENV/IT/000583) ([http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n\\_proj\\_id=2781](http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=2781)), 2019.
- [206] Tecnotessile, PURIFAST - Advanced Purification Of Industrial And Mixed Wastewater By Combined Membrane Filtration And Sonochemical Technologies (LIFE07 ENV/IT/000439) ([http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n\\_proj\\_id=3284](http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=3284)), 2019.
- [207] ASPEL, Water Saving Processes for Textile Production (WASATEX) (ECO/13/630322) (<https://ec.europa.eu/environment/eco-innovation/projects/en/projects/wasatex>), 2019.
- [208] S-ISPT, ECOLORO: Reuse of Waste Water from the Textile Industry (ECWRTI) (<https://cordis.europa.eu/project/rcn/196830/factsheet/en>), 2019.
- [209] ECWRTI, *ECWRT White paper (EURATEX\_action 13\_information on Zero Discharge Liquid Technology)*, 2019.
- [210] TNO, Water in Industry, Fit-for-Use Sustainable Water Use in Chemical, Paper, textile and Food Industry (AQUAFIT4USE) (<https://cordis.europa.eu/project/rcn/88881/factsheet/en>), 2019.
- [211] UPC, ElectroChemical technique combined with UV irradiation for the treatment and reuse of dyeing textile wastewaters: Industrial marketing (ECUVal) (<https://ec.europa.eu/environment/eco-innovation/projects/en/projects/ecuval>), 2019.
- [212] EURATEX, *EURATEX\_action 13\_Additional information on Zero Discharge Liquid Technology*, 2019.
- [213] Feyaerts M., 'Waterhergebruik in de textielindustrie:“Duurzaamheid omarmt Economie” (ECWRTI/ECOLORO)', *Symposium “Innovaties in de industriële waterzuivering”*; 27 juni 2017 –U AntwerpenWaterhergebruik, 2017.
- [214] EIPPCB, *Report of the site visit carried out in Belgium on 13-14 March 2019*, 2019.
- [215] Dasgupta et al., 'Remediation of textile effluents by membrane based treatment techniques: A state of the art review', *Journal of Environmental Management* 147 (2015) 55e72, 2015.
- [216] Zietlow B., *German contribution to action 2*, UBA, 2020.
- [217] EURATEX, *EURATEX comments on JRC informal meeting*, 2021.
- [218] Zietlow B., *German proposal for BAT # 23-25 without mass flow thresholds*, 2021.
- [219] Hemkhaus et al., *Circular Economy in the Textile Sector*, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) On behalf of: German Federal Ministry for Economic Cooperation and Development, 2019.
- [220] LFU BW/BY, *Emission reduction at Textile finishing plants - Part I*, 2004.

- [221] COM, *COMMISSION DECISION of 18 December 2014 amending Decision 2000/532/EC on the list of waste pursuant to Directive 2008/98/EC of the European Parliament and of the Council (Text with EEA relevance) (2014/955/EU)*, 2014.
- [222] EU, Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives, 2008.
- [223] Derden et al., 'Brominated flame retardants in textile wastewater: reducing Deca-BDE using best available techniques, *Journal of Cleaner Production* 53 (2013) 167-175', 2013.
- [224] Seaman S., 'UK comments about the wool scouring sludge', Personal Communication, 2019.
- [225] Spain, *Contribution made by Spain to the Second Draft of the original BREF: Substitution of conventional lubricants with hydrosoluble oils in knitted fabric manufacturing*, 2002.
- [226] Alagirusamy R., NPTEL on-line lecture on ring spinning machine, 2013.
- [227] Textile Today, 'Effects of Compact Spinning on Yarn quality', *Textile today*, Vol. January 2011, 2011.
- [228] Textilelearner, An Overview of Developments in Yarn Spinning Technology, 2019.
- [229] Textilelearner, Vortex Spinning Process - Principle of Vortex Spinning System, 2019.
- [230] MURATA, Spinning system VORTEX III 870, 2019.
- [231] VITO, *Information submitted by L. Bettens on behalf of VITO about the Application of the Oxidative Route*, 2001.
- [232] Levy D., 'Peroxide desizing: a new approach in efficient, universal size removal', Personal Communication, 1998.
- [233] UBA, *Contributions of UBA Germany about dry cleaning*, 2019.
- [234] bluesign, *Usage of tetrachloroethylene for continuous dry cleaning (solvents scouring) in pre-treatment or aftertreatment of textiles*, 2016.
- [235] Santex Rimar Group, Santex Rimar Group website <https://www.santexrimar.com/brands/sperotto-rimar/machinery/nova/>, 2020.
- [236] EURATEX, *EURATEX additional information on BAT 37*, 2021.
- [237] Bettens L., *A summary of findings of the assessed documentation, including conclusions and proposals*, 2000.
- [238] bluesign, *Guidance sheet special processes: radiative drying, plastic welding, laser & ozone*, 2019.
- [239] Inditex, Water action plan best technology: ozone bleaching of denim, 2019.
- [240] Clothing industry, Ozone fading of Denim: waterless Denim finishing, 2019.
- [241] Körlü A., 'Use of Ozone in the Textile Industry [Online First]', *IntechOpen*, Vol. DOI 10.5772, No intechopen.81774, 2018.
- [242] Puchol et al., *Sustainable textile finishing using ozone and nanobubble technologies (presented at RESET project ILE3 Bucuresti(Romania))*, 2017.
- [243] OSPAR, *PARCOM Recommendation 94/5 Concerning Best Available Techniques and Best Environmental Practice for Wet Processes in the Textile Processing Industry, Annex 9.*, 1994.
- [244] UBA, *Dyeing of polyester, protein and polyamide fibers with levelling agents made from recycled waste*, 2020.
- [245] Vigneswaran et al., '2 - Industrial enzymes (in Bioprocessing of Textiles - Fundamentals for Applications and Research Perspective, pp. 23-52)', 2014, pp.23-52.
- [246] Ibrahim F.D., 'Sustainable Line of Cotton Wet Processing', *J Textile Sci Eng* 2013, vol. 3, issue 1, 2014, pp. 1-3.
- [247] Amin et al., 'Sustainable Chemistry Method to Improve the Wash-off Process of Reactive Dyes on Cotton', *ACS Sustainable Chemistry & Engineering*, Vol. 3, 2015, pp. 725-732.
- [248] MCS, *Information brochure about multiflow dyeing*, 2001.

- [249] Brazzoli, *Information brochure about "Sirio" dyeing machines*, 2001.
- [250] Bellini L., *Information brochure about dyeing machines (General Catalogue)*, 2001.
- [251] VITO, *Information and comments submitted by L. Bettens on behalf of VITO about Discontinuous Dyeing*, 2001.
- [252] Pharma, *Textile Softeners*, 2001.
- [253] Bettens L., 'OSPAR POINT 2000-Conclusions', Personal Communication, 2000.
- [254] Hansson S., 'SE comments - Spray batch technique', Personal Communication, 2021.
- [255] IMOGO, *IMOGO - Information about spray batch technique*, 2019.
- [256] ZERO BRINE, *ZERO BRINE IED policy brief*, 2021.
- [257] VITO, *Information submitted by L. Bettens on behalf of VITO about Ecological Sulphur Dye & Dyeing Techniques*, 2001.
- [258] Cottonworks, *Cationic cotton*, 2019.
- [259] Bhuiyan et al., 'Cationization of Cotton Fiber by Chitosan and Its Dyeing with Reactive Dye without Salt', *Chemical and Materials Engineering*, Vol. 2(4), 2014, pp. 96-100.
- [260] Choudhury A.K.R., 'Coloration of Cationized Cellulosic Fibers—A Review', *AATCC Journal of Research*, Vol. May, No June 2014, Vol. 1, No. 3, 2014, pp. 11-19.
- [261] Fu Sha, *Studies on Dyeing Cationized Cotton (Dissertation)*, North Carolina State University, 2016.
- [262] Blahutova M., *CZ comments - Cationic cotton*, 2021.
- [263] Farrell et al., 'Cationic Cotton, Reservations to Reality', *AATCC Review*, Vol. September, No October 2013, 2013, pp. 56-63.
- [264] Choudhury A.K.R., *Textile Preparation and Dyeing*, Science Publishers, 2006.
- [265] Nallathambi et al., 'Industrial scale salt-free reactive dyeing of cationized cotton fabric with different reactive dye chemistry', *Carbohydrate Polymers*, Vol. 174, 2017, pp. 137-145.
- [266] VITO, *Information submitted by L. Bettens on behalf of VITO about Fibre reactive dyeing*, 2001.
- [267] Danish EPA, *Cleaner Technology Transfer to the Polish Textile Industry*, 1999.
- [268] Huntsman, *Technical brochure - Lanazol Black NSC*, 2019.
- [269] VITO, *Information submitted by L. Bettens on behalf of VITO about reducing agents*, 2001.
- [270] CRAB, 'Information submitted by CRAB, Biella, Italy, about low-chrome dyeing techniques"', Personal Communication, 2001.
- [271] Bettens L., *A summary of findings of the assessed documentation, including conclusions and proposals*, 2000.
- [272] Nieminen et al., 'EU COST Action 628: life cycle assessment (LCA) of textile products, eco-efficiency and definition of best available technology (BAT) of textile processing (Journal of Cleaner Production Volume 15, Issues 13–14, September 2007, Pages 1259-1270)', *Journal of Cleaner Production*, Vol. Volume 15, Issues 13–14, September 2007, 2007, pp. Pages 1259-1270.
- [273] VITO, *Information and comments submitted by L. Bettens on behalf of VITO: "Wool chrome dyeing or reactive dyeing?"*, 2001.
- [274] Ozturk et al., 'Sustainable textile production: cleaner production assessment/eco-efficiency analysis study in a textile mill (Journal of Cleaner Production, Volume 138, Part 2, 1 December 2016, Pages 248-263)', *Journal of Cleaner Production*, Vol. Volume 138, Part 2, 1 December 2016, 2016, pp. 248-263.
- [275] ECHA, *Adopted opinions and previous consultations on applications for authorisation.*, 2019.
- [276] CHT, BEMACRON HP-LTD, Bezema Colour Solutions (web page: [https://www.cht.com/cht/web.nsf/id/pa\\_bemacron-hp-ltd-en.html](https://www.cht.com/cht/web.nsf/id/pa_bemacron-hp-ltd-en.html)), 2020.

- [277] VITO, *Information submitted by L. Bettens on behalf of VITO about alkalidischargeable azo disperse dyes containing phthalimide moieties*, 2001.
- [278] Gashti et al., 'Surface and Bulk Modification of Synthetic Textiles to Improve Dyeability (DOI: 10.5772/18706)', *Textile Dyeing*, Ed. Peter Hauser, IntechOpen, 2011 (ISBN: 978-953-307-565-5), 2011.
- [279] Liao et al., 'Literatures on Dyeing Technique of Supercritical Fluid Carbon Dioxide', *American Journal of Analytical Chemistry*, (3) 2012, pp. 923-930, 2012.
- [280] DyeCoo, CO2 Dyeing - Dyecoo (web page: <http://www.dyecoo.com/co2-dyeing/>), 2019.
- [281] Schumacher C., Dyeing with supercritical CO2 – finally a success story? (<https://blog.stepchange-innovations.com/2016/07/dyeing-supercritical-co2-finally-success-story/>), 2016.
- [282] Kohla M., 'Technical information provided orally during the Final meeting', Personal Communication, 2021.
- [283] SPGPrints, *JAVELIN-2 Leaflet*, 2020.
- [284] bluesign, *Guidance Sheet - VOC management for transfer-paper printing*, 2019.
- [285] TextileToday, Uses of laser technology producing 'greener' denims (by Abir Basak) (web page: <https://www.textiletoday.com.bd/uses-laser-technology-producing-greener-denims/>), 2017.
- [286] Lawrance C., *Water Consumption & Energy Saving: The Development of Functional Treatments for Textile Applications utilising MLSE Synthesis Technology (2nd Thematic Conference of RESET project, Porto, Portugal)*, 2017.
- [287] Industry Innovation Centre, Eco-innovation: Multiple Laser Surface Enhancement (MLSE TEXTILES) (web page: <http://textilehouse.co.uk/innovations-and-projects/eco-innovation/mlse-technology/>), 2015.
- [288] JEANOLOGIA S.L., Eco-innovation project: Nano bubble water free process for garment eco-finishing (MNB ECO-FINISHING), 2015.
- [289] EU, 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 (CLP), 2008.
- [290] Saxena et al., 'Challenges in Sustainable Wet Processing of Textiles', *Textiles and Clothing Sustainability*., 2017, pp. 43-79.
- [291] Choudhury A.K.R., *Principles of Textile Finishing (The Textile Institute Book Series)* (<https://www.sciencedirect.com/book/9780081006467/principles-of-textile-finishing>), Woodhead Publishing (Elsevier), 2017.
- [292] SUBSPORT, *SUBSPORT Specific Substances Alternatives Assessment – Formaldehyde*, 2013.
- [293] Zietlow B., *Explanation of the sources of formaldehyde emissions from textile finishing*, 2020.
- [294] Nagaraju et al., 'Technical Briefing: Enzymes, The Combined Bioblasting Concept: Save Energy, Greenhouse Gases and Water', *INTERNATIONAL DYER*, Vol. ISSUE (4) 2013, 2013, pp. 36-38.
- [295] EU, *Regulation (EC) No 850/2004 of the European Parliament and of the Council of 29 April 2004 on persistent organic pollutants and amending Directive 79/117/EEC*, 2004.
- [296] VITO, 'Candidate BAT for alternative flame retardants', Personal Communication, 2019.
- [297] Lubrizol, *Non-halogen Flame Retardant Acrylic-based\_Technical data sheet* <https://www.lubrizol.com/Coatings/Products/Hycar-NH3069#>, Lubrizol, 2021.
- [298] FRX Polymers, *Nofia OL1001 and OL3001 performance properties* <https://www.frxpolymers.com/s/Nofia-OL1001-OL3001-v7-Jan-2019.pdf>, FRX Polymers, 2019.
- [299] Swedish EPA, *Information about phosphonic acid in Pyrovatex CP och Proban CC*, 2020.



## References

---

- [300] SUBSPORT, *SUBSPORT Specific Substances Alternatives Assessment – Chloroalkanes*, 2013.
- [301] SUBSPORT, *SUBSPORT Specific Substances Alternatives Assessment – Hexabromocyclododecane*, 2013.
- [302] EURATEX, *EURATEX contribution to action 11: abatement of organophosphorous flame-retardants*, 2020.
- [303] Derden et al., *Beste Beschikbare Technieken (BBT) voor de drankenindustrie.*, VITO, 2008.
- [304] US EPA, *An Alternatives Assessment for the Flame Retardant Decabromodiphenyl Ether (DecaBDE)*, 2014.
- [305] US EPA, *Flame retardants in printed circuit boards*, 2015.
- [306] UMass Lowell, *An Investigation of Non-Halogen Substitutes in Electronic Enclosure and Textile Applications*, 2005.
- [307] UK, EURATEX, *Candidate BAT for ammonia based treatment of cellulosic fibres for flame retardant finish*, 2019.
- [308] Cotton Incorporated, *Technical bulletin TRI 4002: Fabric flame retardant treatment "precondensate"/NH3 process*, 2003.
- [309] Danish EPA, *Danish EPA report on alternatives to PFAS in textiles*, 2015.
- [310] COM, *The use of PFAS and fluorine-free alternatives in textiles, upholstery, carpets, leather and apparel*, 2020.
- [311] RUDOLF, BIONIC-FINISH@ECO, 2020.
- [312] Holmquist et al., 'Properties, performance and associated hazards of state-of-the-art durable water repellent (DWR) chemistry for textile finishing', *Environment International*, Vol. 91, 2016, pp. 251-264.
- [313] SUPFES, 'Presentation made at the conference "Nachhaltige Outdoor-Textilien", Bremen, 14.03.2018', 2018.
- [314] LEITAT, *MIDWOR LIFE project LIFE14 ENV/ES/000670 - Deliverable B.6.3 "Recommendations to update voluntary schemes"*, 2018.
- [315] Bechtold et al., 'Chlorine free superwash finish of wool - a new standard comes to technical reality', *Melliand International*, Vol. 04, No 2012, 2012, p. 237.
- [316] Blahutova M., *CZ comments - Hercosett process*, 2021.
- [317] Austrian EPA, 'BAT candidate: Chlorine-free anti-felting treatment of wool', Personal Communication, 2018.
- [318] bluesign, *Fact sheet Permethrin*, 2012.
- [319] OSPAR, *PARCOM Recommendation 97/1 concerning Reference values for Effluent Discharges from Wet Processes in the Textile Processing Industry, Annex 12*, 1997.
- [320] Hill I.R., 'Aquatic organisms and pyrethroids. Pestic. Sci., 27: 429-457', *Pesticide Science*, Vol. 27, 1989, pp. 429-457.
- [321] Allanach et al., 'Proceedings of the 9th International Wool Textile Research Conference Vol. 1, 182 -190', 1995.
- [322] Allanach et al., 'Proceedings of the 9th International wool Textile Research Conference Vol.3, 325-332', 1995.
- [323] Allanach, 'Proceedings of the 8th International Wool Textile Research Conference, Vol.4, 568-576', 1990.
- [324] TWG, *Comments on the first draft of the Textiles BREF*, 2020.
- [325] AMA, *Extract form of natural textile dyes* ([http://www.amaherbal.com/pages\\_m.php?head\\_id=17&cat\\_id=37&page\\_type=EXTRA CT%20FORM%20OF%20NATURAL%20TEXTILE%20DYES](http://www.amaherbal.com/pages_m.php?head_id=17&cat_id=37&page_type=EXTRA_CT%20FORM%20OF%20NATURAL%20TEXTILE%20DYES)), 2019.
- [326] ARCHROMA, *EarthColors® by Archroma* (<https://www.archroma.com/innovations/earth-colors-by-archroma>), 2019.

- [327] AITEX, LIFE SEACOLORS - Demonstration of new natural dyes from algae as substitution of synthetic dyes actually used by textile industries (LIFE13 ENV/ES/000445) ([http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n\\_proj\\_id=5017](http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=5017)), 2019.
- [328] UNISI, BISCOL - BIoprocessing for Sustainable production of COLOured textiles (ECO/09/256112) (<https://ec.europa.eu/environment/eco-innovation/projects/en/projects/biscol>), 2019.
- [329] Drumond Chequer et al., "'Textile Dyes: Dyeing Process and Environmental Impact" in *Eco-Friendly Textile Dyeing and Finishing*, Melih Gunay (Ed.), (DOI: 10.5772/3436)', 2013.
- [330] Aktek et al., 'Salt Free Dyeing of Cotton Fiber- A Critical Review', *International Journal of Textile Science*, Vol. 6, No 2, 2017, pp. 21-33.
- [331] AITEX, LIFE project Dyes4ever - Demonstration of cyclodextrin techniques in treatment of waste water in textile industry to recover and reuse textile dyes - Layman report, 2016.
- [332] AITEX, LIFE Project DYES4EVER - Demonstration of cyclodextrins techniques in treatment of waste water in textile industry to recover and reuse textile dyes - Summary of FINAL Report, 2016.
- [333] INTEXTER, DYEING BATH REUSE - Direct reutilization of dye baths and self-monitoring of the process "on line" (LIFE03 ENV/E/000166) ([http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n\\_proj\\_id=2381](http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=2381)), 2019.
- [334] SUBSPORT, A biodegradable, protein-based biopolymer to replace acrylic resins and their additives in textile printing (Grafco Srl, Treviso), 2019.
- [335] Hassan et al., 'A review of the sustainable methods in imparting shrink resistance to wool fabrics', *Journal of Advanced Research 18 (2019) pp. 39–60*, 2019.
- [336] SUEDWOLLEGROUP, Antifelting treatment Naturetexx, 2019.
- [337] Canal et al., 'Study on the Influence of Scouring on the Wettability of Keratin Fibers before Plasma Treatment (Fibers and Polymers 2008, Vol.9, No.4, pp. 444-449)', *Fibers and Polymers 2008, Vol.9, No.4, pp. 444-449*, 2008.
- [338] Superwool, Layman's report of the LIFE project ENV/D/000195: Superwool - Sustainable, AOX-free Superwash Finishing of Wool Tops for the Yarn Production, 2009.
- [339] ECHA, Regulation (EU) No 528/2012 Evaluation of active substances Assessment Report Permethrin, ECHA - Assessment report from Ireland, 2014.
- [340] ECHA, ECHA's website - Information on biocides - list of active substances <https://echa.europa.eu/information-on-chemicals/biocidal-active-substances>, 2021.
- [341] Uddin F., 'Flame-retardant fibrous materials in an aircraft (DOI: 10.1177/1528083714540700)', *Journal of Industrial Textiles*, Vol. 45(5) pp. 1128–1169, 2016.
- [342] Drees et al., Cefic's additional comment to the second draft of the questionnaire, CEFIC, 2019.
- [343] EEB, Information on toxicity of organophosphorous flame-retardants - Action point 12, 2020.
- [344] Derden A., BE - phosphor-organic FR Aflammit (same activated substance as Pyrovatex), 2020.
- [345] EEB, (ECHA) Chemical safety report (2014) for THPC-urea, Tetrakis(hydroxymethyl) phosphonitun chloride, oligomeric reaction pro ... (THPC) (CAS number: 27104-30-9), 2021.
- [346] Pirobloc, Textile industry (available at: <https://www.pirobloc.com/en/applications-and-sectors/textile-industry/>), 2021.
- [347] Pillet et al., Methodology to prioritise chemicals for prevention or control of emissions, ECHA, 2020.

## References

---

- [348] EU, *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*, 2012.
- [349] Stewart R.G., *Woolscouring and Allied Technology*, Wool Research Organisation of New Zealand, Christchurch, New Zealand, 3rd edition, 1988.
- [350] Bradbury et al., 'Smart rinsing; a step change in reactive dyes application technology', *JSDC*, Vol. 116, No May-June 2000, 2000.
- [351] MCS, 'Low liquor ratio machinery and new development on rinsing techniques', Personal Communication, 2002.
- [352] Zietlow B., *German contribution to action 3*, Germany, 2020.
- [353] Madden M., 'Comments on database of residues in grease wool - submitted by ENCO', Personal Communication, 2020.
- [354] Bozzetto, 'Comments and contributions submitted by Bozzetto about "Applied Processes and Techniques in the Textile Sector"', Personal Communication, 2000.
- [355] CIA, *Comments made by CIA on the Second Draft of the BREF*, 2002.
- [356] VITO, *Information provided by L. Bettens on behalf of VITO about Flame Retardants*, 2002.
- [357] COM, *Best Available Techniques (BAT) Reference Document for the Production of Large Volume Organic Chemicals (LVOC BREF)*, European Commission, Joint Research Centre, Seville, EUR 28882 EN, doi:10.2760/77304, European Commission, JRC Seville EIPPCB, 2017.
- [358] TEGEWA, *International Textile Auxiliaries Buyers' Guide*, 2000.
- [359] Kuster, 'Dye/ finish applicators - Information submitted by L. Bettens on behalf of VITO',

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