European Commission

JRC SCIENCE FOR POLICY REPORT

Best Available Techniques (BAT) Reference Document for the Ceramic Manufacturing Industry

Colour code:

~~Black: Deleted text from the original CER BREF (2007)~~

Yellow highlights are messages to the TWG, not part of the BREF

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

JOINT RESEARCH CENTRE
Directorate B – Fair and Sustainable Economy
Circular Economy and Sustainable Industry Unit
European IPPC Bureau

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Source: Cover page illustration - [41, Cerame-Unie 2020], [42, Cerame-Unie 2021]

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WORKING DRAFT IN PROGRESS

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

Reference Document on Best Available Techniques (BREF)	**Code**
Ceramic Manufacturing Industry	CER
Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector	CWW
Common Waste Gas Management and Treatment Systems in the Chemical Sector	WGC
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
Textiles Industry	TXT
Waste Incineration	WI
Waste Treatment	WT
Reference Document (REF)	
Economics and Cross-media Effects	ECM
Monitoring of Emissions to Air and Water from IED Installations	ROM

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

~~EXECUTIVE SUMMARY~~

[The executive summary of the 2007 CER BREF was deleted.]

PREFACE

1. Status of this document

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

This document is a working draft of the European IPPC Bureau (of the Commission's Joint Research Centre). It is not an official publication of the European Union and does not necessarily reflect the position of the European Commission.

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

Chapters 1 and 2 provide general information on the Ceramic Manufacturing Industry and on the industrial processes and techniques 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, the 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.
[This chapter will be drafted and shared for comments at a later stage.]

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.
[This chapter will be drafted and shared for comments at a later stage.]

4. Information sources and the derivation of BAT

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

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

- identification of the key environmental issues for the sector;
- 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 greatly on the specific situation of the installation concerned, which cannot be evaluated fully in this document. In the absence of data concerning costs, conclusions on the economic viability of techniques are drawn from observations on existing installations.

5. Review of BAT reference documents (BREFs)

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

6. Contact information

All comments and suggestions should be made to the European IPPC Bureau at the Joint Research Centre (JRC) at the following address:

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Best Available Techniques (BAT) Reference Document for the Ceramic Manufacturing Industry

[Note to the TWG: please note that the colour code in not applied in the table of contents, list of figures and list of tables below]

List of figures

List of tables

SCOPE

[Note to the TWG: This section has been completely rewritten compared to the original CER BREF]

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

3.5. Manufacture of ceramic products by firing, in particular roofing tiles, bricks, refractory bricks, tiles, stoneware or porcelain with a production capacity exceeding 75 tonnes per day and/or with a kiln capacity exceeding 4 m^3 and with a setting density per kiln exceeding 300 kg/m^3.

6.11. Independently operated treatment of waste water not covered by Directive 91/271/EEC[1], provided that the main pollutant load originates from the activities covered by these BAT conclusions.

This document also covers the following:

- Directly associated activities such as spray drying and calcining of raw materials.
- The co-incineration of waste in ceramic manufacturing kilns and the on-site reuse of residues and recovery of waste.
- The combined treatment of waste water from different origins provided that the main pollutant load originates from the activities covered by these BAT conclusions and that the waste water treatment is not covered by Directive 91/271/EEC1 .
- On-site combustion processes that are directly associated with the activities covered by these BAT conclusions, provided that the gaseous products of combustion come into direct contact with objects or materials (e.g. in heating, drying, any other treatment of objects or materials).

This document does not cover the following:

- The quarrying of raw materials (e.g. clays).
- On-site combustion plants, generating hot gases that are not used for direct contact heating, drying or any other treatment of objects or materials. These may be covered by the BAT conclusions for Large Combustion Plants (LCP) or by Directive (EU) 2015/21932 of the European Parliament and of the Council.
- Waste incineration; this may be covered by the BAT conclusions for Waste Incineration (WI).
- Waste treatment; this may be covered by the BAT conclusions for Waste Treatment (WT).
- The manufacturing of glass ceramics, the production of refractory ceramic fibres and the production of frits; these may be covered by the BAT conclusions for the manufacture of glass (GLS).
- The porcelain/vitreous enamelling of metals.

Other reference documents which could be relevant for the activities covered by these BAT conclusions include the following:

- Production of Cement, Lime and Magnesium Oxide (CLM), for the production of magnesium oxide;
- Monitoring of Emissions to Air and Water from IED Installations (ROM).

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[1] Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment (OJ L 135, 30.5.1991, p. 40).

[2] Directive (EU) 2015/2193 of the European Parliament and of the Council of 25 November 2015 on the limitation of emissions of certain pollutants into the air from medium combustion plants (OJ L 313, 28.11.2015, p. 1).

1 GENERAL INFORMATION ON CERAMIC MANUFACTURING

1.1 Historical origins

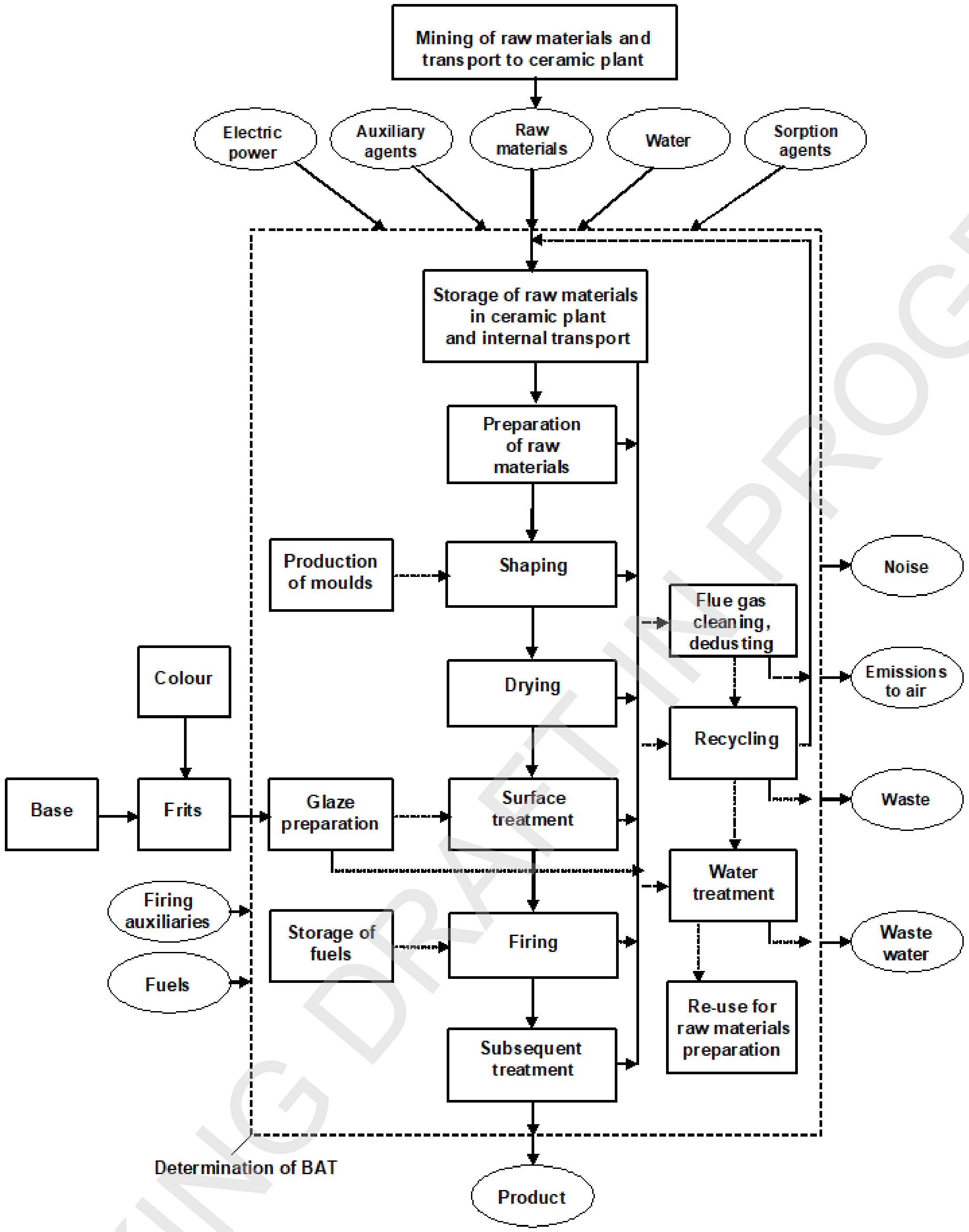
The term ‘ceramics’ is derived from the Greek ‘keramos’ meaning ‘burned earth’ and is used to describe materials of the pottery industry. ~~Recent research shows that t~~ The processing of clay started around 19000 BC. The oldest findings of pottery in southern Japan are dated between 8000 BC and 9000 BC. As early as 4000 BC fired bricks were used for the construction of temple towers, palaces and fortifications. More than 2000 years ago the Romans spread the technique of brick making into large parts of Europe. In Egypt, glazed ceramic plates were used as wall decorations for the pyramids in 2600 BC and in China, the art of china porcelain making has been known since 1000 BC.

1.2 ~~Characteristics of ceramics~~ Ceramic manufacturing and process steps

Generally the term ‘ceramics’ (ceramic products) is used for inorganic materials (with possibly some organic content), made up of non-metallic compounds and made permanent by a firing process. In addition to clay-based materials, today ceramics include a multitude of products with a small fraction of clay or none at all. Ceramics can be glazed or unglazed, porous or vitrified.

Firing of ceramic bodies induces time-temperature transformation of the constituent minerals, usually into a mixture of new minerals and glassy phases. Characteristic properties of ceramic products include high strength, wear resistance, long service life, chemical inertness and non-toxicity, resistance to heat and fire, (usually) electrical resistance and sometimes also a specific porosity.

The main steps in the manufacture of ceramic products are largely independent of the materials used and the final product. ~~The following figure~~ Figure 1-1 schematically shows the typical process and possible or necessary supply and disposal facilities. The process is made up of the steps: mining/quarrying of raw materials and transport to the ceramic plant (neither of these two steps is covered in this document), storage of raw materials, preparation of raw materials, shaping, drying, surface treatment, firing and subsequent treatment [23, TWG 2005].



Source: [9, COM 2007]

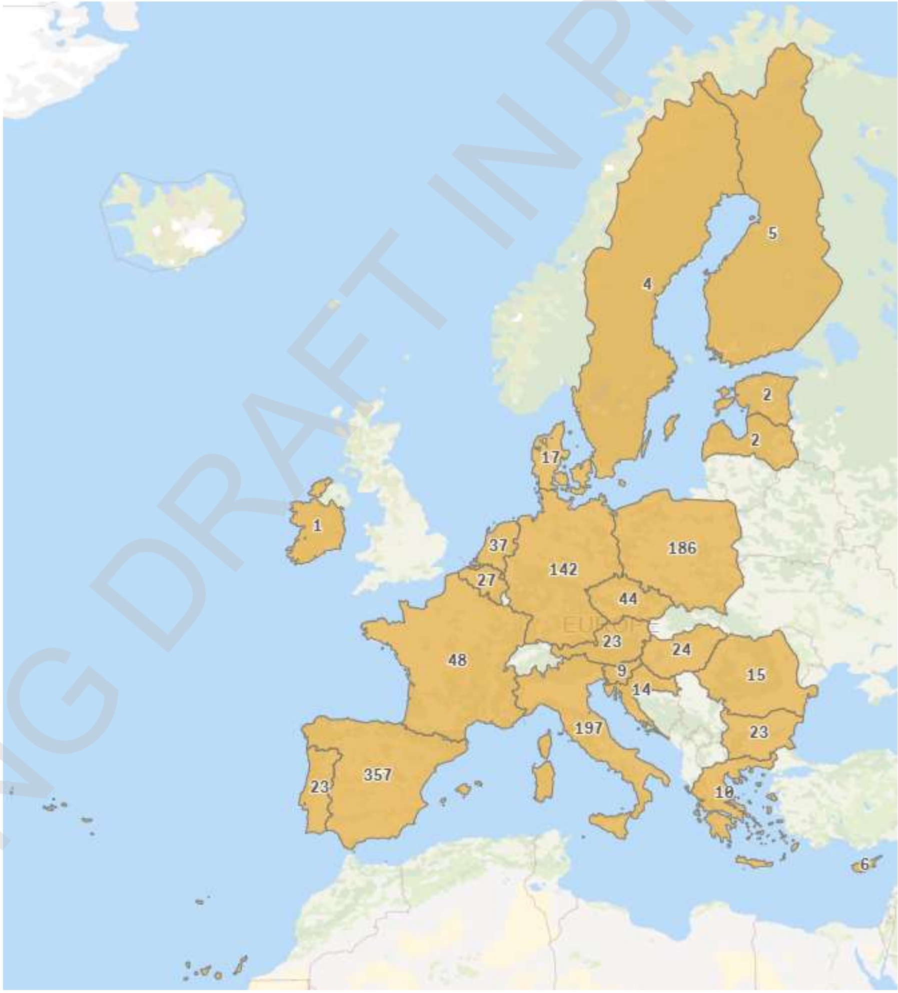
Figure 1-1: Stages Steps in the manufacture of ceramic products

The best available techniques for integrated environmental protection in the ceramic industry ~~named~~ given in this document are related to the processes employed within the bordered area.

1.3 Geographical distribution and general economic considerations

[Note to the TWG: please provide information to update this section.]

Clay raw materials are widely distributed throughout Europe, so ceramic products like bricks which are relatively inexpensive (but which incur high transport costs due to their weight) are manufactured in virtually all Member States. Building traditions and heritage considerations result in different unit sizes from country to country. More specialised products which command higher prices tend to be mainly produced in a few countries, which have the necessary special raw materials and – equally important – traditions of skill and expertise. For example, a large percentage of ceramic tiles are manufactured in Italy and Spain; tableware in~~ the United Kingdom,~~ Germany, the Netherlands, Portugal and Poland~~ and France~~; vitrified clay pipes in Germany, ~~United Kingdom~~, Belgium and Poland ~~and the Netherlands~~. [44, COM 2020], [9, COM 2007]. A geographical distribution of ceramic manufacturing IED installations within the EU in 2019 is given in Figure 1-2.



Source: [68, EEA 2019]

Figure 1-2: Geographical distribution of ceramic manufacturing IED installations within the EU in 2019

There is considerable international trade in wall and floor tiles, refractory products, table- and ornamentalware, technical ceramics, vitrified clay pipes and sanitaryware.

The importance of the ceramic industry in terms of employment and economics is shown in Table 1.1. ~~the following table [20, Ceram-Unie 2004], [23, TWG 2005], [26, UBA 2005], [30, TWG 2005]~~.

[Note to the TWG: please provide information to complete the table below. Also if possible to update the production of wall and floor tiles in tonnes. The table from the 2007 CER BREF has been struck through below]

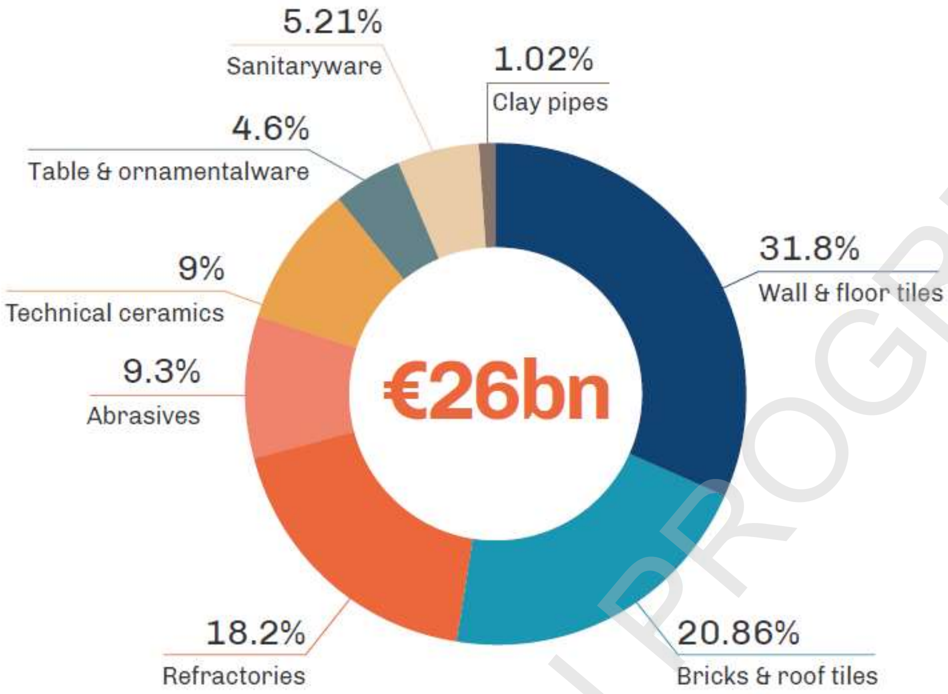
Table 1.1: Ceramics output, sales and employment figures

Ceramic products	**EU-27 Outputs 2019**	**EU-27 Outputs 2021**	**EU-27 Sales 2019 (million EUR)**	**EU-27 Sales 2021 (million EUR)**	**Manpower 2018 (x 1000)**
Wall and floor tiles	1 197 849 970 m^2	1 307 932 715 m^2	9 899	11 408	59
Brick and roof tiles and clay pipes	ND	ND	5 520	5 902	42
Table and ornamentalware	330 000 tonnes	300 000 tonnes	1 553	1 571	48
Refractory products	ND	ND	ND	ND	ND
Sanitaryware	ND	ND	1 386	1 553	16
Technical ceramics	ND	ND	2 773	3 033	15
Expanded clay	ND	ND	277	321	ND

ND: No data.
Source: [64, Cerame-Unie 2023]

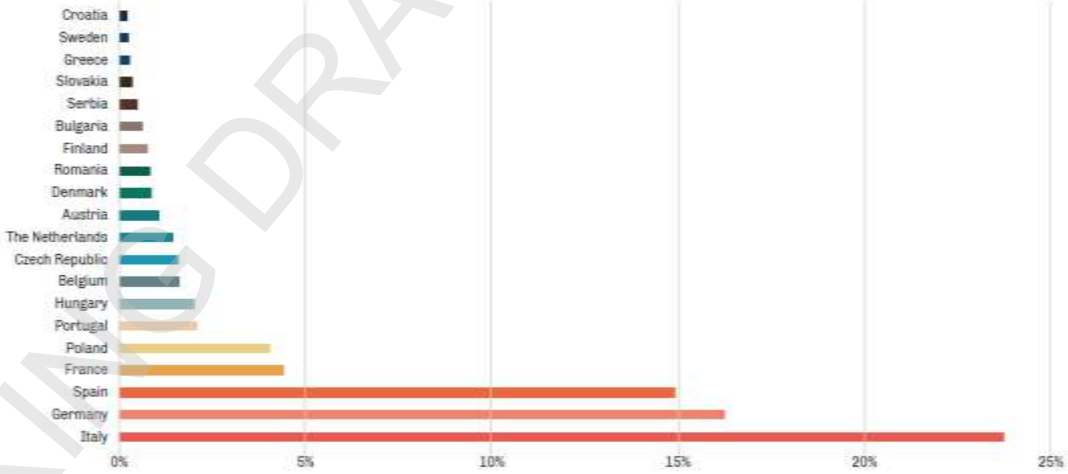
~~Sector of Ceramic industry~~	**~~EU-15 Output 2000 (x million tonnes)~~**	**~~EU-15 sales 2003 (x million EUR)~~**	**~~Manpower 2003 (x 1000)~~**
~~Wall and floor tiles~~	~~25.0~~	~~10100~~	~~69~~
~~Bricks and roof tiles~~	~~55.0~~	~~6800~~	~~50~~
~~Table- and ornamentalware~~	~~0.5~~	~~2000~~	~~48~~
~~Refractory products~~	~~4.5~~	~~3100~~	~~18~~
~~Sanitaryware~~	~~0.5~~	~~1900~~	~~25~~
~~Technical ceramics~~	~~0.15~~	~~2000~~	~~9~~
~~Vitrified clay pipes~~	~~0.7~~	~~300~~	~~2~~
~~Expanded clay aggregates (2002)~~	~~3.0~~	~~300~~	~~2.5~~
~~Inorganic bonded abrasives (2003)~~	~~0.04~~	~~260~~	~~3.1~~

The European ceramic industry has a total turnover of EUR 26 billion, and more than a third of the production volume is exported outside the EU. Figure 1-3 shows the production value per ceramic sector and Figure 1-4 the percentage of production value by European country in 2020. The industry provides more than 200 000 direct and 400 000 indirect jobs, across every country in Europe [42, Cerame-Unie 2021].



Source: [42, Cerame-Unie 2021]

Figure 1-3: Production value per ceramic sector in 2020



Source: [42, Cerame-Unie 2021]

Figure 1-4: Percentage of production value of ceramics manufactured by European country in 2020

1.4 Ceramics sectors

[Note to the TWG: This section has been moved from Section 1.5 in the 2007 CER BREF]

The fundamental methods and steps in the production processes hardly differ in the manufacture of the various ceramic products, besides the fact that, for the manufacture of, e.g. wall and floor tiles, table- and ornamentalware (household ceramics), sanitaryware and also technical ceramics, often a multiple-stage firing process is used. This is one historical reason why the various ceramics sectors can be summarised in two groups, the group of ‘coarse’ or ‘construction’ ceramics including the bricks and roof tiles, vitrified clay pipes, refractory products and expanded clay aggregates sectors and the group of ‘fine’ or ‘traditional and industrial ceramics’, including the wall and floor tiles, table- and ornamentalware, sanitaryware, technical ceramics and inorganic bonded abrasives sectors.

The technical ~~realisation~~processes, however, can be very different, according to the specific requirements of the products and the characteristics of the raw materials used. For example, there are various continuously operated (e.g. tunnel kilns) and periodically operated (e.g. shuttle kilns) kilns used for firing the same or different ceramic products.

Products of the ‘fine’ or ‘traditional and industrial’ ceramic industry differ from products of the ‘coarse or construction’ ceramic industry in principle in their texture. The border between ‘fine’ or ‘traditional and industrial’ and ‘coarse’ or ‘construction’ ceramics varies between equivalent particle diameters of 0.1 mm and 0.2 mm. ‘Coarse’ or ‘construction’ ceramic products show an inhomogeneity of more than 0.2 mm but the borderline between ‘fine’ or ‘traditional and industrial’ and ‘coarse’ or ‘construction’ ceramics is not really fixed today. For example, the processing technology for ‘fine’ or ‘traditional and industrial’ ceramics is used for the production of super refractory products. Therefore this document does not follow the above-mentioned distinction between the two groups, but only distinguishes between the following nine sectors of ceramic products [32, TWG 2006]:

- bricks and roof tiles;
- vitrified clay pipes;
- refractory products;
- expanded clay aggregates;
- wall and floor tiles;
- table- and ornamental ware (household ceramics);
- sanitaryware;
- technical ceramics;
- inorganic bonded abrasives.

1.4.1 Bricks and roof tiles

[Note to the TWG: please provide information to update and to complement this section]

Bricks and roof tiles products are produced in large quantities~~, which~~ and are used as materials in numerous branches of building and contracting. ~~For the most part, bricks and tiles are not designated according to the shaping technique used, but according to the intended application:~~

- ~~building bricks (e.g. clay blocks, facing bricks, engineering bricks (‘klinker bricks’) and lightweight bricks)~~
- ~~roof tiles (e.g. extruded tiles, pressed tiles)~~
- ~~paving bricks~~
- ~~chimney bricks (e.g. chimney pipes).~~

For the classification of products, different approaches are used (e.g. dedicated use of the product, mechanical/thermal properties, density, etc.) Table 1.2 includes a classification of brick and roof tiles according to their application and perforation volume.

Table 1.2: Classification of products in the brick and roof tile sector

Solid bricks with a perforation volume < 20 % of the total volume intended to be used in unprotected masonry	
• Pavers	
• Facing bricks: ○ extruded ○ moulded ○ brick slips	
• Roof tiles	
Perforated bricks with a perforation volume > 20 % of the total volume intended to be used in protected masonry	
• Clay blocks (mainly applied in cavity walls, e.g. in Belgium, Germany, Austria, the Netherlands, etc.)	
• Hollow bricks (mainly applied where the solid wall was built with natural stone, e.g. in France, Spain, Italy, etc.)	
Source: [56, COM 2023]	

~~Due to the different techniques in manufacture, different types of brickyards have specialised in various groups of products, e.g. clay roof tile works and building bricks works.~~

~~In 2003, the European clay brick and roof tile industry had total sales of around EUR 6800 million and a labour force of around 50000 [20, Ceram-Unie 2004], [23, TWG 2005].~~

~~There are variations in the number of clay brick works, paving works and roof tile works as follows:~~

~~Italy has the highest amount of factories, i.e. 238 works, followed by Germany (183), Portugal (150), France (136) and the United Kingdom (134). Less than 70 factories are operational in other countries like the Netherlands (58), Belgium (40), Austria (30), Switzerland (27) and Denmark (26).~~

~~The average number of brick works per million inhabitants is as follows:~~

~~Portugal (1.5), Denmark (5.1), Italy (4.1), Belgium (4.0), Austria (3.8), Switzerland (3.7), the Netherlands (3.7), United Kingdom (2.3), France (2.3) and Germany (2.2).~~

~~A comparison of the data [3, Ceram-Unie 2003] related to inhabitants in the following countries (situation in 2001) indicates:~~

- ~~roof tile production is high in France (0.89 m^2 per inhabitant) followed by Italy (0.61), Germany (0.54), Spain (0.5), Switzerland (0.48), Denmark (0.4) and Austria (0.28). In other countries, e.g. United Kingdom and Belgium, the production of roof tiles is much lower. Finland and Norway do not produce roof tiles~~
- ~~bricks and blocks are manufactured in each country of EU-15. The highest production is recorded in Belgium (0.29 m^3 per inhabitant), followed by Spain (0.28), Italy (0.26), Austria (0.24), Germany (0.17), Switzerland (0.08) and with lower values in the other countries.~~

~~Perforated units are important, e.g. in Austria (97 %), Germany (87 %); facing bricks in the Netherlands (94 %), United Kingdom (82 %) and Denmark (85 %). Hollow units are favoured in France (63 %) and Italy (62 %).~~

~~The average number of employees per factory varies between the different European States:~~

- ~~United Kingdom (66)~~
- ~~Belgium (44)~~
- ~~France (39) and the Netherlands (38)~~
- ~~Austria (35), Germany (34) and Italy (34)~~
- ~~Switzerland (24) and Denmark (21).~~

1.4.2 Vitrified clay pipes

[Note to the TWG: please provide information to update this section]

Vitrified clay pipes and fittings are used for drains and sewers, but also tanks for acids and products for stables and animal housing. ~~The annual production in 2000 in EU-15 amounted to 708000 tonnes~~ [3, Ceram-Unie 2003] [4, UBA 2001].

Production plants are situated in Belgium, Germany, ~~Italy, ~~and Poland [44, COM 2020]. ~~Netherlands and the United Kingdom~~. ~~Their products are delivered to all EU-15 Member States on the basis of a European Standard EN 295, which was ratified in 1991 and meanwhile implemented in all EU-15 and EFTA member states and in some other associated CEN Member States.~~

In this document, the term ‘pipes’ is used to include fittings which together are needed to form a pipeline for sewage transportation, buried in the ground.

~~The following table shows general information about the vitrified clay pipes industry in Europe, in the year 2000 [3, Ceram-Unie 2003], [30, TWG 2005].~~

[Note to the TWG: please provide information to update the table below]

Table 1.3: The vitrified clay pipes industry in Europe

Country	BE	DE	IT	NL	UK	EU-~~15~~27
~~Number of inhabitants (10^6)~~	~~10~~	~~82~~	~~57.5~~	~~15.7~~	~~58.5~~	
Number of plants *)	~~1~~	~~8~~	~~1~~	~~2~~	~~5~~	~~17~~
Annual sales of pipes and fittings (tonnes)	~~115000~~	~~208000~~	~~74000~~	~~102000~~	~~209000~~	~~708000~~

Country	**BE**	**DE**	**IT**	**NL**	**UK**	**EU-~~15~~27**
Total number of employees	~~250~~	~~500~~	~~150~~	~~213~~	~~800~~	~~1913~~
Average staff per plant	~~377~~	~~115~~	~~207~~	~~107~~	~~220~~	~~166~~
*) The plants may operate more than one kiln. *Source:* [9, COM 2007]						

1.4.3 Refractory products

[Note to the TWG: please provide information to update this section]

Refractory products are ceramic materials capable of withstanding temperatures above 1 500 ºC. Numerous refractory products in a wide variety of shapes and forms are used in many industrial applications of the steel, iron, cement, lime, glass, ceramic, aluminium, copper and petrochemicals industries, in incinerators, power plants, and house heating systems including night storage heater blocks. They are vital to high-temperature processes and resist all types of stresses (mechanical, thermal, chemical) such as erosion, creeping deformation, corrosion and thermal shocks.

The resistance of refractory materials to high temperatures is defined so that their softening point is not less than 1 500 ºC. A classification of ‘refractory materials’ with a softening point of between 1 500 ºC and 1 800 ºC and ‘high refractory materials’ with a softening point of more than 1 800 ºC is commonly used [23, TWG 2005].

Initially based on using higher purity clays as raw materials, refractory manufacture is now based on the use of a great diversity of raw materials which can be both natural and synthetic. Many are imported from countries outside Europe.

The demand for refractory products is closely linked to the levels of production and investment ~~occurring~~ in the consuming industries. For instance, the quantity of refractory materials consumed per tonne of manufactured products such as steel or cement has greatly decreased ~~over the past decade~~ because of technical innovation and processes. Longer lifetimes for the linings of steelmaking furnaces or for casting ladles, along with less time for their repair and maintenance, markedly improved the productivity for the industries which use them.

Refractory products are usually applied in industries that are major energy consumers like the metals, ~~the~~ cement, ~~the~~ petrochemical and ~~the~~ glass industries. As the quality of the lining of the furnaces is very important for the energy efficiency of their processes, the refractories industry has a considerable impact on the energy efficiency of these industries. The continuous improvement of refractory products leads – through better insulation and longer lifetimes of the lining – to a decreasing specific energy consumption of the operations of the consuming industries.

~~The manufacture of refractory products in the EU-15 is the most important worldwide with a total production in 2001 of 4.6 million tonnes (the German industry being the leader with an estimated total production of 1.5 million tonnes) corresponding to approximately EUR 3300 million in 2002. About 65 % of this amount relates to iron and steel production; 5 to 8 % to the production of cement, glass, ceramics and the rest to non-ferrous metallurgy, chemical, petrochemical, energy production and incineration. In 2002, the EU-15 industry was employing 18505 people [20, Ceram-Unie 2004], [12, CTCV 2004].~~

~~The following table shows the EU-15 manufacture of refractory products for the year 2001/2002 [20, Ceram-Unie 2004], [21, Almeida, M., Vaz, S., Baio, D. 2004].~~

[Note to the TWG: please provide information to update and complete the table below for recent years]

Table 1.4: EU-15 manufacture of refractory products in 2001/2002

Countries	~~2002~~ Total Production (10^3 tonnes)
Austria ~~(2001)~~	~~710~~
Benelux	~~n.a.~~
France	~~524~~
Germany	~~931~~
Greece ~~(2001)~~	~~33~~
Italy	~~556~~
~~Nordic Countries (2001)~~	~~147~~
Portugal	~~23~~
Spain	~~417~~
~~United Kingdom~~	~~204~~
Source: [9, COM 2007]	

1.4.4 Expanded clay aggregates

[Note to the TWG: please provide information to update this section]

Expanded clay aggregates are porous ceramic products with a uniform pore structure of fine, closed cells and with a densely sintered, firm external skin. They are manufactured from raw materials containing clay minerals. The raw material is prepared, moulded and then subjected to a firing process at temperatures of between 1 100 ºC and 1 300 ºC, resulting in a significant increase in volume due to expansion.

The products can be manufactured in any quantity and with precisely adjustable grain size and characteristics to meet a wide range of technical requirements for numerous areas of application.

They are used as loose or cement-bound material for the construction industry (for instance loose fillings, lightweight concrete~~,~~ blocks and other prefabricated lightweight concrete components, structural lightweight concrete for on-site processing) and also loose material in garden and landscape design (e.g. embankment fillings in road construction, substrates for green roofs, filter and drainage fillings).

The diverse range of industrially produced lightweight aggregates (LWA) covers a wide spectrum of technical characteristics. Properties such as grain size, porosity, weight and grain strength can be controlled during the manufacturing processes. Aggregates with grain densities of between 0.15 kg/dm^3 and 1.7 kg/dm^3 are available to suit a wide range of requirements and applications. These lightweight aggregates have excellent insulating characteristics. This is due to the large number of finely distributed pores inside the material. Thermal conductivity values for loose fills of industrially produced lightweight aggregates range from 0.07 W/(mK) to 0.18 W/(mK), depending on the grain size and density of the respective material. Standardised granulometry is described in EN 13055-1 and EN 13055-2.

In addition to expanded clay aggregates, industrially produced lightweight aggregates also include expanded slate and shale, bottom ash, sintered hard coal flue dust and expanded glass, but this document does not deal with these other product groups.

Manufacturers of expanded clay aggregates are to be found in Denmark, Germany, ~~Sweden,~~ Norway, Finland, Estonia, Belgium, ~~Austria~~, Poland, Spain, Italy, Portugal and the Czech Republic. In central and eastern Europe, expanded clay is usually known ~~under~~ by the name 'keramzit'. The total plant capacity in Europe is estimated to be around 7-8 ~~10~~ million cubic metres.

1.4.5 Wall and floor tiles

Ceramic tiles (see EN 14411) are thin slabs made from clays and/or other inorganic materials, generally used as coverings for floors and walls. Ceramic tiles are usually shaped by extrusion or dust pressing at room temperature, then dried and subsequently fired at temperatures sufficient to develop the required properties.

The most common tile shapes are squares and rectangles, but other polygonal shapes (hexagons, octagons, etc.) are also available. As for size, tile sides range from only a few centimetres (mosaics) to slabs with 60-100 cm sides. Thickness ranges from around 5 mm for wall tiles to over 25 mm for some extruded tiles.

There are several types of ceramic tiles available on the market: shaped through dust pressing or extrusion; with porous, compact or vitrified bodies; with white (whitish) or coloured (reddish) bodies; unglazed or glazed.

The types of ceramic tiles manufactured in the Member States are similar; however, they differ in some characteristics due to cultural, formal, functional, commercial or technical reasons. Therefore it is difficult to establish the equivalence between the different types of products and their designations in the different Member States.

To overcome this difficulty, a general classification of ceramic tiles has been adopted in European and International standardisation. According to EN 14411, ceramic tiles are divided into nine groups, according to their method of manufacture (shaping method) and their water absorption. Water absorption is associated with the porosity of the material: high water absorption means high porosity, while low water absorption is associated with a compact, vitrified structure.

This classification is assumed as a general reference in this document. However, the nine groups specified in EN 14411 do not reflect significant differences as far as the environmental aspects discussed in this document are concerned. Therefore, for the specific purpose of this document, the ~~following~~ simplified classifications~~, as~~ shown in Table 1.5 ~~the following table,~~ will be used [3, Ceram-Unie 2003]. Some ceramic tiles are not considered in this classification, because in total they represent a very minor part as their production process and characteristics are quite different and no significant or useful information is available.

[Note to the TWG: please provide information to update and/or to replace the table below]

Table 1.5: Simplified classification of ceramic tiles

Class	Description/specification
A	Extruded tiles
BIa	Dust pressed tiles with impervious body
BIb-BII	Dust pressed tiles with compact body
BIII	Dust pressed tiles with porous body

Source: [9, COM 2007]

Ceramic wall and floor tiles are important wall and floor covering products used in the building and housing industry and, therefore, the maintenance and renovation market is of special importance to these products. Other applications ~~are, e.g.~~ include the use of tiles for external facades, swimming pools and public areas.

The European industry sells tiles worldwide, being by far the biggest exporter. ~~A quarter~~ In 2019-2021, more than one third of the European production was ~~is~~ exported to countries outside the EU-27~~15: the European industry takes a ¾ share of international trade in tiles. In 2001, the European industry sold close to 1400 million m^2 of tiles for a total value of EUR 10000 million. Around 71000 people were employed by the industry in that year [3, Ceram-Unie 2003].~~ An important part of the industry is concentrated in two regions: the Sassuolo region in Italy (Emilia-Romagna) and Castellón in Spain (Comunidad de Valencia).

Table 1.6: Exports value and volume of wall and floor tiles

Exports EU-27	2017	2018	2019	2020	2021
Million EUR	418	404	401	393	482
m^2	ND	470 483 930	470 082 977	447 787 357	525 165 984

ND: No data.
Source: [64, Cerame-Unie 2023]

For the manufacture of tiles, highly refined clays are ~~being~~ used, which in most cases can be obtained in Europe ~~itself~~. In addition, a variety of substances are ~~being~~ used for glazing purposes. Energy can be considered ~~as~~ a raw material as well, as it transforms the clays into ceramics through firing. Energy sources used are mainly natural gas and electricity.
~~The following table shows the energy consumption per Member State [20, Ceram-Unie 2004], [21, Almeida, M., Vaz, S., Baio, D. 2004]~~

[Note to the TWG: please provide information to update and complete the table below for recent years]

Table 1.7: Energy consumption per Member State (specific energy consumption in TJ per 1000 tonnes produced)

Countries	~~1980~~	~~1990~~	~~1997~~	~~2001~~
DE				~~7.58~~
EL	~~11.61~~	~~8.68~~	~~8.1~~	
ES	~~15.78~~	~~7.00~~	~~5.49~~	~~5.78~~
FR	~~6.97~~	~~5.84~~	~~5.71~~	~~6.42~~
IT	~~11.22~~	~~6.19~~	~~5.12~~	~~5.48~~
NL	~~10.94~~	~~8.46~~	~~8.76~~	
PT			~~6.20~~	~~6.00~~
~~UK~~	~~18.05~~	~~13.15~~	~~11.33~~	

Source: [9, COM 2007]

1.4.6 Table- and ornamentalware (household ceramics)

[Note to the TWG: please provide information to update this section]

The manufacture of household ceramics covers tableware, artificial and fancy goods made of porcelain, earthenware and fine stoneware. Typical products are plates, dishes, cups, bowls, jugs and vases.

The total production is small compared with other major industrial ceramic products (see Table 1.8). Tableware and ornamentalware have a completely different value to weight ratio.

Table- and ornamentalware follow the general processes applicable to all ceramics. ~~conform to the general description of processes which apply to all ceramics. The following table summarises the output of the different wares [21, Almeida, M., Vaz, S., Baio, D. 2004], [20, Ceram-Unie 2004]~~.

[Note to the TWG: please provide information to update and complete the table below for recent years]

Table 1.8: Output of table- and ornamentalware

Countries	Wares	Tonnes per year
Germany	Tableware from porcelain other tableware ornamentalware	~~69000~~ ~~4000~~ ~~estimated 500~~
Luxembourg	Total tableware	~~5370~~
The Netherlands	Tableware (earthenware, china, vitrified hotelware) ornamentalware	~~5500~~ ~~250~~
Portugal	Total tableware and ornamental ware	~~90000~~
~~United Kingdom (2001)~~	~~Total tableware and ornamentalware~~	~~86000~~
Source: [9, COM 2007]		

1.4.7 Sanitaryware

[Note to the TWG: please provide information to update this section]

Ceramic goods used for sanitary purposes are all included under the collective name sanitaryware. Typical sanitary ceramic products are lavatory bowls, bidets, wash basins, cisterns and drinking fountains. These products are mainly made of vitreous china (semi-porcelain) or earthenware.

The total production is small compared with other major industrial ceramic products, e.g. bricks or refractory products (see Table 1.1). Sanitaryware has a completely different value to weight ratio to bricks or refractory products.

The manufacture of sanitaryware follows processes similar to those which apply to all the other ceramic products. The raw materials are mixed with water to produce a clay slip of the required characteristics. The clay slip is then stored in tanks and used for slip casting in separate moulds or in pressure casting machines. The product is produced directly from the pressure casting machines or is released from the moulds used for the slip casting process. Pieces must be dried before they can be worked further, or transported.

~~Glazing is~~ Glazes are applied directly to the clay surface and fired at the appropriate temperature of the product concerned, normally around ~~between approximately~~ 1 200 ~~– 1210~~ °C for vitreous china and ~~at about 1220 °C for~~ fireclay.

Spraying of the glaze provides the colour and 'vibrancy' to the underlying shape. The colour or colour combinations required are achieved by using pigments in association with the glaze. The majority of pigments are metal oxides. The quantities of pigments used are minimal compared with the weight of raw materials (clays) and other constituents.

The finished product enters the warehouse or storage facility for selection, dispatch and distribution.

1.4.8 Technical ceramics

[Note to the TWG: please provide information to update this section]

The European manufacturers of technical ceramics produce a great variety of products, which at least in part are based on clays, but also on synthetic raw materials. Like in the other ceramic sectors, the raw materials are fired in kilns, using mainly natural gas, but also electricity (in 2003: approximately~~.~~ ~~2/3~~ two thirds natural gas and ~~1/3~~ one third electricity), in the process.

Technical ceramics are applied in many industries and cover both established products like insulators and new applications. They supply elements for the aerospace and automotive industries (engine parts, catalyst carriers), electronics (capacitors, piezo-electrics), biomedical products (bone replacement), environment protection (filters) and many others.

Important manufacturers of technical ceramics are to be found in Germany, ~~the United Kingdom, France and~~ the Netherlands and Poland [44, COM 2020].

Due to the high added value of some products of technical ceramics, parts of this industry are not ~~so~~ as highly energy-intensive in relation to the turnover ~~than~~ as other sectors. ~~Relative to the mass, the consumption of energy is comparable. The European industry had an estimated total sales level of EUR 2500 million in 2001. While no precise data are available on total production in volume they were estimated to be at around 0.15 million tonnes in 2003 for the whole European industry~~ [3, Ceram-Unie 2003], [23, TWG 2005].

1.4.9 Inorganic bonded abrasives

[Note to the TWG: please provide information to update this section]

A principal characteristic of grinding – one of the oldest known production processes – is the effect of numerous, not orientated cutting materials in the workpiece. Abrasive products, which apply this principal characteristic, are tools widely used in working every kind of materials: not only grinding, but also cutting off, polishing, dressing, sharpening, etc. for metals, plastics, wood, glass, stones, etc.

Basically, a distinction can be made between bonded abrasives (‘grinding wheels’) and coated abrasives (‘abrasive paper and tissues’). Furthermore, loose abrasives exist, which do not have any solid linkage to a backing (e.g. polishing pastes). This document only deals with ‘inorganic bonded abrasives’, a subgroup of the bonded abrasives.

An inorganic bonded abrasive (or ‘vitrified bonded grinding wheel’ as manufacturers say) is a tool where a synthetic abrasive – contemporary abrasive materials are special fused alumina, synthetic corundum, silicon carbide, cubic boron nitride (CBN) or diamond, prescreened in uniform grit size – is blended with a vitrified bond (the normal ratio by weight is nine parts of abrasive to one part of the body).

Then the product is fired at a temperature at which the body (e.g. glass, clay), ~~that~~ which constitutes the bonding element, vitrifies and, after cooling down, binds together the abrasive grains [14, UBA 2004], [23, TWG 2005], [30, TWG 2005].

1.5 Key environmental issues

[Note to the TWG: This section has been moved from Section 1.4 in the 2007 CER BREF]

Depending on the specific production processes, plants ~~making~~ manufacturing ceramic products cause emissions to be released into air, water and land (waste). Additionally, the environment can be affected by noise and odour~~ unpleasant smells~~. The type and quantity of air pollution, wastes and waste water depend on different aspects such as ~~parameters. These parameters are, e.g.~~ the raw materials used, the auxiliary agents employed, the fuels used and the production methods and can be summarised as follows:

- eEmissions to air: particulate matter/dust can arise from the handling or processing of raw materials or product finishing and also soot can arise from firing fuel oil or different solid fuels. Gaseous emissions arise during the ~~firing or spray drying~~ thermal processes of ceramics production and may be derived from the raw materials and/or from the fuels employed. Carbon oxides, nitrogen oxides, sulphur oxides, inorganic fluorine and chlorine compounds, as well as organic compounds, are of particular importance among the gaseous emissions. Due to the use of substances for decorative purposes which contain heavy metals, or due to the usage of heavy oil as fuel, heavy metals can also be emitted.
- eEmissions to water: these mainly occur during the manufacturing processes of ceramic products, especially during the manufacture of traditional ceramics, and the resulting process waste water mainly contains mineral components (insoluble particulate matter). Depending on the production method, the process waste water also contains further inorganic materials, small quantities of numerous organic materials as well as some heavy metals. Apart from process water, which often is ~~cleaned~~ treated and reused in closed circuits, cooling water, rainwater and sanitary waste water may also contribute to the emissions to water from the plant.
- pProcess losses/waste: process losses originating from the manufacture of ceramic products~~,~~ mainly consist of the following materials:
    - different kinds of sludge (sludge from process waste water treatment, glazing sludge, plaster sludge, grinding sludge);
    - broken ware from shaping, drying, firing and refractory material;
    - dust from flue-gas cleaning and dedusting units;
    - used plaster moulds;
    - used sorption agents (granular limestone, limestone dust);
    - packaging waste (plastic, wood, metal, paper, etc.);
    - solid residues, e.g. ashes arise from firing with solid fuels.

Parts of the accumulated process losses mentioned above~~,~~ can be recycled ~~and~~ or reused within the plant due to product specifications or process requirements. Materials~~,~~ which cannot be recycled internally~~,~~ leave the plant as waste and are supplied to external recycling or disposal facilities.

~~•~~ eEnergy consumption/CO_2 emissions: all sectors of the ceramic industry are energy-intensive, as a key part of the process involves drying followed by firing to temperatures of between 800 ºC and 2 000 ºC. ~~For the manufacture of porcelain, energy accounts for between less than 10 to 18 % of the total costs. For the manufacture of bricks, the share of the energy costs varies between 17 and 25 % with maximum levels of up to 30 %.~~

~~The following~~ Table 1.9 shows the specific energy consumption in the ceramics industry in Europe
[30, TWG 2005].

[Note to the TWG: please provide information to update the table below]

Table 1.9: Specific energy consumption in the ceramics industry in Europe

Sector	Unit	~~1980~~	~~1985~~	~~1990~~	~~1995~~	~~2000~~	~~2003~~
Bricks and roof tiles	GJ/t	~~2.65~~	~~2.45~~	~~2.19~~	~~2.06~~	~~2.38~~	~~2.31~~
Wall and floor tiles	GJ/t	~~11.78~~	~~9.16~~	~~6.76~~	~~5.45~~	~~5.74~~	~~5.60~~
Refractory products	GJ/t	~~4.88~~	~~4.96~~	~~6.51~~	~~4.91~~	~~5.41~~	~~5.57~~
Sanitaryware	GJ/t	~~26.56~~	~~24.214~~	~~22.27~~	~~22.76~~	~~20.88~~	~~21.87~~
Vitrified clay pipes	GJ/t			~~5.75~~	~~5.77~~	~~6.1~~	~~5.23~~
Table- and ornamentalware	GJ/t			~~47.56~~	~~38.91~~	~~43.46~~	~~45.18~~
Technical ceramics	GJ/t					~~34.72~~	~~50.39~~
Source: [9, COM 2007]							

~~Today n~~Natural gas~~, liquefied petroleum gas (propane and butane) and fuel oil EL are~~ is the ~~mainly~~ main fuel used for firing, while liquefied petroleum gas (LPG, e.g. propane, butane), extra light fuel oil, heavy fuel oil, liquefied natural gas (LNG), biogas/biomass, electricity and solid fuels (e.g. coal, petroleum coke) can also play a role as energy sources for burners. The use of heavy fuel oil, coal and petroleum coke is limited mainly to brickworks.

~~In the following table the share of the different fuels in the total fuel consumption (without electricity) in Germany is listed according to the different sectors [4, UBA 2001] [30, TWG 2005].~~

~~Table1.10: Share of used fuels in Germany per sector in 1998~~

~~Sector~~	~~Natural gas (%)~~	~~Fuel oil EL (%)~~	~~Heavy fuel oil (%)~~	~~Other (%)~~
~~Household ceramics~~	~~98.0~~	~~1.6~~	–	~~0.4~~
~~Sanitaryware~~	~~97.7~~	~~2.3~~	–	–
~~Technical ceramics~~	~~96.2~~	~~3.6~~	–	~~0.2~~
~~Refractory products~~	~~90.2~~	~~7.3~~	~~0.1~~	~~2.4~~
~~Wall and floor tiles~~	~~98.1~~	~~1.1~~	~~0.8~~	–
~~Bricks and roof tiles~~	~~88.6~~	~~5.3~~	~~5.3~~	~~0.8~~
~~Vitrified clay pipes~~	~~100~~	–	–	–
~~Expanded clay aggregates~~ 1)	–	–	–	–
~~Inorganic bonded abrasives~~ 2)	~~90.6~~	~~9.4~~	–	–
1) ~~no data available~~ 2) ~~VDI estimated values for Germany~~				

Based on the information above, at the kick-off meeting for the review of the CER BREF, the Technical Working Group (TWG) identified the following key environmental issues (KEIs) to be investigated during the review:

- emissions to air: dust, SOX, NOX, CO, CO_2, gaseous chlorides such as HCl, gaseous fluorides such as HCl, TVOC, acetaldehyde, benzene, formaldehyde, phenols, styrene, polycyclic aromatic hydrocarbons (PAHs), dioxins and furans (PCDD/F), ammonia, boron and its compounds, lead and its compounds and other metals and metalloids (As, Cd, Cr, Co, Cu, Hg, Ni, Sb, Se, Sn, Tl, Te, V, Zn);
- emissions to water: AOX, boron and its compounds, metals (As, Ba, Cd, Co, Cr, Cu, Ni, Pb, Zn), total hydrocarbons/hydrocarbon oil index, TOC, COD, TSS, naphthalene, fluoride;
- odour;
- noise;
- energy consumption for firing kilns, spray dryers and ware dryers;
- water consumption and waste water discharge;
- raw material consumption (e.g. pore-forming agents and chemicals);
- residues/waste generated and sent for disposal (e.g. sludge, broken ware and off-gas cleaning waste) [67, COM 2021].

1.6 Decarbonisation in the ceramic industry

The European Green Deal aims to achieve no net emissions of greenhouse gases by 2050. The decarbonisation of energy-intensive industries such as the manufacturing of ceramics is essential to achieve this goal.

The European Climate Law (July 2021) regulates the objective set out in the European Green Deal for Europe's economy and society to become climate-neutral by 2050. The law also sets the intermediate target of reducing net greenhouse gas emissions by at least 55 % by 2030, compared to 1990 levels. The European ceramic industry represented by Cerame-Unie stated its commitment to the European Union's climate ambitions for 2030 and 2050 in the Ceramic Roadmap to 2050 [42, Cerame-Unie 2021]. As the principal component of greenhouse gas emissions is CO_2, decarbonisation is a major pillar in the ceramic industry's commitment to the European climate ambitions.

According to various options and application fields, a combination of several techniques is the most probable path to decarbonisation.

The Ceramic Roadmap to 2050 includes the following main measures with the highest potential for achieving progress:

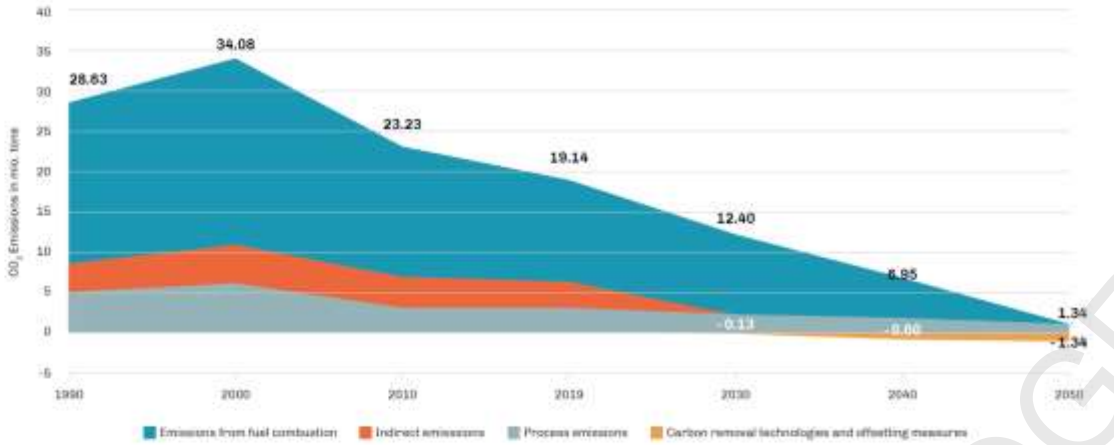
- a switch to renewable energy (e.g. green hydrogen, biofuels and decarbonised electricity);
- a reduction in CO_2 process emissions;
- innovation and increased efficiency in the manufacturing process;
- CO_2 capture CCS/CCU;
- other carbon removal technologies and offsetting measures.

In the forecast of the Cerame-Unie Roadmap, the emissions reduction model used combines a range of measures to achieve a gradual reduction of emissions to reach carbon neutrality by 2050. The pathway is given in Figure 1-5 [42, Cerame-Unie 2021].

Emission sources from the ceramic industry can be classified into three main categories depending on the step of the manufacturing process where they are produced:

- emissions from fuel combustion, typically produced during drying and heating;
- process emissions generated from the transformation of the materials;
- indirect emissions, mainly coming from electricity production.

According to Cerame-Unie, for the ceramics sector 64 % of emissions come from fuel combustion, whereas only 17 % and 19 % correspond to process and indirect emissions respectively.



Source: [42, Cerame-Unie 2021]

Figure 1-5:CO_2 reduction pathway in the Cerame-Unie 2050 Roadmap

1.6.1 Decarbonisation to reduce emissions from fuel combustion

In the 1980s the ceramic industry achieved a significant reduction in carbon emissions when European ceramics almost entirely switched from solid fuel (mainly coal) to natural gas, the most carbon-efficient fossil fuel. In 2020, 64 % of CO_2 emissions in the ceramic industry corresponded to emissions from fuel combustion for firing and drying products [42, Cerame-Unie 2021]. On average, the firing represents 60 % and drying 40 % of the natural gas consumption of a ceramic production unit. [45, Cerame-Unie 2021]

The two main approaches for decarbonisation of thermal processes are:

- preventing the generation of CO_2 emissions from fuel (fuel switch, energy efficiency, alternative heat source, electrification, etc.);
- preventing the release of the CO_2 generated (CCU/CCS).

According to the Cerame-Unie Roadmap, the main technologies deployable in the ceramic industry to contribute to climate-neutrality targets can be summarised in Table 1.10.

Table 1.10: Techniques to contribute to climate neutrality

Technique	**Technological advancement status (1 = low advancement; 5 = fully available)**	**Applied process step**
Microwave-assisted drying	2	Drying
Heat pumps	4	Drying
Biomass	5	Additives, Firing, Drying
Biogas	4	Firing, Drying
Syngas	2	Firing, Drying
Green hydrogen	2	Firing, Drying
Electrification	2	All processes
CCS/CCU	1	Firing, Drying
Source: [42, Cerame-Unie 2021]		

An increase in energy efficiency, also needs to be considered [42, Cerame-Unie 2021]. Keeping in mind that, from the thermodynamic point of view, approximately 8 % of the total energy delivered to the product is used for endothermic physico-chemical reactions in the ceramic process, a considerable potential for energy efficiency could be assumed [43, TWG 2022].

The decarbonisation options for the Dutch ceramic industry include potential CO_2 reduction rates using different techniques. A compiled list is given in Table 1.11 [46, MIDDEN 2020].

Table 1.11: Potential CO_2 reduction in the Dutch ceramic roadmap

Technique	Category	Process(es)	Maximum CO_2 abatement	Availability
Green gas	Fuel substitution	Firing, Drying	74 %	Commercially available
Hydrogen	Fuel substitution	Firing, Drying	74 %	Lab scale
Electric heating	Fuel substitution	Firing, Drying	74 %	Concept
Microwave radiation	Fuel substitution	Firing, Drying	74 %	Concept
Heat exchange	Fuel substitution/use of residual energy	Drying	26 %	Pilot scale
Heat pumps	Fuel substitution/use of residual energy	Drying	26 %	Commercially available (for the relevant temperature)
Hybrid drying	Fuel substitution/use of residual energy	Drying	Varies	Pilot scale
Ultra-deep geothermal energy	Fuel substitution/ process design	Drying	26 %	Commercially available, but depends on the region
Extended tunnel kiln	Process design	Firing	26 %	Commercially available
CCS or utilisation	CCS or re-use	Firing, Drying	90 %	Commercially available
Dematerialisation of products	Process design	Firing, Drying	Varies	Concept
Source: [46, MIDDEN 2020]				

Biomass is widely employed for drying and firing operations in the ceramic sector in some countries (e.g. Spain) [48, TWG ES 2021].

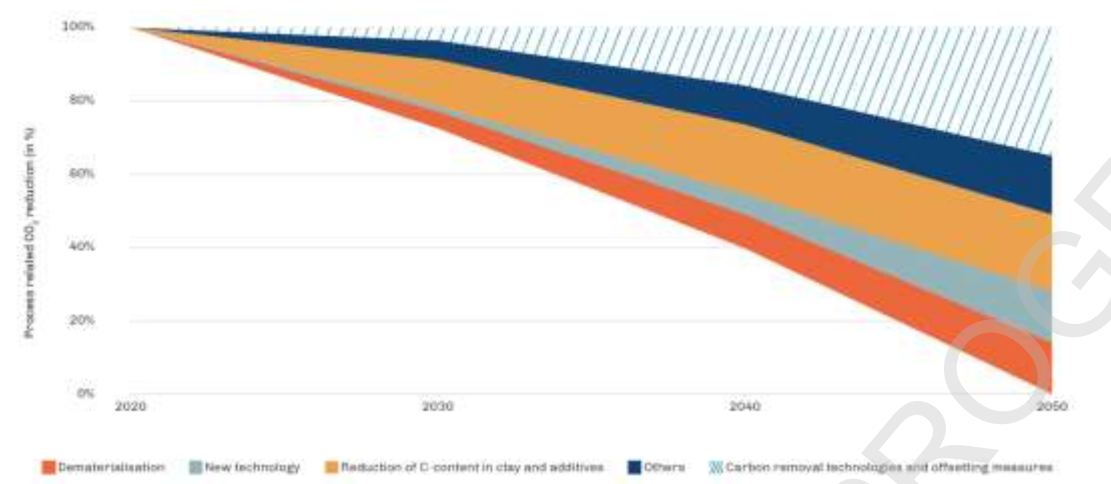
1.6.2 Decarbonisation to reduce process emissions

In 2020, 17 % of CO_2 emissions in the ceramic industry corresponded to process emissions. These are caused by the chemical decarbonisation of carbonates contained in raw materials during firing. The CO_2 emissions from processes depend on the specific sector and the raw material. In general, the following measures could be combined to reduce process emissions [42, Cerame-Unie 2021]:

- reduction of carbon-containing additives;
- minimisation/optimisation of the carbon content of clay mixtures, while ensuring that this does not lead to higher transport-related emissions;
- dematerialisation (smaller quantities of raw materials for the same use);
- carbon removal technologies and offsetting measures.

The extent to which these approaches could be applied is detailed in Chapter 2. The general pathway for the process-related emissions is given in Figure 1-6 [42, Cerame-Unie 2021].

[Note to the TWG: please provide information especially on ‘new technologies’ (see graph below)]



Source: [42, Cerame-Unie 2021]

Figure 1-6: Measures for the reduction of process-related CO_2 emissions

1.6.3 Decarbonisation reduce indirect emissions

In 2020, 19 % of CO_2 emissions in the ceramic industry corresponded to indirect emissions, mainly from electricity generation. Considering that the origin of the electricity consumed on site is not usually under the control of the ceramic manufacturer, actions may be limited. However, these emissions may not be considered as irrelevant. Moreover, a tailored case-by-case approach may be applied to assess contributions in this field (e.g. shipping vs trucking).

1.7 Circular economy in the ceramic industry

The European Green Deal launched a strategy for a climate-neutral, resource-efficient and competitive economy. Circular economy plays a decisive role towards climate neutrality and resource efficiency. The transition from a linear 'produce, use, waste' model to a circular model where resources and materials are reused, recycled or recovered is a high-priority topic on the EU policy agenda. This transition also calls for new business models and encourages the development of innovative solutions in the industry.

Ceramic products have a high durability, requiring little or no maintenance, and in general can have a long life span (e.g. construction ceramics up to 150 years, sanitary ware and wall and floor tiles up to 50 years). Given the inert nature of fired clay, ceramic products can be reused, recycled or recovered after the end-of-life stage. However, as ceramic products are frequently used in combination with other non-ceramic products (e.g. mortar, glue), this depends on the extractability of the ceramic product in the end-of-life residue. In this context, solutions with the aim of minimising the raw material consumption and waste generation during the production process, and increasing the reuse or recycling of products are needed. In other words, resource efficiency is not only about 'using less', but also 'using better'. Dedicated examples of circular economy achievements in each sector are given in Chapter 2 [41, Cerame-Unie 2020].

Due to the chemical transformation of the raw material in the ceramic process, 100 % closed loop recycling is hard to achieve but rather provides a valuable input for an open loop industry. In this open loop, the ceramic industry uses secondary raw materials from other sectors. The cement, paper, steel, alumina, glass, coal mining and metallurgical industries are the major suppliers of secondary raw materials (paper fibres, glass, schiste granite powder, and loam) to some sectors of the ceramic industry. Also, internal secondary raw materials are used as mineral sludge from cutting and grinding the ceramic products. The possibility to use secondary raw materials and substitute resources varies depending on the sector and the product to be made [47, Cerame-Unie 2021]. Sludge from solvent extraction from grape pip flour and olive oil industries is also used in some ceramic manufacturing installations [48, TWG ES 2021]

The main secondary raw materials generated within the ceramic industry are the following [47, Cerame-Unie 2021]:

- broken ware from ceramics are used in ceramic and cement production;
- sludge from waste water treatment is used in the ceramic or cement industry;
- waste water not purified is reused in the ceramic process;
- gypsum moulds from tableware or sanitary ware are used in the cement industry;
- fired scrap is used in construction works, and in ceramic processes or environmental restoration, road substrates;
- materials used to polish the ceramic tiles;
- materials from gas cleaning are used in the cement industry;
- residues generated during shaping, drying and firing are reused internally or externally as by-products, e.g. broken bricks for tennis courts.

The following aspects need to be considered when introducing a secondary raw material in a ceramic process [47, Cerame-Unie 2021]:

- stable quality;
- stable availability;
- transport distance;
- price, as in some cases the energy cost to obtain the secondary raw material could be higher than the cost of the virgin raw material.

2 APPLIED PROCESSES AND TECHNIQUES IN CERAMIC MANUFACTURING

2.1 Raw materials, additives and chemicals

A wide range of materials is employed by the ceramic industry to match the diversity of its product range. Both natural and synthetic materials are used, many produced within Europe but a few ~~are~~ imported. Sectoral needs ~~are different~~ vary and details of raw materials are listed in the chapters regarding the different sectors.

Formulas (or bodies) of clay-based ceramics may consist of one single clay or more clays, mixed with mineral modifiers, so-called ‘non-plastics’, such as powdered quartz and feldspar.

Common clay minerals (‘plastic clays’) are hydrated aluminium silicates that have resulted from the weathering of rocks and there are two structural units involved in most clay mineral lattices. One is the ‘silica sheet’ formed of tetrahedra consisting of a Si^{4+}-ion surrounded by four oxygen ions. The other structural unit is the ‘aluminium hydroxide or gibbsite sheet’, consisting of octahedra in which an Al^{3+} ion is surrounded by six hydroxyl groups. These octahedral sheets condense with the silica sheets to form the clay minerals.

There are a number of mineral species called clay minerals, but the most important are ‘kaolinite’ ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$), ‘montmorillonite’ ($Al_2O_3 \cdot 4SiO_2 \cdot H_2O$) and ‘halloysite’ ($Al_2O_3 \cdot 2SiO_2 \cdot 3H_2O$) [8, Ullmann's 2001], [11, Shreve, R. N. 1945].

Advanced ceramic products, which contain only a small fraction of clay or none at all, are based on the following materials: oxides, carbides, nitrides and borides of Al, Mg, Mn, Ni, Si, Ti, W, Zr and other metal ions. Typical examples are Al_2O_3 (alumina), MgO (periclase or dead-burned magnesia), SiC (silicon carbide), TiN (titanium nitride) and WB_2 (tungsten boride) [8, Ullmann's 2001].
Clays or argilliferous materials (sedimentary clays, schistous clay, loamy clay, marl) are mostly used for the manufacture of bricks, roof tiles and clay pipes. Organic additives (e.g. sawdust, paper binding substances, formed polystyrene) or inorganic auxiliary agents such as ~~kieselguhr~~ diatomaceous earth or perlite can be added in order to obtain a greater pore volume. In the facing brick and roof tile industry, metallic oxides such as MnO_2, TiO_2~~,~~ and Fe_2O_3, chromites, and minerals such as $CaCO_3$~~,~~ and $CaMgCO_3$ can be added to obtain the desired colour and/or to enhance the porosity of the finished product. $BaCO_3$ can be added to reduce efflorescence. Such additives are added just before the shaping process, or in the raw material preparation, either in solid or liquid form.

Refractory products consist of clay, chamotte (calcined and crushed raw plastic clay) and certain natural rocks such as quartzite, dolomite, bauxite and magnesite, but also of the above-mentioned synthetic materials, ~~as~~ for example sintered corundum, silicon carbide or spinels. In order to produce compressible masses, binders and aggregates are added to the milled raw materials.

The expanded clay industry uses clays with a specific expandability. Additives (e.g. flux, expansion aids, and release agents) are used for promoting expansion [26, UBA 2005].

Products manufactured by the wall and floor tiles, household ceramics and sanitaryware industry predominantly consist of aluminium silicates and the clay minerals serve as plastic raw materials. However, technical ceramics and inorganic bonded abrasives often contain only a small amount of clay or in the case of technical ceramics none at all and are, therefore, based on the metal borides, carbides, oxides and nitrides as mentioned above.

Quartz, feldspar, ~~in some cases chalk~~, dolomite, wollastonite and steatite are used as fillers and fluxing materials. Various ceramic products are glazed or engobed on the visible or whole surface with glaze frits, ~~or~~ engobing slips, digital inks or complex inorganic pigments.

In addition to the above-mentioned raw materials and auxiliary agents, additional auxiliary agents, firing auxiliaries, fuels and sorption agents are necessary for the manufacture of ceramics. Organic slip additives and binding agents are employed as auxiliary agents in the shaping process. The firing auxiliaries consist of reusable fire-proofed capsules, plates and stanchions. Sorption agents such as calcium carbonate, calcium hydroxide and fine chalk are employed in flue-gas treatment.

A wide range of chemical substances and mixtures are used for different purposes in the ceramic manufacturing industry. Table 2.1 shows several examples of chemicals that may be used in different process steps and sectors of ceramic manufacturing.

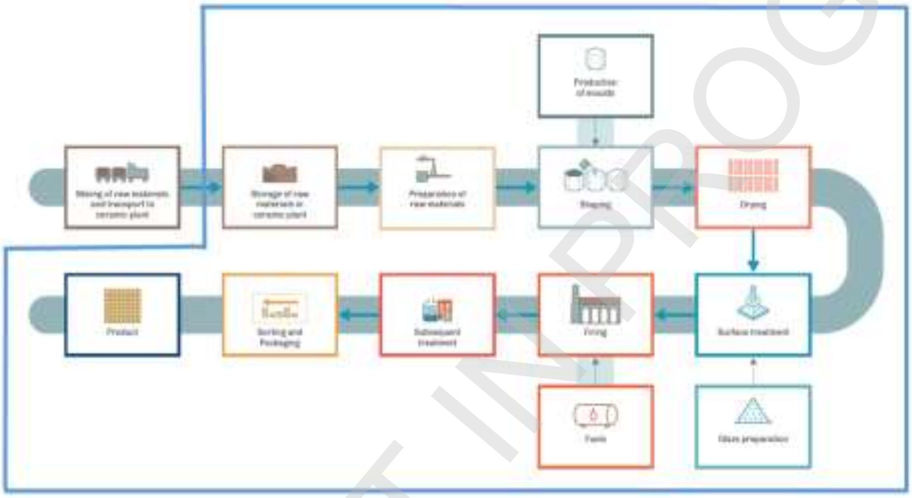
[Note to the TWG: please provide information to complete the table below with other substances used in e.g. glazes, engobes, binders, slip additives]

Table 2.1: Examples of chemicals used in ceramic manufacturing

Chemical substance	**Examples of use in ceramic manufacturing**
Acetaldehyde	Surface treatment in wall and floor tiles
Aluminosilicate refractory ceramic fibres	Insulating material in the production of sanitaryware
Barium carbonate	Use in the production of bricks and roof tiles to avoid the appearance of efflorescence stains in the fired products. Also, use as a component of glazes
Cobalt aluminate blue spirel	Glazes and inks in surface treatment and decoration
Cobalt oxide	Engobes and glazes in surface treatment and decoration
Cobalt sulphate	Glazes in surface treatment and decoration, colouring of ceramic bodies in mixing and shaping
Diiron trioxide	Engobes in surface treatment and decoration
Disodium tetraborate	Glazes in surface treatment and decoration
Ethylene glycol	Preparation of glazes in wall and floor tiles
Lead monoxide	Glazes in surface treatment and decoration
Manganese	Glazes in surface treatment and decoration, colouring of ceramic bodies in mixing and shaping
Manganese dioxide	Glazes in surface treatment and decoration, colouring of ceramic bodies in mixing and shaping
Orange lead	Glazes in surface treatment and decoration
Sodium silicate	Preparation of clay suspension in wall and floor tiles
Titanium dioxide	Glazes in surface treatment and decoration
Trimanganese tetraoxide	Glazes in surface treatment and decoration, colouring of ceramic bodies in mixing and shaping
Tricobalt tetraoxide	Engobes and glazes in surface treatment and decoration
Zinc oxide	Glazes in surface treatment and decoration, colouring of ceramic bodies in mixing and shaping
Source: [35, TWG 2023]	

2.2 General production process description

The manufacture of ceramic products takes place in different types of kilns, with a wide range of raw materials and in numerous shapes, sizes and colours. The general process of manufacturing ceramic products, however, is rather uniform, besides the fact that, for the manufacture of wall and floor tiles, table- and ornamentalware (household ceramics), sanitaryware and also technical ceramics, ~~often~~ a multiple-stage firing process is ~~used~~ may be used. A simplified flow sheet of the major process steps in ceramic manufacturing is given in Figure 2-1 [42, Cerame-Unie 2021].



Source: [42, Cerame-Unie 2021]

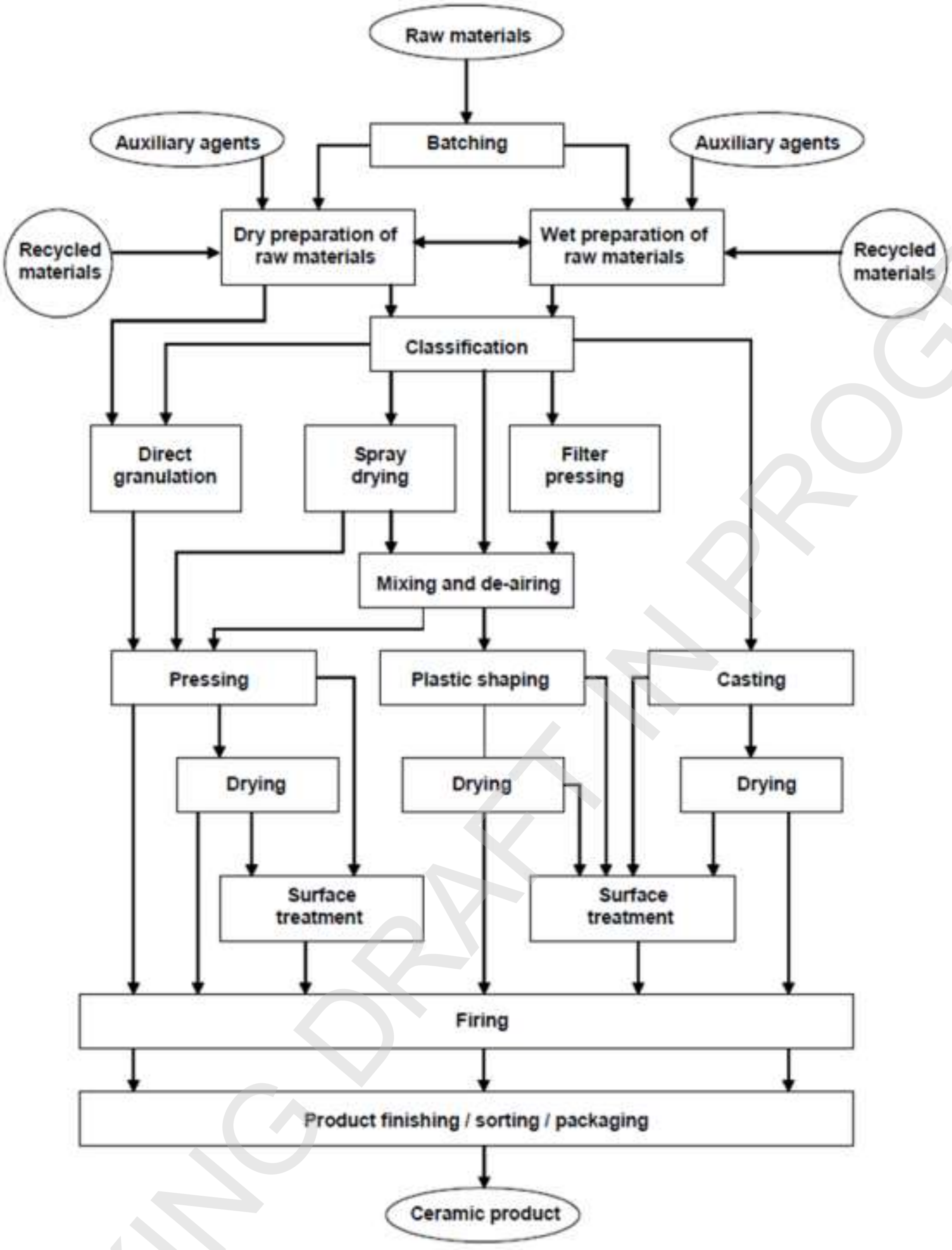
Figure 2-1: Simplified flow sheet of the main process steps in ceramic manufacture industry

In general, raw materials are mixed and cast, pressed or extruded into shape. Water is regularly used for a thorough mixing and shaping. This water is evaporated in dryers and the products are either placed by hand in the kiln (especially in the case of periodically operated kilns) or placed onto carriages that are transferred through continuously operated kilns. In most cases, the kilns are heated with natural gas, but liquefied petroleum gas, fuel oil, coal, petroleum coke, biogas/biomass or electricity are also used.

An irreversible ceramic structure for the product is reached during the firing process in the kiln. This demands a very accurate and product-specific temperature gradient during firing to ensure that the products obtain the right treatment. Afterwards controlled cooling is necessary, so that the products release their heat gradually and preserve their ceramic structure. Then products are packed and stored for delivery.

[The following picture has been moved from Chapter 2.2.13 of the 2007 BREF]

Figure 2-2 summarises the description of the different processes and illustrates different possible paths in the manufacturing of ceramic products [9, COM 2007].



Source: [9, COM 2007]

Figure 2-2: General process flow diagram showing different processing paths

In ~~the following~~ Sections 2.2.1 to 2.2.11, the most important units of a ceramic manufacturing plant, as well as the basic steps and variations in the production processes, will be explained ~~[1, BMLFUW 2003], [2, VITO 2003], [3, Ceram-Unie 2003], [4, UBA 2001], [5, InfoMil 2003], [6, Timillini 2004], [7, Dodd, A. 1994], [8, Ullmann's 2001], [10, Navarro, J. E. 1998], [13, SYKE 2004], [14, UBA 2004], [17, Burkart, M. 2004], [23, TWG 2005], [26, UBA 2005], [28, Schorcht, F. 2005], [29, IMA-Europe 2005], [30, TWG 2005], [32, TWG 2006],~~ [9, COM 2007].

~~Regarding the standard conditions for measurements of volume flows and concentrations, see the following definitions, which are also stated in the Glossary:~~

~~m^3/h~~	~~volume flow: if not otherwise mentioned in this document, the volume flows refer to 18 vol-% oxygen and standard state.~~
~~mg/m^3~~	~~concentration: if not otherwise mentioned in this document, the concentrations of gaseous substances or mixtures of substances refer to dry flue-gas at 18 vol-% oxygen and standard state, and benzene concentrations refer to 15 vol-% oxygen and standard state.~~
~~standard state~~	~~refers to a temperature of 273 K and a pressure of 1013 hPa.~~

2.2.1 Storage and transportation of raw materials

The mining of clay, kaolin, clayey materials, feldspar, quartz and most of the other raw materials used~~,~~ usually takes place in mines or quarries and in some cases the clay is also obtained from ,riversides near the production plant (for instance in the Netherlands). Transportation to the production plant is mainly undertaken by truck but also by railway, ship, or, if the mine or quarry is located very ~~near~~close to the production plant, conveyor belts can also be used.

Depending on their characteristics and the stage of processing, the raw materials are stored in open stockpiles, warehouses which are subdivided into boxes, large-volume feeders, tempering silos, ageing silos, souring silos or dry silos. The silos are equipped with level indicators, overload valves and filters or gas displacement units, where displaced dusty air is blown off. Some materials are also delivered in liquid or slurry form and therefore are stored in tanks or other vessels.

The equipment for transportation within the plant is chosen according to the characteristics of the material conveyed, such as granularity, resistance to attrition and flowability, temperature, flow rate and the given space. The materials are moved with mine hoists such as bucket elevators, chain conveyors, screw conveyors, pneumatic conveyors and slides. The casting slip is partly pumped though pipelines.

2.2.1.1 Decarbonisation and circular economy in storage and transport of raw material

[Note to the TWG: please provide information on decarbonisation and circular economy in storage and transport of raw materials]

CO_2-efficient transportation is used (i.e. bulk material is preferably carried by train or shipment if possible) and is considered in eco-labelling of products. On-site transportation and transfer is electrified.

2.2.2 Preparation of raw materials

First, size reduction and preliminary homogenisation of raw materials ~~is~~are usually achieved in the quarrying operation, but, in order to meet the stringent technical requirements of modern ceramic products, further preparation is necessary. One or more of the following processes described in Sections 2.2.2.1 to 2.2.2.10 may be employed, although not necessarily in the same order.

2.2.2.1 ~~Pre-~~Raw material drying before mixing and shaping

Sometimes certain raw materials need to be pre-dried, for instance sand may be dried using fluidised bed technology ~~and also~~ or rotary dryers ~~may be used~~. Many refined ceramic raw materials are purchased from specialist suppliers – usually in a dry state.

2.2.2.2 Pre-blending

Blending of clays can begin in the quarry, e.g. by selective digging or by stacking the material in superimposed horizontal layers, and then scraping this stockpile vertically to supply feed to the factory.

2.2.2.3 Weathering/souring

Large quantities of clay and mineral raw materials need to be stored at works producing clay bricks and roof tiles, and initial storage is often in the open air. In certain cases – especially in soft-mud processes – storage for a number of months improves the workability of the clay. The process is known as 'souring' and the weathering action is most effective over the winter period.

2.2.2.4 Primary and secondary crushing, grinding and screening

Coarse primary crushing of relatively dry/brittle clays may be effected by large-toothed kibbler rollers, usually located in the quarry, or by large jaw crushers. Very hard raw materials (often used to manufacture refractory products) are also reduced in size using jaw or cone crushers, both of which compress the lumps of mineral between a stationary and a moving hard surface.

Hammer mills achieve size reduction by impact forces – pieces of raw material fed into the mill are shattered when struck by the rapidly rotating hammers.

Edge runner mills (e.g. dry or wet pan grinders) are suitable for reducing the particle size of ~~more~~ plastic raw materials. Pans with perforated base plates ensure a defined maximum particle size, and wet pans have the added function of allowing the tempering of clays with added water.

Crushing rollers are widely employed in the heavy clay industry to disintegrate, flatten and homogenise clay particles. Pairs of parallel, smooth hard-steel rollers are driven in opposing directions so that the raw material, fed between the rollers, undergoes nipping, shearing and flattening. Size control is achieved by setting the gap between the rolls.

Clay shredders (and also roller mills) are useful in the case of plastic raw materials, and consist of a rotating slotted drum fitted with cutter knives. The clay lumps are forced through the slots in the form of shavings.

Impact rotor crushers have two rotors carrying bolted-on impactors or 'shoes'. They rotate towards each other and achieve continuous turning, mixing and disintegration of the feed material.

2.2.2.5 Dry or wet milling (grinding)

The ~~comminution~~ crushing process described above typically achieves particle sizes of 2 mm or more. Further size reduction is necessary for many ceramic applications, such as wall and floor tiles, refractory products and tableware. Dry or wet roller mills are used to obtain particles of around 1 mm diameter. They consist of rotating vertically orientated rolls operating within an outer ring, and pressure is developed between the roller and ring, e.g. by centrifugal force. Raw material from the primary crushing stage is introduced to the mill with or without water, and ground until the required size grading is achieved. Even finer grinding can be obtained using continuous or batch ball mills (in which hard ceramic spheres are tumbled within horizontally mounted drums).

Ball mills are the normal choice for the ceramic floor and wall tile industry, and when used wet they can produce powders graded below ~~two hundred~~ 200 microns.

2.2.2.6 Dry screening/air classification

In order to optimise certain properties of ceramics (e.g. density), it is sometimes necessary to blend defined size-gradings of material. Dry screening usually involves vibrating screens, heated electrically to prevent the build-up of material and clogging.

Air classifiers based on separating cyclones may also be used for dry powder sizing. In either case, oversize material is usually fed back to the grinder.

2.2.2.7 Spray drying

This process is widely employed in the wall and floor tile industry and also carried out for the manufacture of tableware, technical ceramics and refractory products. The aqueous suspension of raw material resulting from wet ball milling (solids content ~ 60-70 %) is sprayed under pressure to produce fine droplets, which come into contact with a stream of hot air. Drying of the droplets produces highly uniform, more or less spherical hollow granules (with a moisture content of typically 5.5-7 %). This form of powder that flows easily ~~has high flowability~~, facilitating accurate filling of the press dies and the subsequent pressing of ~~quite~~ large single tiles. Today, certain companies are specialised in the preparation of spray-dried powder. They deliver the prefabricated material directly to the plants of the ceramic industry where further processing then takes place.

2.2.2.8 Calcining

Some ceramic raw materials are pre-fired, usually in rotary kilns, tunnel kilns or shaft kilns, to improve their properties. For example, certain oxides (e.g. dolomite, magnesite) need to be 'dead-burned' at high temperatures, sometimes in excess of 1 800 ºC, in order to make them suitable for refractory manufacture. Calcining of clays (e.g. kaolin) reduces the plastic shrinkage of bodies to which they are added, aiding size control of products and speeding firing cycles. Today, certain companies are specialised in the preparation of calcined raw materials. They deliver the prefabricated material directly to the plants of the ceramic industry where further processing then takes place.

This document does not deal with these upstream raw material calcining processes, but useful information regarding the calcination of dolomite and the production of magnesium oxide ~~'dead burned oxides' and 'calcined chamotte, pigments and fillers'~~ can be found in the Production of Cement, Lime and Magnesium Oxide (CLM) ~~Cement and Lime~~ BREF [62, COM 2013]. ~~– where the calcination of dolomite is described; in the BREF for Management of Tailings and Waste-Rock in Mining Activities – where the processing of kaolin is described~~; ~~in the draft BREF on Large Volume Inorganic Chemicals (Solids and Others) – where the production of magnesium oxide is described and in the draft BREF on Speciality Inorganic Chemicals, where the production of speciality inorganic pigments is described.~~

2.2.2.9 Synthetic base materials

It should be noted that some synthetic materials such as silicon carbide may be manufactured by specialist suppliers, but may still need to go through the comminution process.

2.2.2.10 Frits and glazes, glaze preparation

In ceramic wall and floor tile glazing, raw materials of a glassy nature (frits) are used. Frits are vitreous compounds, insoluble in water, prepared from crystalline materials, made by melting at high temperatures (1 500 ºC) followed by fast cooling. Frits are supplied to the ceramic tile industry by frit manufacturers (for more information see also the BREF on Glass Manufacturing). Apart from frits, the major glaze components are silica (glass former), as well as additives that act as fluxes (alkalis, alkaline earths, boron, lead, etc.), opacifiers (zirconium, titanium, etc.), and as colouring agents (iron, chromium, cobalt, manganese, etc.)

In the glaze preparation process, the frits and additives are usually ground in discontinuous drum ball mills until a preset reject is obtained. The glaze passes through vibrating sieves. The conditions of the aqueous suspension are then adjusted. Suspension characteristics will depend on the application method to be used.

A wide variety of glazes are formulated depending on the type of product, firing temperature, and the desired effects and properties of the finished product. The liquid glaze can be prepared in the wall and floor tile manufacturing installation or acquired from an external supplier, ready to be used.

2.2.2.11 Decarbonisation and circular economy in preparation of raw materials

[Note to the TWG: please provide information on decarbonisation and circular economy in preparation of raw materials, e.g. dry granulation in spray drying, electrification of mechanical process]

2.2.3 Component mixing

2.2.3.1 General

Mixing time, intensity and sequence have a significant impact on the properties of the mix and consequently on the ~~ultimate~~final product. The prepared raw materials, in controlled proportions, must be mixed and homogenised to achieve the required physico-chemical uniformity. Depending on the ceramic sector concerned, mixing may range from large-scale continuous operations to carefully controlled small-scale batch mixing. Proportioning may be on a volume basis (e.g. via box feeders placed on conveyor belts), or by mass (e.g. via screw feeders linked to weigh-belts).

Most ceramic forming operations require raw materials with a defined water or bonder content, and minor additives such as pigments, anti-scum agents and binders must be accurately dosed and then uniformly distributed in the mix. In refractory manufacture, the properties of some products are optimised by the careful blending of several raw material fractions with different grain sizes ~~several grain size fractions of raw material~~. Proportioning of the mix components is ~~now~~ often automated, with computer control of the feeder mechanisms allowing rapid alteration of the ‘composition’ for the blend. ~~In some cases, mainly in the manufacture of bricks, the clay is also mixed with solid fuel additives (such as fine coke) to reduce firing times.~~

2.2.3.2 Continuous mixers

Double shaft mixers: these are very widely used in the heavy clay industry and consist of a trough bearing two parallel shafts, which rotate towards each other. The shafts are fitted with paddles and knives, providing a vigorous mixing action. The pitch of the paddles moves the mass forward to the discharge end.

Single shaft mixers: these ~~give~~ provide gentler mixing than the double shaft version, but are useful for tempering clay mixes with water prior to extrusion. The mixer usually terminates in a screw auger (pug sealer) which compresses the prepared clay mix.

Pan mills (muller mixers): the grinding function of these pans was described in Section 2.2.2.4. In the dry pan version, the pan rotates and the mullers (heavy steel idler-wheels) have a stationary axis, whereas, in the case of the wet pan, the pan is stationary and the mullers are driven in a rotary path around the vertical axis. Considerable mixing of clay mix, water and some additives is possible.

Clay shredders and impact rotor crushers: these were also mentioned in Section 2.2.2.4, and again they serve a dual function, giving very good mixing as well as comminution.

2.2.3.3 Batch mixers

The Z-blade mixer (dough mixer): there are several designs, but all work on the same principle of cutting and kneading. They usually deal with plastic raw materials, but can also handle drier powders.

Drum mixers: these are suitable for mixing relatively dry materials of uniform size. The charged drum is rotated for the requisite time period.

Rotating pan mixers: these operate on the same principle as large concrete mixers, and are best charged with measured amounts of the individual components whilst the pan is moving. Scrapers, ploughs and baffles are used to achieve intimate blending, and these mixers can mix granular clay with fine powders.

Rotating shaft mixers (blungers): in this version, the pan is stationary and a central shaft rotates, usually carrying arms which themselves bear rotating paddles or blades. The latter sweep the base of the pan with a planetary motion, and achieve similar batch mixing efficiency as the rotating pan type.

Stirred tanks: these are employed for mixing a range of aqueous slurries, slips and suspensions used in the ceramic industry. Although suspending agents are normally included, it is frequently necessary to maintain the stirring action until the slips, etc. are used, either in the mixing tank or in a separate storage tank.

2.2.3.4 Decarbonisation and circular economy of component mixing

[Note to the TWG, please provide information on decarbonisation and circular economy in component mixing e.g., substitution of raw materials to avoid process emissions in firing]

2.2.4 Shaping/forming of ware

2.2.4.1 General

Traditional ceramic products were always shaped from raw materials in the plastic state~~,~~ and for several millennia~~,~~ this was a manual operation. ~~At the present time, the demand is for ever more stringent technical specifications covering such properties~~ The shaping process has to cover more stringent technical specifications such as dimensional tolerance, density, strength, durability and refractoriness. In many cases, aesthetic qualities are also of prime importance. The method of forming the ware can have a profound effect on their ultimate properties, and a wide range of shaping techniques has evolved in the various sectors of the ceramic industry.

2.2.4.2 Pressing

2.2.4.2.1 Mechanical pressing

This method is still employed for the manufacture of bricks (e.g. semi-dry pressing) and of refractory products. ~~Die boxes~~ Moulds are charged with a preset volume of clay granules, and pressure is usually applied from above and below, with pistons being driven by cam action and aided by heavy flywheels.

2.2.4.2.2 Hydraulic pressing

Modern hydraulic presses can provide high compaction force, high productivity, consistency and easy adjustment. Many presses are now fitted with electronic control units, which can check the height of units and automatically adjust the cycle to ensure size uniformity. Such presses can be readily adjusted to meet a variety of requirements, including complicated press programmes such as those used in forming complex refractory shapes. Hydraulic pressing is widely adopted for the shaping of tiles. In the case of ceramic tiles, the moist powder (at 5-7 % moisture content) is pressed in shallow dies, whereas clay roof tiles are usually formed by pressing plastic clay ‘bats’ cut from an extruded column.

2.2.4.2.3 Impact pressing

This involves a high-energy-rate forming via pneumatic-mechanical impact between a high-velocity ram striking powder in a die. The technique is employed in the manufacture of special refractory products.

2.2.4.2.4 Friction pressing

Mechanically driven friction (screw) presses are, in general, used for producing refractory shapes, although they are gradually being replaced by hydraulic presses.

2.2.4.2.5 Isostatic pressing

Some high-quality products require uniform densification, which can be achieved by applying pressure equally on all surfaces. In the isostatic press, rubber or polyurethane moulds are filled with ceramic powder and placed in a liquid-filled vessel. A high hydrostatic pressure is then applied, followed by a demoulding of the objects. This technique is used in the refractory and technical ceramics sectors as well as for the manufacture of tiles and tableware.

2.2.4.2.6 Continuous lamination

One of the available technologies for producing large tiles is based on the continuous lamination of spray-dried powder. The spray-dried powder is pressed by a rolling lamination system. This means that, by means of mechanical pressing, very long pieces can be made, the width being limited by the manufacturing line width [49, TWG ES 2021].

2.2.4.2.7 Unconfined band pressing

Initially, this technology was used for big and very thin tiles, from 3 mm to 4 mm. Nowadays, the machinery for this technology allows the manufacture of tiles with thicknesses up to 20 mm.

This shaping technology is similar to the traditional pressing technology, since the compacting is made by uniaxial pressing. The main difference from traditional pressing is that, instead of pressing the spray-dried powder into a mould, it is placed in a polymeric band that is used to transport the powder and the compacted tiles [49, TWG ES 2021].

2.2.4.3 Extrusion

Extrusion is widely employed for the manufacture of clay bricks and blocks, vitrified clay pipes and ceramic floor and wall tiles. The process is also used to make semi-finished 'bats' for subsequent pressing into roof tiles, refractory shapes, etc. The extrusion process demands a plastic raw material, which usually implies substantial clay content. The plastic body is tempered to the required consistency with water, and then forced through the die of the extruder – usually by a powerful auger. A vacuum de-airing stage is usually included prior to the auger, leading to improved consolidation of the clay column. The latter is finally cut into units of the required length by forcing sections of the column through a number of tightly stretched vertical wires.

Extrusion is well suited to the large-scale continuous production of bricks, pipes, etc. and is ideal for making perforated ware including large lightweight building blocks.

2.2.4.4 Moulding

This is a very ancient method of shaping clay objects – the earliest known brick (unfired) dates back more than 10 000 years. In many parts of the world, adobe systems are still in regular use. Hand moulding was employed, and simple wooden moulds were developed to ensure a more uniform size and shape. Moulding of clayware demands far less power and energy than pressing or extrusion, but requires a much softer (wetter) mix, leading to higher drying shrinkage and more heat energy input for drying.

Moulded bricks made by the ~~so-called~~ 'soft-mud' process have special textural and aesthetic qualities, which are in great demand – partly to maintain the rich architectural heritage of many cities and regions of Europe. Hand-thrown bricks are still made and command high prices, but many moulded bricks are now produced mechanically on sophisticated machines ~~in Western Europe~~. The machines still 'throw' individual clots of clay into pre-sanded moulds. Moulding of ware is also performed in the refractory sector, in order to form large products (sometimes weighing more than one tonne). The mix, which must have a precise viscosity, is cast into the mould. In this case, vibration (applied to the mould or directly to the mix using vibrating pokers) is used to consolidate the mix and ensure complete filling of the mould. This process is known as 'vibro-casting forming'.

2.2.4.5 Slip casting

This process is extensively used in the manufacture of sanitaryware and table- and ornamentalware, and for manufacturing special and complicated refractory products and technical ceramics. The finely ground mineral material is mixed with water to produce a clay slip (a stable aqueous slurry) which is poured into a porous mould, traditionally made of set gypsum plaster. The capillary suction of the mould draws the liquid from the slurry to form a high-solid cast on the inner surface of the mould. Wall thickness increases progressively, and with time a completely solid body can be achieved (if required) before removal from the mould.

Sanitaryware products are relatively large and are formed by conventional slip casting or (more directly) in pressure casting machines.

2.2.4.6 Fusion casting

This technique is expensive in terms of both cost and energy, so its use is confined to specialist ceramic applications. Refractory bricks are subject to severe chemical and physical attacks from molten slag, clinker, etc. Fusion casting involves pre-melting the selected raw materials and pouring into moulds. The resulting units have high density, low porosity and very strong intercrystalline coherence with a regular microstructure. These properties confer improved resistance to corrosion and erosion, and excellent mechanical strength at high temperatures. A feature of the process is the high shrinkage of the oxide~~s~~ melt on solidification, (of the order of 15 % by volume). Controlled slow cooling is necessary to avoid fracture of the cast pieces and to control the crystallisation process.

2.2.4.7 Decarbonisation and circular economy of shaping/forming of ware

[Note to the TWG: please provide information on decarbonisation and circular economy in shaping/forming of ware e.g. on replacement of gypsum moulds]

2.2.5 Drying of ware in ceramic ~~products~~ manufacturing processes

2.2.5.1 General

Traditionally, most clay articles were dried ‘naturally’ by standing in the air at an ambient temperature. In many parts of Europe, this was only effective during summertime. Simple drying ‘hacks’ were employed in the brick and roof tile industry, enabling the setting of superimposed rows of ware under a simple light wooden cover which excluded rain.

In the modern ceramic industry, it is necessary to optimise drying in terms of speed, thermal efficiency and low wastage. With the exception of slow, gentle drying processes, it is necessary to ~~maintain close control of~~ strictly control heating rates, air circulation, temperature and humidity. Heat for drying air is now mainly supplied by gas burners and by hot air ~~recovered~~ conveyed from the cooling zone of kilns. The heat for drying air can also be supplied with ~~a~~ cogeneration or another fuel such as coal, biomass, biogas or petroleum coke.

Some installations use thermal oil as a heat exchange fluid to recover heat for drying from the hot flue-gases of the firing zone of the kiln [49, TWG ES 2021].

Ceramic raw materials vary in their sensitivity to drying, but most benefit from an initial warming-up period in conditions of high humidity (and little or no moisture removal) followed by the main drying stage where the ~~units~~ pieces meet hotter and drier air. The last few per cent of water ~~is~~ are harder to remove, requiring the hottest and driest air. Various forms of dryers have evolved to meet the needs of the different sectors of the industry, in which the nature and size of the ceramic components vary enormously.

2.2.5.2 Hot floor dryers

[Note to the TWG: please provide information if this process is still in use]

This simple method of drying is no longer widely used, and does not lend itself to mechanisation or automation. However, it is still useful for the slow, gentle drying of large and complex ceramic items such as sanitaryware or some refractory products. Some special shaped bricks are also dried in this manner. As the name implies, the drying action arises from heat conducted directly to the base of the units in contact with a heated floor, and by convection currents in the air above that floor. Lateral airflow is minimal, and all surfaces of the ware dry at a low rate, avoiding undue stresses on the body during drying.

2.2.5.3 Chamber dryers (intermittent)

These consist of a battery of chambers with close-fitting entry doors, usually served by rail tracks carrying drying cars. The latter are loaded with drying pallets or racks, stacked vertically with uniform spacing. Fully automatic conveying systems have now been developed with transfer-car feeding of permanent racks in the dryer.

Ceramic units such as bricks, blocks, pipes and refractory shapes are set on the racks, and the loaded drying cars are transported into the chambers which are sealed when full. ~~In modern works, the whole operation is highly automated.~~ The whole operation can be automated. The chamber temperature is raised at a controlled rate either directly – by the injection of warm air – or indirectly, via heat transfer surfaces. Recirculation of air is used to improve drying efficiency. Heat transfer is mainly through convection, plus a little radiation from the hot air and from heated surfaces. Specific temperature-humidity profiles are followed to suit the particular ceramic product.

Chamber dryers are particularly useful in situations where various ceramic bodies are manufactured; where the bodies have a high water content; or when production is intermittent. It is also relatively easy to build on extra chambers if necessary.

2.2.5.4 Tunnel dryers (continuous)

These are essentially a long tunnel structure through which a line of dryer cars loaded with the green ceramic ware is pushed. ~~High temperature~~ Hot air is fed into the tunnel at the discharge end, and this is induced to flow towards the entry end by one or more fans. As the air flows down the dryer, it transfers heat to the product and its humidity content increases. Recirculation fans are normally installed, thereby increasing turbulence and the drying efficiency. The length of the tunnel dryer depends on the rate of product throughput required, and the water content of the ceramic material.

2.2.5.5 Vertical ‘basket’ dryers

The vertical dryer is used mainly in the ceramic tile sector and the tiles are fed into baskets consisting of several decks of rollers. The groups of baskets move upwards through the dryers, where they meet hot drying gases. The temperature in this type of dryer is normally less than 200 ºC, and the drying cycles range from 35 to ~~50~~ 120 minutes.

2.2.5.6 Horizontal multi-deck roller dryers

These dryers are also widely used by ceramic tile makers. The horizontal dryers are designed on the principle of the roller hearth kiln. The individual tiles are fed onto different decks within the dryer, and are conveyed horizontally by driven rollers. Burners located on the sides of the dryer produce the hot drying air, which flows countercurrently to the ware.

The maximum temperature in these dryers is usually higher than in the vertical option (around 350 ºC) and the drying cycles are shorter, between 15 and ~~2~~35 minutes.

2.2.5.7 Dehumidifying dryers

[Note to the TWG: please provide information about the process below]

These dryers are normally intermittent ~~(chamber)~~ units. The technique relies on maintaining the humidity level of the air in the drying chamber well below saturation, so that water continues to evaporate from the ware, without requiring an increase in temperature. To maintain this effect, water vapour must be continuously removed from the chamber, which is usually achieved by circulating the air through a refrigerated condenser.

Such dryers must be extremely well sealed to prevent ingress of potentially moist ambient air, and are normally equipped with programmable humidity controls to optimise drying. The scale of such dryers is limited but they are well suited to drying sensitive ceramic products, special shapes, etc. This drying technique only produces liquid water as a waste stream.

Another possibility is to introduce saturated steam into a tunnel dryer. In this tunnel vapour dryer, the moisture of the drying air is reduced in the different sectors of the dryer to guarantee controlled drying.

2.2.5.8 Infrared and microwave dryers

Infrared and microwave dryers can in principle also serve as alternatives to conventional dryers. ~~In this context, especially regarding microwaves see Chapter 6 ‘Emerging techniques for ceramic manufacturing’.~~

2.2.5.9 Decarbonisation and circular economy of drying of ceramic products

[Note to the TWG: please provide information, e.g. on heat pumps, electrification of drying, microwave supported drying, steam drying, geothermal energy]

2.2.6 Surface treatment and decoration of ceramic products

2.2.6.1 Texturing of clay products

The surface of clay products may be textured for functional reasons, e.g. to provide a non-slip finish to floor tiles.

A wide range of textures is also applied to clay products for aesthetic reasons. Soft-mud bricks acquire a pleasing random ‘fold’ pattern as the clay clot is thrown into the mould, and hand throwing produces especially desirable finishes. Extruded products can be drag-textured by scraping the surface of the ~~clay column~~ freshly extruded body. An alternative technique is to extrude slightly oversize, then to trim to the correct height and width using cutting wires.

A better drag texture can sometimes be obtained by omitting de-airing of the clay column. Textured rollers can impart a variety of textures to extruded products.

Pressed bricks are often ~~quite~~ hard in the green state and, after assembling as a continuous column on a conveyor belt, rotary cutters are used to ‘rusticate’ or otherwise texture these bricks. They may also be roll-textured, often after a preliminary mist-spray with water to soften the surfaces.

2.2.6.2 Applied facings

Soft mud bricks receive a surface coating of sand from the inside of the moulds, which are pre-coated with the sand to act as a release agent. A variety of textures and fired colours can be achieved by selecting the sand to suit the aesthetic requirements.

In the case of pressed or extruded unfired bricks, blocks or roof tiles, sand or other granular minerals can be applied to header and stretcher surfaces via compressed air blasting guns. In many cases, pigments are added to the sand in order to vary the aesthetic finish.

2.2.6.3 Glazing, engobing and other decorating techniques

There is a small specialist market for glazed bricks. Glazing is most common in the manufacture of ceramic wall and floor tiles, sanitaryware and tableware and ~~currently~~ there is a ~~growing~~ market share for roof tiles as well. Engobing is mainly employed in the manufacture of clay roof tiles and ceramic wall and floor tiles.

Engobes consist of a clay mixture with metal oxides, which is deposited as a thin film on the surface of the unfired ceramic body. Glaze has a greater glass content and builds up a thicker layer on the surface of the unfired ceramic body [56, COM 2023].

An engobe is usually applied after the drying process, in some cases the products are engobed even as green or fired ware. During the engobing process, a fine-grained, non-transparent light or coloured layer of a ceramic mass is spread onto the visible or whole surface by dipping or pouring.

Finely ground glaze components – mainly frits in the case of ceramic tiles – are prepared as aqueous suspensions. The viscosity and suspension characteristics are adjusted to suit the method of application, which may be spraying, waterfall glazing, dry glazing or decorating. During the glazing process, the dried green ceramic ware is, in most of the sectors mentioned above except sanitaryware, hardened by biscuit firing and then, depending on the applied glaze components, covered with a glassily melting, smooth, closed transparent or dusky layer.

~~An engobe is usually applied after the drying process, in some cases the products are engobed even as green or fired ware. During the engobing process, a fine grained, non-transparent light or coloured layer of a ceramic mass is spread to the visible or whole surface by dipping or pouring.~~ Screen printing is one of the decorating techniques for tiles, due to the ease of application in the glazing lines. The technique consists of printing a given design by means of one or more printing screens (tensioned fabric with a set mesh aperture). The screen surface is masked, and the printing ink only penetrates the openings of the designs to be reproduced. A squeegee forces the ink through these openings, thus printing the design on the tile.

Other decorating techniques are the gravure technique and flexo space printing. In these techniques, the pattern is transferred directly onto one or more rolls. The ink is applied to the tile from these rolls and this technique enables printing on the edges of the tiles or relief tiles. ~~Also, the inkjet printing technique is emerging nowadays.~~ In the case of tableware, often hand painting or sliding ornaments are also applied.

The incorporation of inkjet printing systems in the ceramic tile sector has achieved a significant reduction in manufacturing costs and an increase in production capacity, as well as a higher level of customisation of the final product. Inkjet printing has replaced many other decoration techniques (screen printing, flexography and rotogravure) used until then in this context.

The reliability of inkjet printing is dependent on careful design, implementation and operation. Inkjet technology consists of a digitally controlled ejection of tiny droplets only when required (Drop-on-Demand) from a piezo-printhead onto a ceramic tile substrate. Generally, droplets are formed by the generation of an electric pulse (waveform) which leads to the deformation of a piezoelectric device (commonly lead zirconium titanate). This mechanically generated distortion creates a pressure pulse that causes a drop to be ejected by a nozzle directed to the substrate.

The dynamic behaviour of the droplets during their ejection and impact on a ceramic surface converts the spherical initial droplet into a flat dot, its shape and size being strongly dependent on the physico-chemical properties of the ink and the substrate. Hence, inkjet ink will penetrate into the pores very quickly, causing the formation of a non-spherical dot, commonly known as ‘feathering’.

With respect to the ceramic inkjet inks, their main function is to place functional molecules on a substrate, after being jetted from the piezo-printhead. The ink can generally be regarded as being composed of complex mixtures consisting mainly of a solids component of an inorganic nature including inorganic pigments, refractory materials, and/or ceramic frits (25-55 wt-%), solvents of a different chemical nature (45-65 wt-%), and different additives: dispersants, stabilisers, and/or visco-depressers (1-10 wt-%) [49, TWG ES 2021].

2.2.6.4 Decarbonisation and circular economy in surface treatment and decoration of ceramic products

[Note to the TWG: please provide information on decarbonisation and circular economy in surface treatment and decoration, e.g. on electrification, choice of raw materials to avoid process emissions]

2.2.7 Firing

~~2.2.7.1 Aims of firing~~

Firing is a key process in the manufacture of ceramic products, as it controls many important properties of the finished ware. These include mechanical strength, abrasion resistance, dimensional stability, resistance to water and chemicals, and fire resistance.

The shape of the firing curve (temperature as a function of time) essentially depends on the body composition and, in glazed ceramics, on the nature of the glaze (glossy, opaque, matte, etc.) In general, every traditional ceramic firing cycle includes the following steps:

- Heating: In this step, the unfired products are heated from ambient temperature to about 800 °C (depending on the raw material composition). This is the step in which outgassing of the ceramic body needs to take place to avoid problems of bloating, bubbles, pinholing, glaze porosity, and colour differences at higher temperatures. Various transformations take place in the material during heating, such as the removal of free water, combustion of organic matter, allotropic transformation of quartz, loss of hydroxy groups in the clays, and carbonate decomposition. All these chemical reactions lead to a series of internal stresses in the ceramic product owing to gas release, changes in volume, etc. If these stresses exceed the mechanical strength of the as yet 'unfired' ceramic product, failure will occur.
- Firing: The actual firing step runs from about 800 °C to the programmed peak temperature, typically between 850 °C and 1 350 °C, which depends on the product being made. The main physico-chemical transformations take place in this step. These reduce the ceramic material's porosity. They lead to the most important dimensional changes (shrinkage) in low-porosity products (stoneware and porcelain ware) and to the formation of stable crystalline phases (calcium silicates) in porous products (earthenware wall tiles and structural ceramics).
- Cooling: This begins when the heat input ends. In the cooling step, product temperature decreases from peak temperature to near ambient temperature. In traditional ceramics, the cooling rate is essentially constrained by quartz phase transformation at 573 °C, as this produces a volume change that can cause cracking in the product if cooling does not take place uniformly throughout the material, owing to the low thermal conductivity of ceramic materials [50, S. Ferrer 2015].

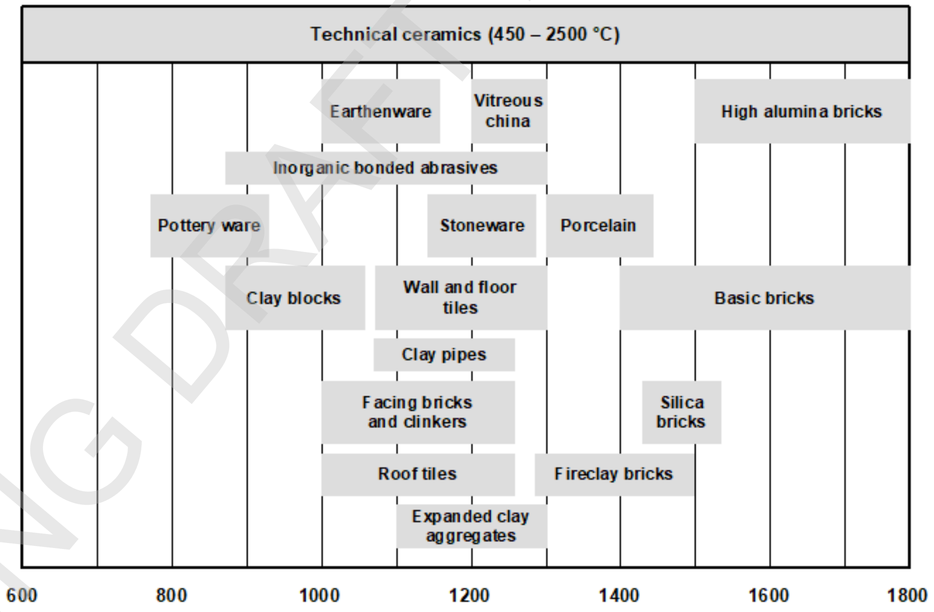
~~2.2.7.2 Physico-chemical changes during firing~~

Physico-chemical changes during the above-mentioned steps are related to the mineral composition of the raw materials. Raw materials used in ceramic bodies are usually complex mixtures of clay minerals, with other mineral matter such as quartz, feldspars, carbonates, gypsum, iron oxides and sometimes organic matter. Refractory products are also made from a wide range of non-clay minerals, together with specialised additives and binders (which may include some clays). When clay-based ceramic products are fired in a kiln, any residual moisture is driven off at temperatures of between 100 ºC and 200 ºC. If organic matter and iron pyrites are present, oxidation takes place at temperatures of between about 300 ºC and 500 ºC. Water combined within the structure of clay minerals (‘crystal water’) is usually released at temperatures of between 500 ºC and 650 ºC, whilst carbonates such as calcite and dolomite dissociate with the release of carbon dioxide in the temperature range 750 ºC to 950 ºC.

The most important changes relating to the development of ceramic properties involve the breakdown of the lattice structure of the original clay minerals, followed by the formation of new crystalline compounds and glassy phases. The temperature at which vitrification (glass formation) takes place~~,~~ varies according to the mineralogy of the clay. Vitrification usually commences at about 900 ºC and is completed by about 1 050 ºC (for many brick clays) or about 1 100 ºC in the case of more refractory-type fireclays.

During the vitrification stage of ceramic firing, many non-clay minerals such as quartz, oxides or iron, lime compounds and alkalis (oxides of sodium and potassium) become incorporated in the fired body. Some sintering and solid solution occur~~s~~, and eutectic reactions take place at the interface of mineral grains and melt phases.

Non-clay products such as some refractory products also depend on sintering, vitrification or recrystallisation stages, but in most cases much higher temperatures are required to achieve the desired properties. ~~In the following figure~~ Figure 2-3 presents the ranges of industrial maturing temperatures for different product groups ~~are presented~~ [4, UBA 2001], [23, TWG 2005], [30, TWG 2005].



Source: [9, COM 2007]

Figure 2-3:Ranges of industrial maturing temperatures for different product groups

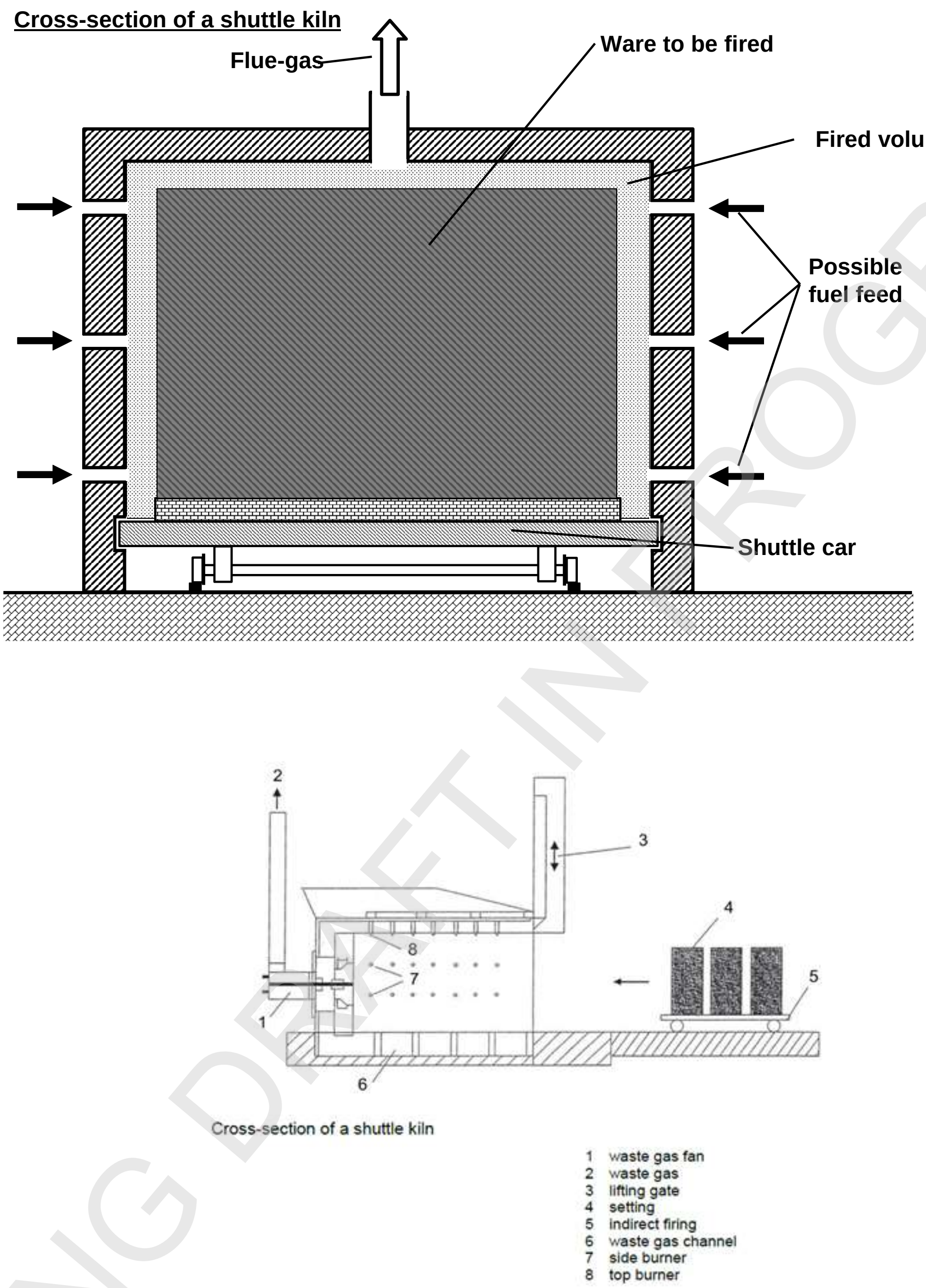
The temperatures necessary for the firing process are mainly created by burning natural gas ~~and fuel oil~~. In some cases, solid fuels, biogas/biomass and electric power are also used for heat generation.
Several waste materials may be used in the raw material mix, e.g. as pore-forming agents in clay blocks or expansion additives in expanded clay aggregates, and are co-incinerated during firing.

2.2.7.1 Intermittent (periodic) kilns

These include shuttle and hood-type kilns, based on single chambers, which are charged with pre-dried ceramic products~~ (in a hood-type kiln, the hood equipped with the heating unit is placed on the bottom by a hoisting unit; in shuttle kilns, the ware to be fired is brought to the hearth area in a shuttle car)~~, sealed, and then subjected to a defined firing cycle. In a hood-type kiln, the hood equipped with the heating unit is placed on the bottom by a hoisting unit; in shuttle kilns, the ware to be fired is brought to the hearth area by a shuttle car). Gas burners are usually employed and good control of temperature and kiln atmosphere (oxidising or reducing) can be achieved.

Electricity can also be used to heat intermittent kilns, for instance in the manufacture of technical ceramics. Special kiln types for technical ceramics ~~are, e.g.~~include HIP (hot isostatic pressing), high-temperature kilns, and kilns with a protective atmosphere.

Intermittent kilns are mainly used for smaller scale manufacture of specialised products, such as special shaped bricks and pipe fittings, roof tile fittings, refractory products~~, etc~~. They offer flexibility when the ceramic body composition is altered frequently, and th~~ese~~is ~~advantages~~benefit outweighs their somewhat lower energy efficiency. ~~The following figures~~ Figure 2-4 shows the cross-sections of a shuttle kiln [4, UBA 2001], [30, TWG 2005], [52, VDI 2018].



Source: [52, VDI 2018], [9, COM 2007]

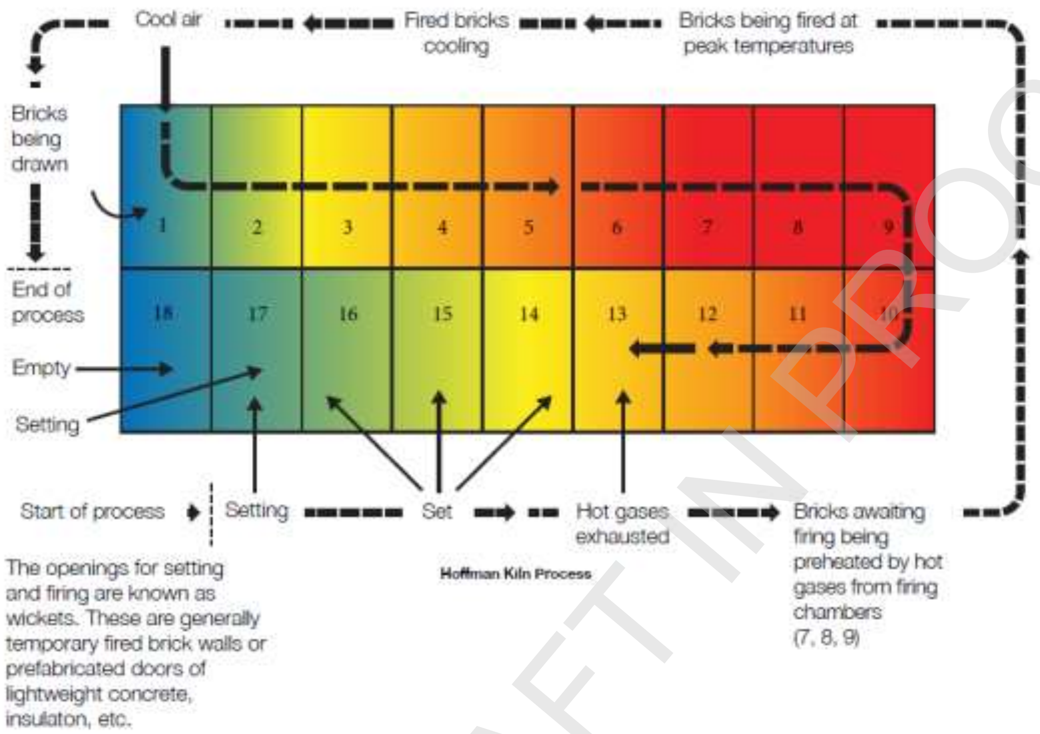
Figure 2-4: Cross-sections of a shuttle kiln

2.2.7.2 Continuous kilns

2.2.7.2.1 Chamber (Hoffmann) kilns

These consist of a series of linked chambers, which are sequentially filled with dry ware (e.g. bricks), sealed, fired quasi-continuously and the hot gases are drawn from one chamber to the next, i.e. the fire travels around the chambers (as shown in the diagram below).

This connecting system with flues and holes between the chambers also allows the preheating of the ware~~,~~ and the cooling of the flue-gases and so results in improved thermal efficiency and lower costs compared to intermittent kilns. The kilns are now mainly gas-fired, but top feeding with oil or coal is occasionally practised. They are mainly used for the manufacture of specialised products, for example special coloured bricks.



Source: [40, BrickUK 2017]

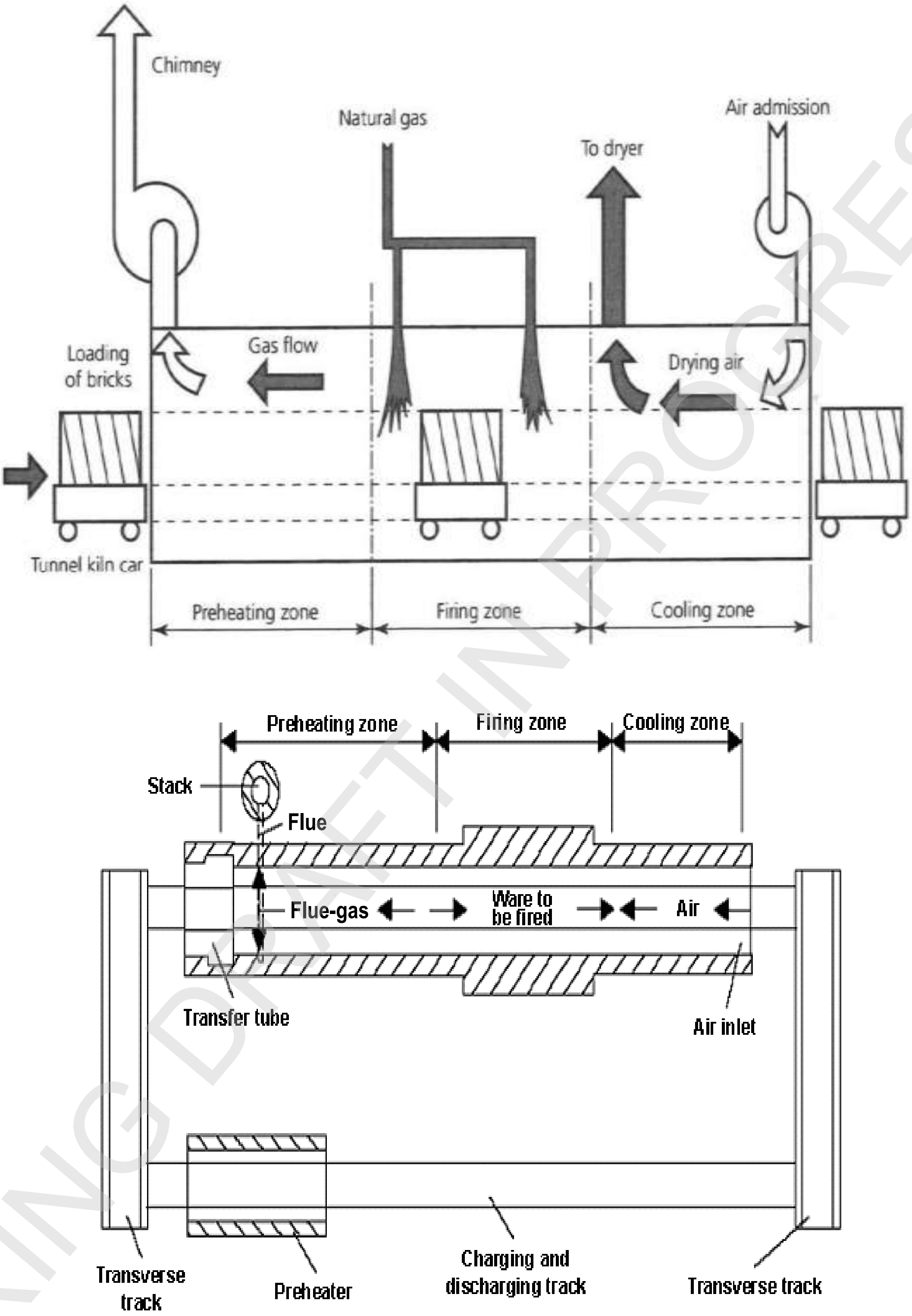
Figure 2-5: Schematic view of a Hoffmann kiln

2.2.7.2.2 Tunnel kilns

These are essentially refractory tunnels served by rail tracks carrying kiln cars. The latter have refractory decks on which dried ware is set in defined stable patterns. The cars are pushed through the kilns at set intervals, countercurrently to a flow of air drawn by fan(s) to an exhaust duct near the car entry zone. Most tunnel kilns are now gas-fired, with ~~a~~the maximum temperature in the firing zone near the centre of the kiln. Incoming ware is preheated by hot gases from the firing zone, whilst incoming air cools the fired ware and is itself preheated for its combustion role. A proportion of this air from the cooling zone is usually drawn off to the adjacent dryers, giving significant fuel economies.

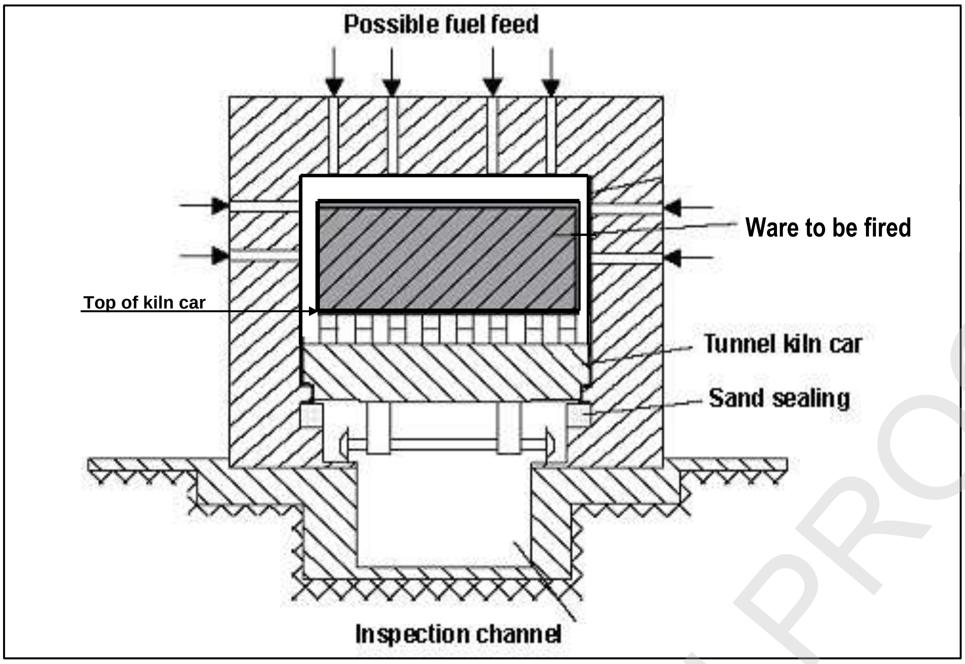
The firing chamber and kiln cars are usually sealed against secondary air with a sand seal. The latest kiln constructions are sealed by water or other improved mechanical solutions. The aim of these procedures is to reduce firing times and energy consumption by having a gas-tight firing chamber.

Figure 2-6 and Figure 2-7 show a schematic view of the layout and cross-section of a tunnel kiln [4, UBA 2001], [23, TWG 2005].



Source: [33, Ramboll 2019], [9, COM 2007]

Figure 2-6: Schematic view of a tunnel kiln

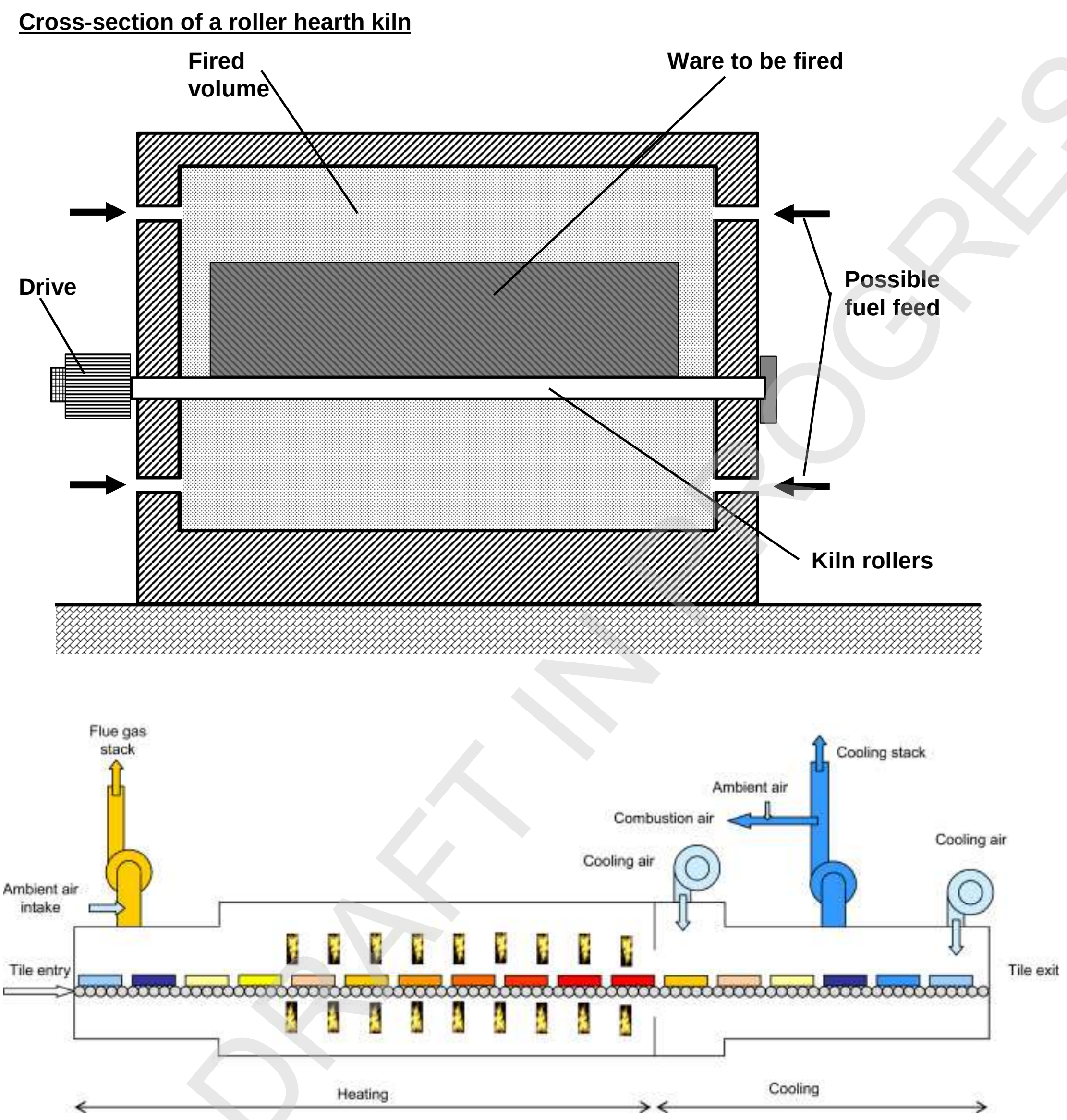


Source: [9, COM 2007]

Figure 2-7: Cross-section of a tunnel kiln with a tunnel kiln car

2.2.7.2.3 Roller hearth kilns

Single-deck roller kilns are now almost universally used for wall and floor tile production, and firing schedules have been reduced to less than 40 minutes. Tiles travel over driven rollers, and the heat required for firing is provided by natural gas-air burners located at the sides of the kiln. The main heat transmission mechanisms are convection and radiation, and, as the kilns are non-muffled, the heat transmission coefficients are raised, reducing the firing cycle and energy consumption. Roller hearth kilns are also sometimes used for the production of clay roof tiles, vitrified clay pipes, sanitaryware and tableware. ~~The following figure~~ Figure 2-8 shows the cross-section of a roller hearth kiln [4, UBA 2001], [30, TWG 2005].



Source: [69, Mezquita et al. 2014], [9, COM 2007]

Figure 2-8: Cross-section of a roller hearth kiln

2.2.7.2.4 Sliding bat kilns

These are also fast firing~~,~~ and operate on a similar principle to the roller hearth kiln. However, the ware in this case is placed on refractory 'carriages' which move on wheels borne by tracks outside the kiln proper. The sliding bat kiln can accept ware of a more irregular shape and size, whereas a roller hearth kiln can only deal with regularly shaped items.

2.2.7.3 Clamp firing

[Note to the TWG: please provide information, i.e. if this process step is still in use]

A limited production of traditional stock bricks is still carried out by clamp firing. Dried bricks containing a solid fuel additive (such as fine coke) are built into large, dense rectangular settings– called clamps – on a foundation of fired bricks. Flues are left in the base layers, with layers of coke to initiate firing. The clamp is finally clad with fired bricks, sloping the outer walls inwards for stability.

Once ignited, the fire progresses slowly by combustion of the fuel within the bricks. Firing of the clamp takes several weeks, including time for cooling, after which the clamp is stripped down manually and the bricks sorted into defined grades.

2.2.7.4 Rotary kilns

A rotary kiln has the form of a long cylinder, usually inclined, and is slowly rotated about the axis. The kiln is fired by a burner set axially at the lower end. Rotary kilns are used for the manufacture of expanded clay aggregates.

Rotary kilns can also be used for the calcination of fireclay and for dead-burning of dolomite or magnesite (see Section 2.2.2.8). ~~This document does not deal with these upstream raw material calcining processes, but useful information regarding ‘dead burned oxides’ and ‘calcined chamotte, pigments and fillers’ can be found in the Cement and Lime BREF – where the calcination of dolomite is described; in the BREF for Management of Tailings and Waste-Rock in Mining Activities – where the processing of kaolin is described; in the draft BREF on Large Volume Inorganic Chemicals (Solids and Others) – where the production of magnesium oxide is described and in the draft BREF on Speciality Inorganic Chemicals, where the production of speciality inorganic pigments is described.~~

2.2.7.5 Fluidised beds

[Note to the TWG: please provide information if this process step is still in use]

A fluidised bed is a bed of solid particles maintained in suspension in a gas and thus behaving rather like a fluid. The powder to be fluidised is supported on a porous base, e.g. a trough of special ceramic material, through which the gas (usually air) is fed from below and under pressure. The principle is used as a method of conveying powders along a slightly inclined porous ceramic trough. The powder can be simultaneously dried and/or calcined.

2.2.7.6 Cooling stage heat recovery

Where possible, the cooling of fired ceramic ware is accelerated by forced air circulation through the products soon after the firing zone. This results in considerable volumes of clean, hot air, much of which is drawn from the kiln by fan action and utilised in the drying operation. In roller hearth kilns, it is possible to use this heat to preheat the oxidising air [49, TWG ES 2021]. This method of heat recovery is particularly effective when applied to tunnel kilns.

2.2.7.7 Decarbonisation and circular economy in the firing process

[Note to the TWG: please provide information on decarbonisation and circular economy in firing processes, e.g. on electrification of kilns, extension of the kiln, reduction of leakage in kilns (oven insulation, kiln cars), fuel switch for decarbonisation (biogas/biomass, H_2), dematerialisation]

2.2.8 Subsequent treatment (product finishing)

2.2.8.1 Machining (grinding, drilling, sawing)

Machining operations may be necessary to produce ceramic products whose final shape or dimensional tolerance cannot be achieved technically or with sufficient accuracy during primary processing (especially for larger shapes or blocks).

2.2.8.1.1 Wet grinding

Wet grinding is utilised to finish products requiring the tightest dimensional tolerance. Grinding is a batch process, in which a number of pieces are fixed to a table, which traverses under a diamond machining head. Bed surfaces of building bricks or blocks are sometimes smoothed by wet grinding to facilitate bonding with thin-layer ‘glues’.

2.2.8.1.2 Dry grinding

Dry grinding of clay block bed surfaces with diamond wheel grinding systems is carried out as subsequent treatment to facilitate bonding with a thin layer of mortar. In the case of dry grinding, the whole grinding device is encapsulated.

2.2.8.1.3 Drilling

Ceramic products, especially refractory products, may need to be drilled when the ‘hole’ required cannot be achieved with the necessary accuracy during the pressing and firing operations.

2.2.8.1.4 Sawing

This is a finishing operation used when the final shape of a ceramic brick, especially a refractory brick, cannot be effectively produced at the pressing stage. In this situation, oversize bricks are pressed and fired, then sawn to the required dimensions.

Facing bricks may be sawn in the manufacture of ‘cut and stuck’ special shapes. In virtually all machining operations, a closed loop water system provides lubrication and sweeps lubricated particles away from the work~~ing~~ surfaces – at the same time, minimising dust release.

2.2.8.2 Polishing

In some cases, particularly involving porcelain tiles, the fired surface is polished to achieve a shiny, unglazed homogenous tile.

2.2.8.3 Carbon enrichment (refractory products)

Refractory products are required to work in extremely hostile working environments, and for certain applications it is necessary to impregnate fired ware with petroleum-based pitch. The presence of carbon in the final product offers several advantages:

- it acts as a lubricant, beneficial for the working surfaces of sliding-gate plates;
- the relatively high thermal conductivity of carbon increases the thermal shock resistance of the product;
- the carbon acts as a pore filter reducing the permeability of the product, which in turn offers increased resistance to penetration by slag and metal.

Pitch impregnation is a batch process, typically carried out in three upright cylindrical vessels fitted with hinged lids. Products for treatment are loaded into metal baskets, which fit inside the vessels. The ware is heated in the first vessel to ~ 200 ºC via a circulating stream of hot air, then the basket and contents are transferred to the second vessel (referred to as an autoclave), which has a heating jacket to maintain the temperature. The autoclave is then sealed, evacuated and filled with liquid pitch (drawn from bulk storage tanks maintained at temperatures of around 180 ºC to 200 ºC). Impregnation is achieved by releasing the vacuum, then applying nitrogen at an elevated pressure. After draining, the basket and contents are transferred to the third vessel for cooling to a temperature below that at which volatile pitch components may be ~~evolved~~generated.

Finally, it is necessary to remove a high proportion of pitch volatiles, which would adversely affect the working environment when the refractory products were put into service. Typically, this is achieved by transferring the impregnated ware to an oven, to undergo a defined heating cycle. The oven exhaust fan discharges into a thermal oxidiser (incinerator) held above 800 ºC, with a dwell time of at least 0.5 seconds. These conditions ensure that all pitch volatiles (complex hydrocarbons) are fully oxidised.

Products which have been through the above treatment emerge coated in light, brittle carbonaceous deposits which must be removed prior to packaging or further processing. This is usually achieved by ~~short~~ blasting the products briefly on a blasting table.

2.2.8.4 Tumbling of facing bricks

Certain facing bricks are given an antique finish by passing them through a rubber-lined rotating inclined drum. Sharp corners are removed by attrition, producing a softer profile. In some cases, splashes of calcium carbonate (ground limestone), soot or pigment are added, reproducing the appearance of recovered bricks, which have a recognised architectural role.

2.2.8.5 Decarbonisation and circular economy in subsequent treatment (product finishing)

[Note to the TWG: please provide information on decarbonisation and circular economy in product finishing, e.g. electrification, reuse of grinding dust]

2.2.9 Addition of auxiliary materials

2.2.9.1 Jointing materials (pipes)

Since most pipes are installed underground as drains, sewers, etc., reliable jointing is necessary. Stable plastic sleeves and seals have been developed by the industry.

2.2.9.2 Silicones/water repellents

Fired clay units show a wide range of porosity values, and spraying or dipping of the ware in silicone solutions is sometimes employed to give more impermeability and to avoid organic growth and efflorescence. This technique is especially used for roof tiles.

2.2.9.3 Insulation materials

Insulation materials – e.g. polystyrene or mineral wool – are inserted into certain large hollow clay blocks and ~~LWA~~lightweight expanded clay aggregate blocks in order to enhance their thermal insulation properties.

2.2.9.4 Carding and plating (refractory bricks)

To assist the installation of refractory products and the burning-in of the kiln or furnace lining, thick cards or metal plates may be glued to one or more surfaces of fired bricks. A card acts as an expansion joint, burning away as the kiln/furnace is brought up to the operating temperature. Metal plates will melt under similar circumstances, effecting a bond between adjacent bricks.

2.2.9.5 Adhesives

Stable adhesives (usually epoxy-based) are used to assemble ‘cut and stuck’ special shapes of roof tile fittings, clay bricks or blocks.

2.2.9.6 Final assembly

Some products are completed in a final assembly step, for example the mounting of metal flanges on high-voltage insulators to fix them in bushings, transformers or other applications.

2.2.9.7 Decarbonisation and circular economy in addition of auxiliary materials

[Note to the TWG: please provide information, e.g. electrification, substitution of specific substances]

2.2.10 Sorting, packaging and storage

Sorting and packaging may still be a manual operation, as in the case of some types of clay bricks, roof tiles, and shaped refractory products, as well as table- and ornamentalware. However, tighter control of firing has considerably reduced broken ware in recent years, so the tendency is towards more automated systems. ~~Even colour can now be measured instrumentally, which is important in the case of ceramic tiles~~. ~~Kiln setting of clay bricks and blocks~~ Kiln-fired clay bricks or blocks ~~showing very low waste~~ are mechanically consolidated into packs ready for shrink-wrapping – the customer accepting the possibility of 1-2 % imperfect units.

Regularly shaped ceramic units such as bricks, blocks, pipes and refractory units are normally strapped into standard sized packs, which are often subsequently polyethylene-wrapped and may be palletised.

Ceramic products at the top end of the value range, such as table- and ornamentalware, demand rigorous inspection and sorting, followed by sophisticated protective packaging. In contrast, unshaped refractory products and expanded clay aggregates are usually simply weighed into bags and then palletised. Metal drums are also used for storage.

Ceramic tiles are – individually – somewhat fragile, but when tightly packed in cardboard boxes, prove remarkably robust during handling and transportation.

Storage of heavy clay goods made on a large scale is often outdoors, but products which are bagged or boxed require warehouse storage, as do certain moisture-sensitive refractory products.

2.2.10.1 Decarbonisation and circular economy in sorting, packaging and storage

[Note to the TWG: please provide information on decarbonisation and circular economy in sorting, packaging and storage, e.g. electric forklifts for transport, material thickness of packaging material, use of smaller quantities of printed plastic (e.g. with company name) and separation from transparent plastic used for packing brick piles (e.g. printed banderoles)]

2.2.11 Supply and disposal (off-gas treatment and process waste water treatment) facilities

Dust extraction, dryer and kiln flue-gas treatment units, process waste water treatment plants and fuel storage are important supply and disposal facilities of plants manufacturing ceramic products. Depending on the dust emissions, dedusting units are built as central or local, e.g. centrifugal force preseparators, fibrous fabric filters, wet separators, ~~and~~ electrostatic precipitators. According to the type of emission, further flue-gas treatment units are used in the ceramic industry, ~~for example~~ e.g. scrubbers and dry sorption plants as well as thermal and catalytic afterburners. These units are mainly located near the main source of emissions, i.e. the kiln.

Process waste water resulting from the manufacturing of ceramic products mainly contains mineral components. Process waste water cleaning units are often built as sedimentation basins. Sedimentation of the inorganic mineral components can be accelerated by the use of flocculation and coagulation agents.

Fuel storage depends on the characteristics of the fuel used. Coal in lumps is stored in open-air storage systems and storage sheds~~,~~ and pulverised coal is stored in silos. Liquefied petroleum gas is stored in special pressure reservoirs. Fuel oil is stored in tanks, whereby heavy fuel oil has to be heated to guarantee pumpability. Natural gas is delivered by the supply network of the gas company. Additional useful information regarding storage of fuels can be found in the Emissions from Storage BREF (EFS) ~~(ESB)~~ [63, COM 2006].

Depending on the processing, further supply facilities such as mould production facilities are necessary. These facilities produce plaster moulds which are used in large quantities, e.g. in the production of roof tiles.

[Note to the TWG: Section 2.2.12 has been transformed to Section 2.5]

[Note to the TWG: Section 2.2.13 has been merged with Section 2.2]

~~2.2.12 .Recycling in the ceramic industry~~

~~Most sectors of the industry recycle materials such as off-cuts, trimmings and substandard articles back to the raw material preparation stage. Fired goods of lower quality may also be recycled within the factories, usually after crushing and screening to form granular ‘grog’. This is non-plastic, and can confer benefits like easier drying and lower shrinkage when added as a controlled proportion of clay bodies due to the increase of permeability. Even if ‘fired process loss’ recycling is not suited to the process from which it originated, it may find an outlet in a different ceramic process.~~

~~Used refractory products removed whilst relining a kiln may be contaminated by slags, salts, glass or metal, which could compromise the refractory properties of any body to which they were added. Similarly, also various other contaminated materials (e.g. with heavy metals contaminated materials, derived from glazes) may be unsuitable for recycling.~~

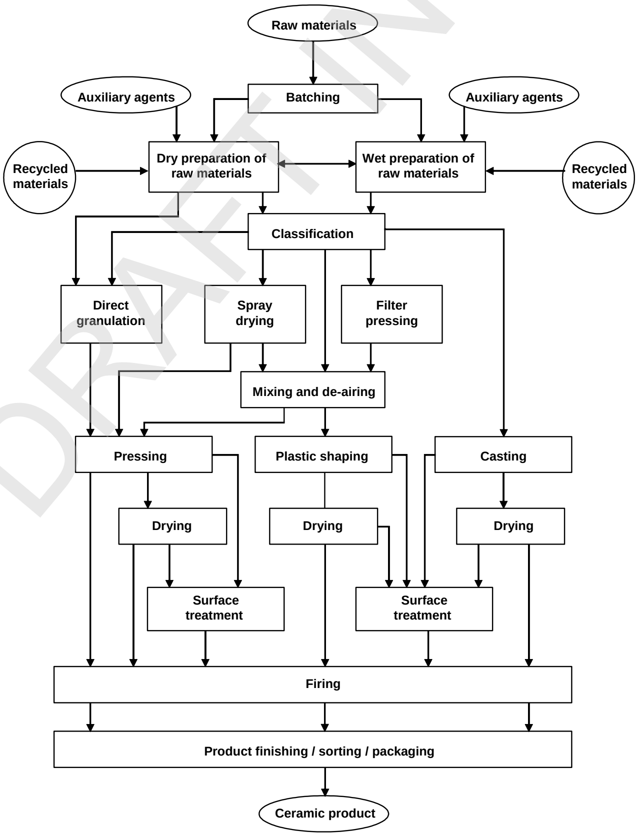
~~Plaster moulds which reach the end of their functional life represent another process loss which cannot be re-used, but in some cases they can be used as raw material in the cement industry.~~

~~However, in other cases – notably facing bricks and clay roof tiles – recovery and re-use is widely practised, and recovered bricks are in a great demand. Throughout Europe, large numbers of Roman bricks are still found in masonry structures. It should be noted that some of the uses of granular or finely ground bricks or roof tiles would be applicable to similar size gradings of fired ware from other sectors. Also crushed and graded 'ceramic process loss material' finds use as a partial aggregate in concrete for construction purposes, or as a filler in asphalt for road construction.~~

~~2.2.12 General process flow diagram showing different processing paths~~

~~The following figure summarises the description of the different processes and illustrates different possible paths in the manufacturing of ceramic products [4, UBA 2001], [23, TWG 2005].~~

[Note to the TWG: this section has been merged with section 2.2]



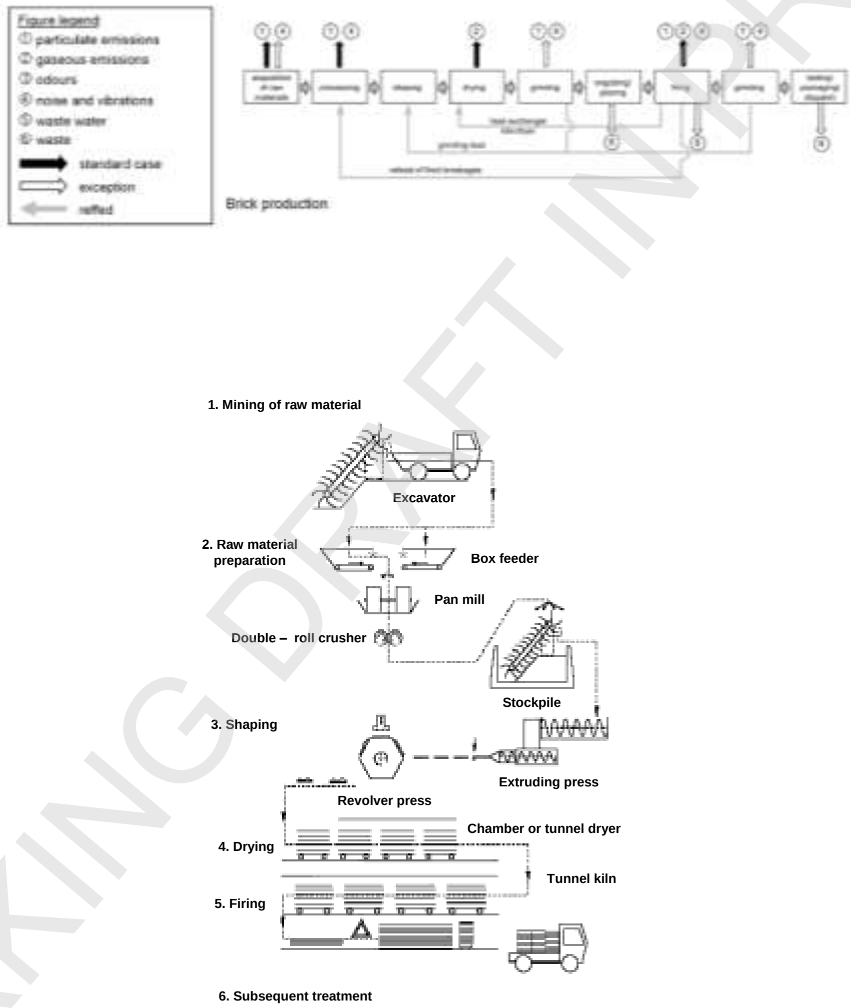
Source: [9, COM 2007]

~~**Figure 2-9:General process flow diagram showing different processing paths**~~

2.3 Description of techniques for the manufacture of ceramic products sector by sector

2.3.1 Bricks and roof tiles

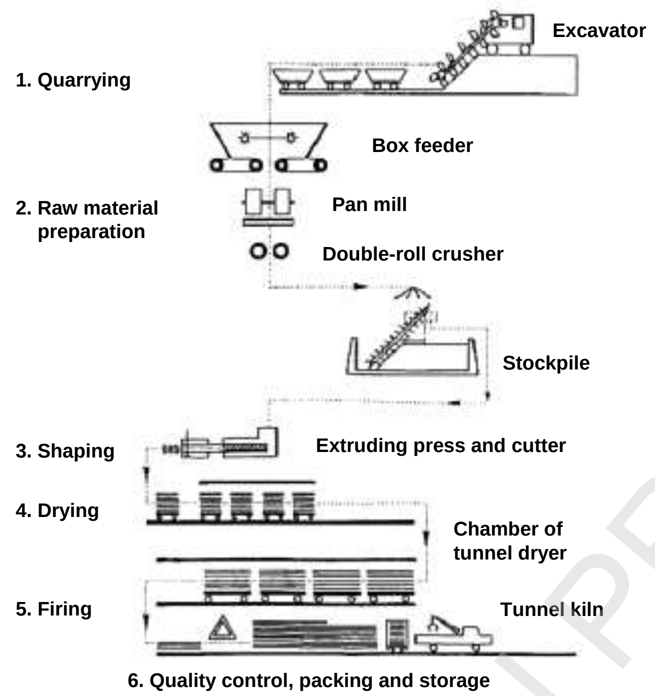
~~In both types of works, brick works and roof tile works, t~~ The manufacture of bricks and roof tiles goes through the stages of mining/quarrying of raw materials (this activity is not covered in this document), storage of raw materials, raw materials preparation, shaping, drying, firing and subsequent treatment. Special requirements for the surface and colour of the products involve a surface treatment by glazing, engobing or profiling~~. The following figure shows, as an example, a schematic view of the manufacture of pressed roof tiles~~ [4, UBA 2001]. Figure 2-9 and Figure 2-10 show, as an example, a schematic view of the brick making process [52, VDI 2018].



Source: [52, VDI 2018], [9, COM 2007]

Figure 2-9: ~~Schematic view of pressed roof tile manufacture~~ Schematic diagram of the brick making process

~~The following figure shows, as an example, a schematic view of the manufacture of masonry bricks [20, Ceram-Unie 2004].~~

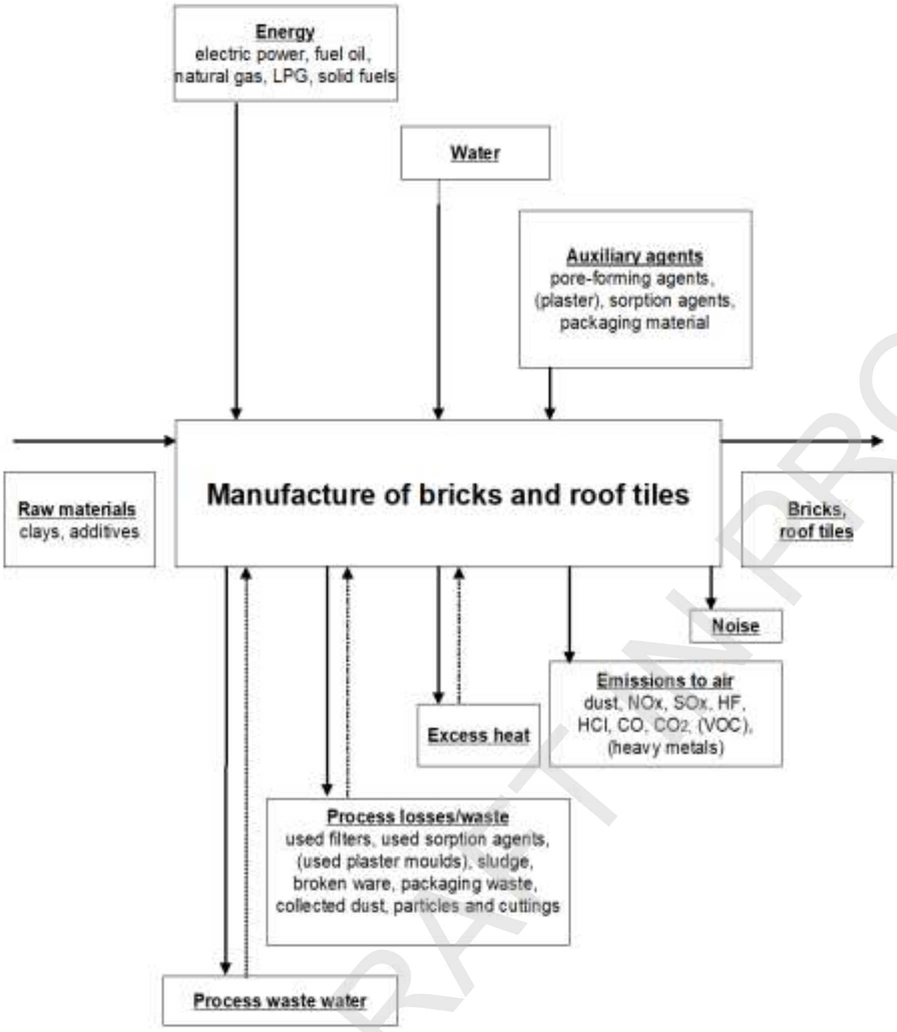


Source: [9, COM 2007]

Figure 2-10: Schematic view of preparation of extruded bricks in masonry brick manufacture

[Note to the TWG: the text and figure below has been moved from Section 2.3.1.7 of the 2007 CER BREF]

Important input and output flows of the brick and roof tile manufacturing process are presented in ~~the following figure~~ Figure 2-11 [4, UBA 2001], [23, TWG 2005].



Source: [9, COM 2007]

Figure 2-11: Input and output flows in brick and roof tile manufacture

2.3.1.1 Raw materials

The geology of brick and roof tile clays used in the European ceramic industry is extremely varied as they cover a wide stratigraphic range from the Cambrian period to recent times. Most brick and roof tile clays are sedimentary in origin and were laid down under a wide range of sedimentary environments: marine, alluvial, fluvial, river-glacier sediments. The range in depositional environments affects the clay mineralogy and the chemical composition. The mineralogical and chemical composition of clays used in the ceramic industry is very different in different European countries. Also, within one country a wide range of compositions can be employed. ~~The following table~~ Table 2.2 shows the ranges of chemical and mineralogical compositions of clay raw materials~~,~~ applied in the brick and roof tile industry in different European countries [20, Ceram-Unie 2004], [30, TWG 2005].

[TWG, please provide information from not included MS if available, e.g. RO, PL, CZ, SP, PT]

Table 2.2: Ranges of chemical and mineralogical compositions of clay raw materials applied in the brick and roof tile industry in different European countries

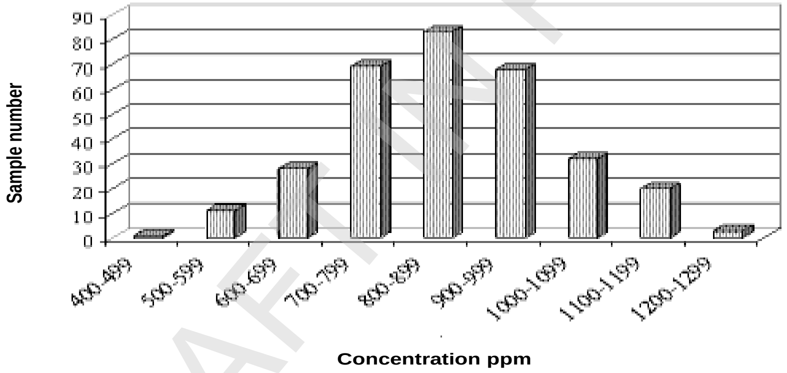
Country		**Austria**		**France**		**Netherlands**		**Hungary**		**Italy**		**Greece**		**Denmark**		**Belgium**		**~~UK~~**		**Switzerland**		**Germany**		**European range in 11 countries**	
Chemistry (wt-%)		**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Min**	**Max**	**Max**	**Min**	**Max**	**~~Min~~**	**~~Max~~**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
S		0.00	1.30	0.00	0.50	<0.01	1.50	0.01	0.75	0.01	0.62			0.03	0.70	0.01	2.05	~~0.01~~	~~2.00~~	<0.01	0.50	0.01	2.00	0.00	2.05
F		0.05	0.10	0.00	0.15	0.02	0.10	0.02	0.10	0.04	0.13			0.03	0.08	0.02	0.07	~~0.02~~	~~0.09~~	0.00	0.08	0.03	0.16	0.00	0.16
CO_2				0.0	14.0	<0.01	10.0							0.0	16.0	0.2	3.6								
SiO_2		50.3	70.8	35.0	80.0	53.2	80.6	42.2	63.0	33.1	74.4	6.85	75.42	49.5	66.3	62.6	74.0	~~40.5~~	~~74.5~~	35.0	77.0	50.0	70.0	33.05	80.60
Al_2O_3 +TlO_2		9.6	18.8					8.6	17.6																
Al_2O_3				8.0	30.0	7.3	18.1			8.1	21.0	5.85	20.22	11.7	17.9	5.5	14	~~9.0~~	~~24.5~~	7.0	29.0	7.0	20.0	5.47	30.0
Fe_2O_3		4.2	8.2	2.0	10.0	2.0	8.4	2.9	7.6	2.7	7.6	2.19	39.03	4.8	7.2	2.8	4.3	~~3.9~~	~~11.5~~	2.4	10.0	1.0	8.0	1.00	11.50
MgO		0.2	3.6	0.0	5.0	0.5	2.7	1.4	4.5	0.7	7.2	0.24	12.90	1.3	2.5	0.9	1.5	~~0.2~~	~~6.6~~	<1	5.2	0.5	3.0	0.00	7.21
CaO		0.6	15.0	0.0	18.0	0.0	8.7	2.1	15.2	0.2	26.0	0.91	25.20	0.3	12.9	0.3	5.6	~~0.2~~	~~17.5~~	3.0	23.0	0.5	15.0	0.00	26.00
Na_2O		0.4	1.7	0.1	1.5	0.2	1.0	0.2	1.2	0.2	14.1	0.37	3.06	0.8	0.8	0.4	1.0	~~0.2~~	~~0.6~~	0.2	1.5	0.3	1.2	0.10	14.13
K_2O		1.7	3.0	0.1	4.5	1.3	2.3	0.6	1.3	1.4	4.3	0.11	3.19	2.9	2.9	1.5	3.0	~~1.6~~	~~5.9~~	1.0	2.7	1.0	4.0	0.10	5.90
TiO_2				0.3	2.0	0.5	1.3			0.5	1.1	0.20	1.22	0.6	0.8	0.5	0.8	~~0.6~~	~~1.6~~	0.3	1.5	0.5	2.0	0.30	2.00
$CaCO_3$												1.63	45.00												
$MgCO_3$												0.50	31.00												
MnO												0.01	0.15												
Mineralogy(%)		**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	Min	Min	**Max**	**Max**	**Min**	**Max**	**~~Min~~**	**~~Max~~**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Quartz		21	49	0	70	39.5	71	16	32	16	54			35	50	34	65	~~10~~	~~55~~	13	55	15	60	0.00	71.00
Feldspar		5	15	infrequent		1	12	3	14	1	24			10	20	10	15	~~0~~	~~25~~	<1	33	1	25	0.00	33.00
Calcite		<2	26	0	30			0	14	1	41			<1	25	0	8	~~0~~	~~17~~	<1	37	1	25	0.00	41.00
Calcite + Dolomite				infrequent		0	20.5	0	24																
Pyrite		<2	<2			<0.01	2.8	0	2					0		0	2	~~0~~	~~7~~	0	0.7	0	2	0.00	7.00
Kaolinite		<3	10	small amount		5	21.5	2	13	1	26			5	15	1	5	~~0~~	~~40~~	5	26	3	40	0.00	40.00
Illite		25	60	dominant amount		7	20	4	21	5	42			10	20	3	15	~~0~~	~~40~~	2	40	10	50	0.00	60.00
Mont – morillonite		2	25	small amount		3	29.5	3	18	2	34			5	20	5	43	~~0~~	~~10~~			10	50	0.00	50.00
Vermiculite				none		7	20	2	4									~~0~~	~~15~~	2	16	-	-	0.00	20.00

Source: [9, COM 2007]

The particle size distribution, the other minerals present, the size range and ratio all fundamentally affect the properties of the clay.

The vast diversity in the composition of the raw materials results in a wide variation in the properties of ceramic products and in the gaseous emissions during firing. Each of these clays or mixtures of them~~,~~ are used to produce roof tiles, facing bricks and extruded blocks. Most plants have their own clay quarry which contributes to the site-specific character of the production techniques used for the different types of products.

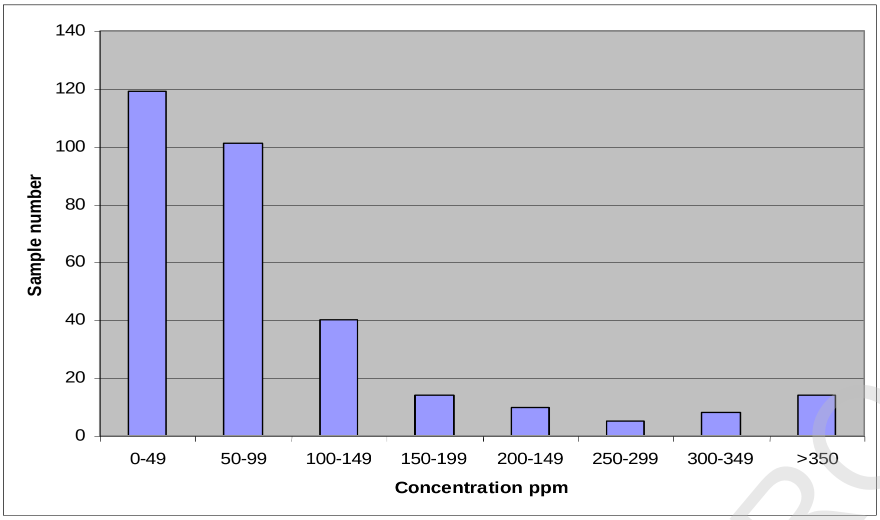
~~An analysis of fluoride and sulphur has been carried out since they effect the emission during firing as is discussed in Section 3.3.1.1 regarding emission data.~~ Fluoride, present in the structure of clay minerals, ~~ranges~~can be presented in levels up to 1 600 ppm throughout Europe and varies to a great extent in each country. As an example, ~~the following figure~~ Figure 2-12 shows a normal frequency distribution of the fluoride content in 312 samples of clays which come from all the geographical areas of Italy [3, Ceram-Unie 2003].



Source: [9, COM 2007]

Figure 2-12: Distribution of fluoride content in Italian clays

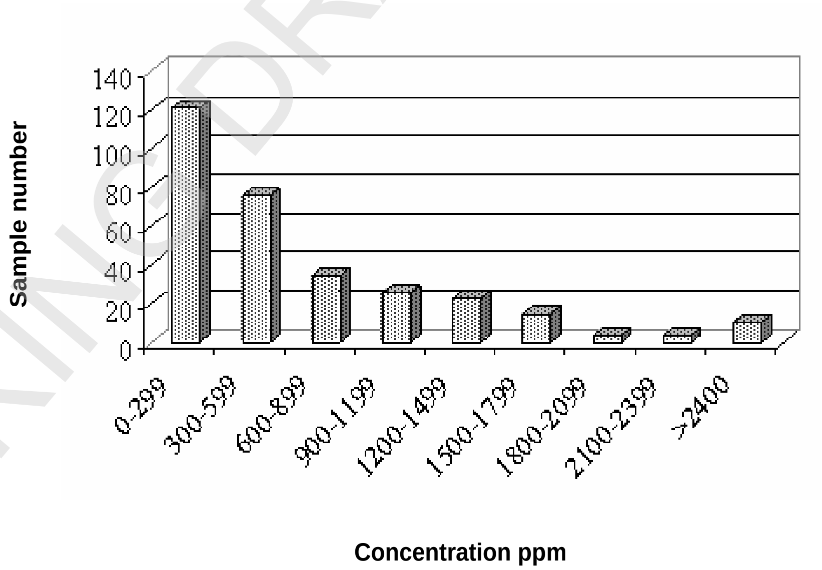
Most of the clays contain trace levels of chlorine. ~~The following figure~~ Figure 2-13 shows an example of the distribution of chlorine content in Italian clays [30, TWG 2005].



Source: [9, COM 2007]

Figure 2-13: Distribution of chlorine content in Italian clays

The considerable variation of sulphur content in the raw materials being used, not only between the different European countries but also within one country, will result in large variations of process emissions. Sulphur mostly occurs as sulphides (pyrite) in the raw materials. Based on Italian research, sulphur shows a lognormal distribution, as shown in ~~the following figure~~ Figure 2-14 [3, Ceram-Unie 2003].

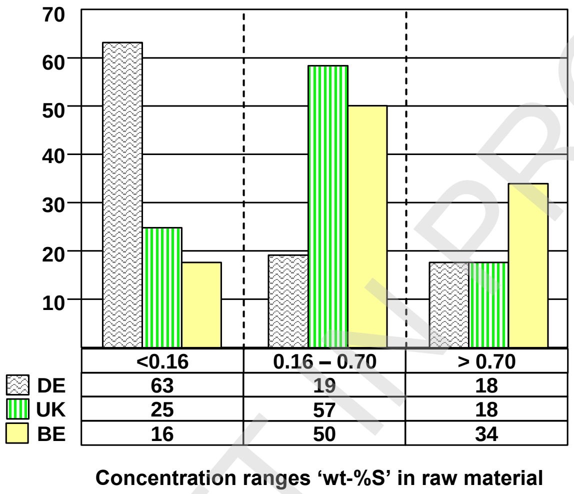


Source: [9, COM 2007]

Figure 2-14: Distribution of sulphur content in Italian clays

Large variations are found not only in the magnitude of the sulphur content, but also in the sulphur content distribution. This is clearly demonstrated by the example of clays used in Germany, the United Kingdom and Belgium, as shown in ~~the following figure~~ Figure 2-15. More than 80 % of the German clays have what is generally regarded as low and medium amounts of sulphur whereas in Belgium and the United Kingdom~~,~~ more than 75 % are medium- and high-sulphur clays [3, Ceram-Unie 2003].

[Note to the TWG, please provide more recent data for this topic: i.e. distribution of chlorine, sulphur and fluoride in clays for brick and roof tiles]



Source: [9, COM 2007]

Figure 2-15: Sulphur content in clays

Another important material, where large variations are also found, is calcium oxide (CaO), mostly present as calcite and/or in the clay mineral structure. The presence of $CaCO_3$ acts as an 'opening agent' due to decarbonisation during firing. The release of HCl, SO_X and fluoride might be influenced by the presence of CaO due to the formation of $CaSO_4$ and CaF_2. However, the concentration of fluoride, SO_X and HCl in flue-gases is not necessarily related to the level of CaO in the raw materials and also depends on the firing temperature and the presence of water vapour during the firing process [23, TWG 2005]

Additives are used to improve the product properties (e.g. to reduce efflorescence or increase compressive strength) [33, Ramboll 2019]. Organic compounds, phosphates and soda are used as plasticisers for argillaceous raw materials. Foamed polystyrene, paper-binding agents, sawdust, coal and inorganic materials such as kieselguhr and perlite are used ~~needed~~ as pore-forming agents. Engobe, used for surface treatment, is often made of white-burning clay, fluxing agents or colouring oxides. Glazes~~ing~~ consist~~s~~ of batch materials mixtures (e.g. Al_2O_3, quartz flour, chalk, $MgCO_3$), fluxing agents, clay and colouring oxides or frits.

Raw materials are stored in the open air or in storage sheds, large-volume feeders, tempering silos, ageing and souring facilities or dry material silos. In many cases, the brickyards are situated ~~at~~ close ~~range~~ to the quarries of the raw materials.

2.3.1.2 Preparation of raw materials

Dry preparation and semi-wet preparation are applied in the manufacture of tiles and bricks; very rarely the dry process route is selected. The preparation method is selected ~~because of~~based on the available materials, the quality specification of the final product, the method of shaping and the economic efficiency.
Dry preparation is mainly employed where relatively dry raw materials of lower plasticity are used or if high-grade products are specified. The purpose of dry preparation is to reduce the particle size in hammer or suspended roller mills and to dry the particles to about ~~three~~ 3-6 % ~~to six per cent~~ water content at the same time. The necessary additives are also added in this process step, e.g. hydrated lime may be added to the clay (~~3.3 to~~ 0.6-3.3 %) to regulate and fix the water content and to maintain a good plasticity in order to facilitate the cutting of the clay column in the extrusion-type process. Dry preparation is ~~given preference~~ preferred in engineering or facing brick manufacture, because facing brick raw materials such as schistous clay have a low pit moisture level, making them particularly well suited for this preparation method.

A second preparation method in the manufacture of bricks and roof tiles is the semi-wet preparation process. Proportioning is carried out by large volume feeders. Volume feeders permit a bulk load and dosification ~~a proportion~~ of several raw materials. In many cases, mixing water is added to the batch at the end of the feeder until the water content is around 20 %. Step-by-step crushing of the hard materials results in a maximum particle size of less than 1.8 mm. Thin products such as roof tiles have a particle size of between 0.5 mm and 0.8 mm. Depending on the characteristics of the raw materials, either clay crushers, knife crushers, double roll crushers or wet pan mills are used. Sand can sometimes be prepared and added separately; jaw crushers, impact crushers, vertical impact crushers and screens are used for this purpose. In some cases, sand and clay are stored separately and mixed just before shaping.

The combined processes of mixing and kneading bring about a homogenisation of the mass to obtain a good plasticity. A clay shredder, double shaft mixer, screen kneader and filter mixer are employed for this purpose. Organic and inorganic pore-forming agents are added in the manufacture of bricks with a low thermal conductivity to reach a large pore volume. In this process step, the mass ~~receives~~ obtains the final shaping water content of 20-22 %. Hot water or hot steam supports the dissolving and opening up of small particles in the mixing process.

For a variety of products (e.g. bricks, porous clay blocks), pore-forming agents (e.g. paper sludge, sawdust, polypropylene) are added to the raw material mix to create fine or coarse pores during the firing process. The mixing contributes to the dispersion of these pore-forming agents.

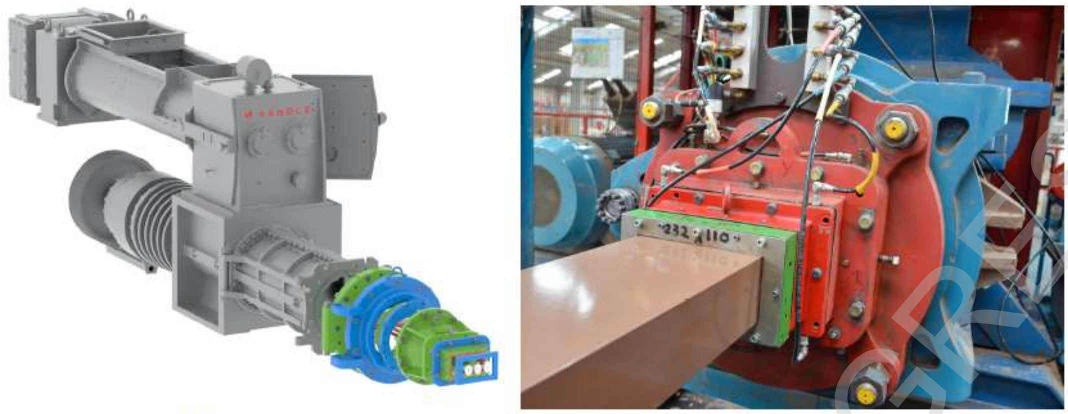
The prepared masses are stored in large volume feeders, clay silos, tempering silos, ageing and souring facilities for further homogenisation.

2.3.1.3 Shaping

Different shaping methods such as pressing, extrusion, and soft-mud moulding (see Sections 2.2.4.2, 2.2.4.3 and 2.2.4.4) are employed, depending on the kind of mass, the water content and the desired product.

In the manufacture of bricks, the extrusion process with subsequent division of the green ware by means of a razor-sharp wire is generally used. The clay is fed from the mixer into a vacuum chamber through which air is removed from the clay. The clay is then forced via a corkscrew-shaped auger through a mouthpiece and extrusion die. The extruder is usually fitted with perforation bars, which produce the characteristic perforations seen in extruded bricks [33, Ramboll 2019]. Figure 2-16 shows a brick extruder and an extruded brick cutter [40, BrickUK 2017].

[Note to the TWG: please provide pictures from plants within the EU]



Extruder

Clay being extruded

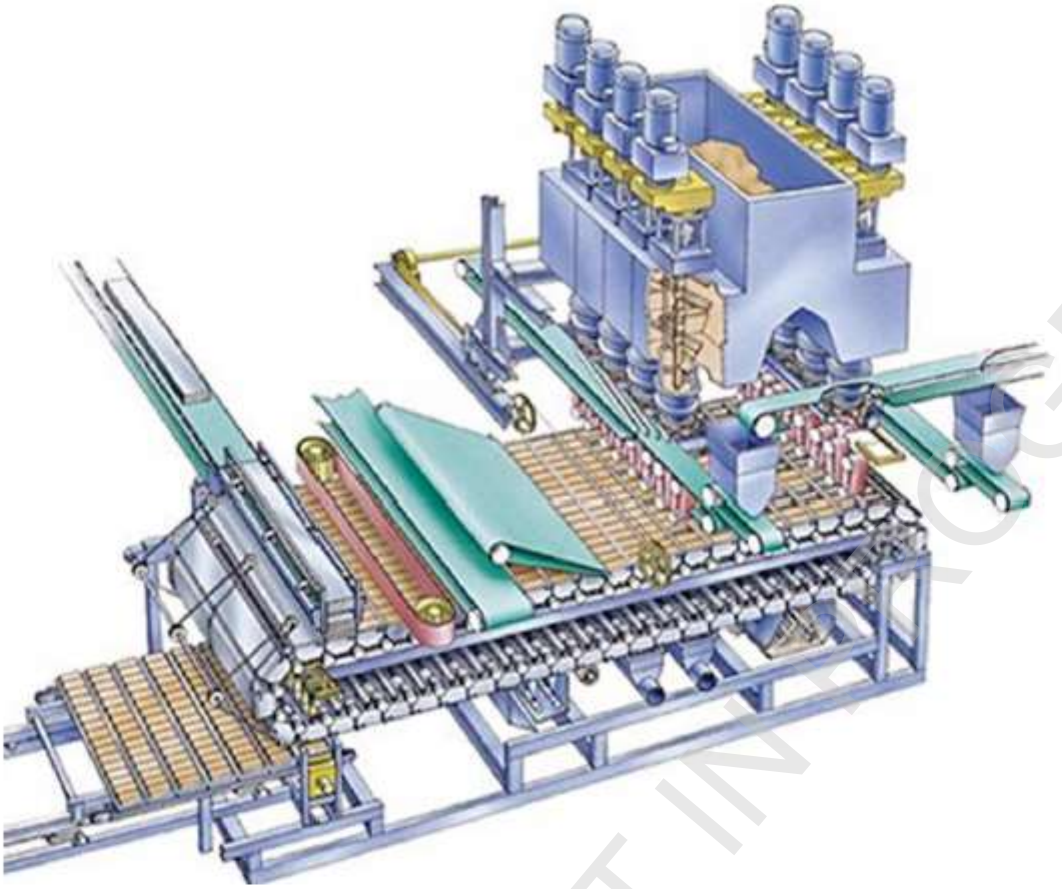
Brick Cutter

Source: [40, BrickUK 2017]

Figure 2-16: Brick extruder and cutter

Soft mud bricks are produced with very soft clay with a high percentage of water, typically 25-30 %. The clay is either ‘pressed’ into a sanded mould box or ‘thrown’ by vertically extruding small pre-sanded clots of clay, which are then accelerated downwards into the mould. Any excess material is automatically trimmed and reused. Modern soft mud machines are capable of manufacturing in excess of 40 000 bricks per hour. A schematic view of a soft moulding machine is given in Figure 2-17.

[Note to the TWG: please provide (schematic) pictures for this topic from plants within the EU]



Source: [40, BrickUK 2017]

Figure 2-17: Schematic view of a soft moulding machine

For the production of roof tiles, the extrusion process and the cutting of columns into individual preforms are followed by stamp or revolver pressing for final shaping into moulds made of gypsum. For beaver tiles (flat tiles), only the extrusion process is applied [33, Ramboll 2019], [40, BrickUK 2017].

~~In practice, the semi-wet prepared raw material is predominantly shaped in presses. The mass is pressed under a pressure of between 0.6 and 1.5 MPa in extrusion presses with or without a vacuum chamber. The die forms the mass into a column. The column is cut into single pieces by a wire cutter. This is the typical processing method in building brick and extruded roof tile production.~~

Pressed roof tiles are manufactured by forming so-called cakes or lumps first. Following this step, the cakes are shaped in another press to the correct geometry. Mechanical and hydraulic revolver presses, anvil presses, swivel beam presses and turntable presses are employed for this purpose. Single- or multiple-mould revolver presses are most commonly used. In revolver presses, an intermittently rotating drum in the form of a five-, six- or eight-sided prism carries a bottom press mould on each of its sides. Each time the drum pauses, the vertical plunger, which carries the top mould, descends into the bottom mould located directly underneath and presses the clot of clay into shape. Following this step, the ware is placed on a special carrier. Different types of open moulds are used, such as plaster moulds, lubricated cast iron moulds, rubber-lined moulds or metallic moulds with vulcanised rubber lining.

The visible surface of roof tiles is partially engobed or glazed. Bricks and facing bricks are treated by profiling, peeling, brushing or sanding to create surface textures. Occasionally, engobing of facing bricks is applied.

2.3.1.4 Drying~~, glazing and engobing~~

Different types of dryers operate in the drying process (see Section 2.2.5), depending on the amount of work, the degree of mechanisation and the sensitivity of the mass. In the manufacture of bricks, chamber and tunnel dryers are usual. In the manufacture of roof tiles, chamber dryers and tunnel dryers are also used. In tunnel and fast dryers, the conditions for drying bricks are between less than 8 hours up to 72 hours at a temperature of approx~~.~~imately 75-90 ºC. Fast dryers operate ~~at~~ for significantly shorter periods of less than 8 hours for blocks~~,~~; some facing bricks take up to 72 hours. In chamber dryers the drying period for bricks lasts up to 40 hours at a temperature of approx~~.~~imately 90 ºC [23, TWG 2005], [30, TWG 2005]. Roof tiles are dried in tunnel dryers or chamber dryers at a temperature of 60-90 ºC in 12 to 48 hours. ~~The water content of the ware before the firing process in a tunnel kiln is lower than three per cent.~~ Dryers are heated mainly by excess heat from the kiln and, in some cases, by natural gas or fuel oil burners or cogeneration. The water content of the ware before the firing process in a tunnel kiln is lower than 3 % [56, COM 2023].

2.3.1.5 Glazing and engobing

[Note to the TWG: the text below was part of Section 2.3.1.4 in the 2007 CER BREF. The numbering of the following sections has been updated]

Roof tiles and facing bricks are sometimes glazed and engobed on the visible surface or on the whole surface to achieve special colours or to increase the density of the product. Glaze and engobe are applied to the body after the drying process. In some cases, glazing and engobing ~~is~~ are carried out after the shaping process.

Engobe is a composition made of clay, fluxing agents, filling material and pigments. The best process to apply larger quantities to the ware is by spraying. Organic binding agents are added to the engobe to achieve a better binding between the fluid engobe and the treated surface.

Glaze is a mixture of batch materials mixtures (Al_2O_3, quartz flour, chalk, $MgCO_3$), fluxing agents, clay and colouring oxides or frits, which are sintered to a vitreous mass. The glaze is usually applied by spraying in a spray chamber.

2.3.1.6 Firing

Today, bricks and roof tiles are mainly fired in tunnel kilns ~~mainly~~ in an oxidising atmosphere. A reduction period in the final firing sector causes special colour effects if needed. In the reduction period, the fuel is supplied to an oxygen-deficient atmosphere. In this way, the raw materials used generate the desired colour effects on the brick products.

The ware to be fired passes through the kiln on a series of kiln cars. Green bricks are placed directly on the tunnel kiln car, while green roof tiles are piled up for the firing process in the classic tunnel kiln in cassettes (H-form or U-form). The setting of the cassettes depends on the specific product to guarantee an optimal flow of the hot firing gases around the product and to consequently achieve a good firing result. The ware to be fired is heated up to a maturing temperature of between 800 ºC and 1 300 ºC.

Following the necessary body formation time of between ~~two~~2 and ~~five~~5 hours at maturing temperature, the ware is cooled down according to plan to 50 ºC.

The firing time of roof tiles in tunnel kilns is between 10 and 40 hours, paving bricks are fired, for 45 to 60 hours and clay blocks 17 to 25 hours. The flue-gas temperature depends on the dew point (and thus on the composition) of the flue-gas, e.g. for clays with a high sulphur content, the dew point will be higher and the flue-gas temperature will be higher. ~~The following table~~ Table

2.3 shows ranges of operating data of classic tunnel kilns [4, UBA 2001], [23, TWG 2005], [27, VDI 2004], [21, Almeida, M., Vaz, S., Baio, D. 2004], [30, TWG 2005].

Table 2.3: Operating data of tunnel kilns

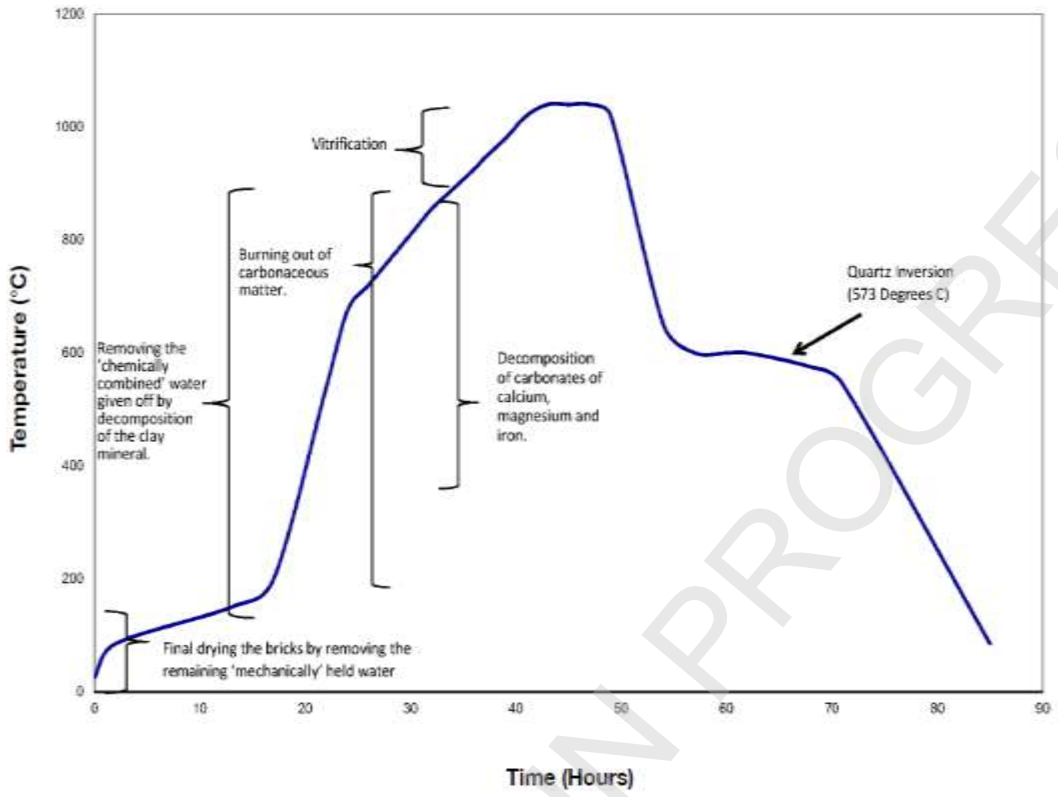
~~Tunnel kilns~~	~~Unit~~	~~Facing bricks and clay pavers~~	~~Clay blocks~~	~~Horizontally perforated clay blocks~~	~~Roof tiles~~
~~Throughput~~	~~t/h~~	~~1 – 15~~	~~3 – 15~~	~~3 – 15~~	~~3 – 6~~
~~Kiln length~~	~~m~~	~~35 – 160~~	~~60 – 120~~	~~60 – 120~~	~~80 – 140~~
~~Cross-section~~	~~m^2~~	~~1.3 – 6.0~~	~~4 – 12~~	~~4 – 12~~	~~4 – 10~~
~~Setting density~~	~~kg/m^3~~	~~650 – 1500~~	~~350 – 500~~	~~250 – 750~~	~~200 – 400~~
~~Firing temperature~~	~~ºC~~	~~1000 – 1300~~	~~900 – 1050~~	~~950 – 1050~~	~~1000 – 1150~~
~~Specific energy requirement (drying + firing)~~	~~kJ/kg~~	~~1600 – 3000~~	~~1000 – 2500*)~~	~~1000 – 2500~~	~~1600 – 3500~~
~~Flue-gas volume flow~~	~~m^3/h~~	~~5000 – 20000~~	~~10000 – 50000~~	~~10000 – 50000~~	~~10000 – 40000~~
~~Flue-gas temperature~~	~~ºC~~	~~100 – 230~~	~~100 – 300~~	~~100 – 150~~	~~170 - 200~~

~~*) Including heat content of the pore-forming agent~~

Tunnel kilns	Unit	Stoneware (pipes/ fittings)	Facing bricks, paving stones	Lining bricks	Roof tiles	Magnesite bricks	Fire-clay bricks	Abrasives
Capacity	t/d	24-144	24-195	72-600	72-290	16-72	72-177	2.4-9.6
Kiln length	m	80-180	80-125	60-120	80-140	100-150	80-120	50-100
Setting density	kg/m^3	150-400	650-1 500	350-1 200	200-500	1 000-2 500	600-1 500	1 500-3 000
Firing temperature	°C	1 100-1 200	1 000-1 250	850-1 050	1 000-1 060	1 600-1 760	1 200-1 300	900-1 300
Specific energy requirements (^{a})	kJ/kg	3 000-4 000 (^{b}) 7 000 (^{c})	1 600-3 000	1 500-2 000	2 000-3 200	9 700	3 200	9 500-13 400
Waste gas volumetric flow (^{d})	m^3/h	4 000-18 000	5 000-20 000	10 000 - 50 000	10 000 - 50 000	15 000-25 000	8 000-15 000	7 000-15 000
Waste gas temperature	°C	160-200	140-200	100-200	140-200	250-400 $^{e)}$	1 500-2 000	100-250

(^{a}) Energy requirements for drying and firing.
(^{b}) Pipes of up to 600 mm in diameter.
(^{c}) Pipes of 600 mm in diameter and greater, up to approximately 1 400 mm in diameter.
(^{d}) Gas volume under standard conditions.
(^{e}) Operation without heat utilisation.
Source: [52, VDI 2018]

Classic tunnel kilns are mainly heated with natural gas or fuel oil, and fast firing kilns are heated with natural gas. In some cases coal, as mentioned above, petroleum coke and peat are also used. An ideal time-temperature profile for brick firing kilns is given in Figure 2-18 [40, BrickUK 2017].



Source: [40, BrickUK 2017]

Figure 2-18: Ideal time-temperature profile for brick firing kilns

The fast firing method in roller hearth kilns is an alternative to the classic tunnel kiln firing technology. With the introduction of single rack flat firing for the manufacture of roof tiles, the firing time was reduced and the mass-ratio of firing auxiliaries to the ware to be fired was reduced. This method partially allows a reduction of the energy consumption in the firing process in some cases.

The fast firing method is performed in smaller kiln units – as opposed to the large classic tunnel kilns. The smaller units allow a greater flexibility in the adaptation of firing parameters to the actual product. The setting density of fast firing kilns can be below 100 kg/m^3. ~~The following table~~ Table 2.4 shows some data, referring to roof tiles, of classic tunnel kilns and fast firing methods [4, UBA 2001].

[Note to the TWG: please provide information to update the information below, especially on the fast firing method]

Table 2.4: Comparison of classic tunnel kilns and fast firing methods (roof tiles)

Type of kiln	Mass-ratio firing auxiliaries/fired ware	Firing time (h)
Classic tunnel kiln	~~6:1~~	~~~50~~
Precision fast firing kiln	~~3:1~~	~~~10~~
Keramono single rack kiln	~~1:1~~	~~~2~~
Roller hearth kiln	~~0:1 to 2:1~~	~~3 to 8~~
Source: [9, COM 2007]		

The applicability of the fast firing method in the manufacture of bricks and roof tiles depends substantially on the specific surface of the product and the possibility of perfusion by hot firing gases. Not only roof tiles~~,~~ but also clay blocks such as honeycomb bricks can be produced using the fast firing method. ~~The following table~~ Table 2.5 shows ranges of operating data of fast firing tunnel kilns [4, UBA 2001], [23, TWG 2005].

[Note to the TWG: please provide information to update the table below]

Table 2.5: Operating data of fast firing tunnel kilns

Fast firing tunnel kilns	Unit	Clay blocks	Facing bricks	Pressed roof tiles
Throughput	t/h	16.60 – 18.75	2.1 – 5.4	1.9 – 5.4
Kiln length	m	130	90 – 120	80 – 125
Cross-section	m^2	to 17.6	to 3.5	to 3.3
Setting density	kg/m^3	n.a.	n.a.	n.a.
Firing temperature	°C	1000	1000 – 1080	1020 – 1150
Firing time	h	2.5 – 3.5	4 – 5	3 – 4
Specific energy requirement (drying + firing)	kJ/kg	1250 – 3500	1590 – 4500	2930 – 4605

Source: [9, COM 2007]

For the manufacture of specialised products, for example hand-formed and special coloured facing bricks, Hoffmann kilns are also used. ~~These consist of a series of linked chambers, which are sequentially filled with dried bricks, sealed, fired quasi continuously and the hot gases are drawn from one chamber to the next. This connecting system, with flues and holes between the chambers, also allows the preheating of the ware and the cooling of the flue-gases. One firing cycle takes usually between three days and two weeks and the setting densities in the linked chambers are more than 300 kg/m³. The kilns are now mainly gas fired, but top feeding with oil or coal is occasionally practised and produces bricks with ageing effects~~ [17, Burkart, M. 2004], [23, TWG 2005].

Intermittent kilns can be used to produce specialised roof tiles, bricks or fittings, typically for smaller batches. Such kilns are operated discontinuously and have firing times of between 20 and 45 hours, firing temperatures of between 1 000 °C and 1 100 °C, and specific energy requirements of around 500-900 kJ/kg [23, TWG 2005].

2.3.1.7 Subsequent treatment

Depending on the result of the firing process, the products are sorted during the unloading of the kiln or the tunnel kiln car automatically or manually. Products such as calibrated bricks are treated in grinding machines.

Sometimes treatment of clay facing bricks, clay roof tiles or fittings with hydrophilic or hydrophobic agents (e.g. siliconising, lanolising) is applied, which changes the behaviour of their surface when wetted by water.

For facing bricks, a final finishing firing step is applied to certain products in intermittent kilns where Fe^{3+} is reduced to Fe^{2+} changing the colour of the product from red to black. This process takes place at 700-750 °C at low oxygen levels [56, COM 2023].

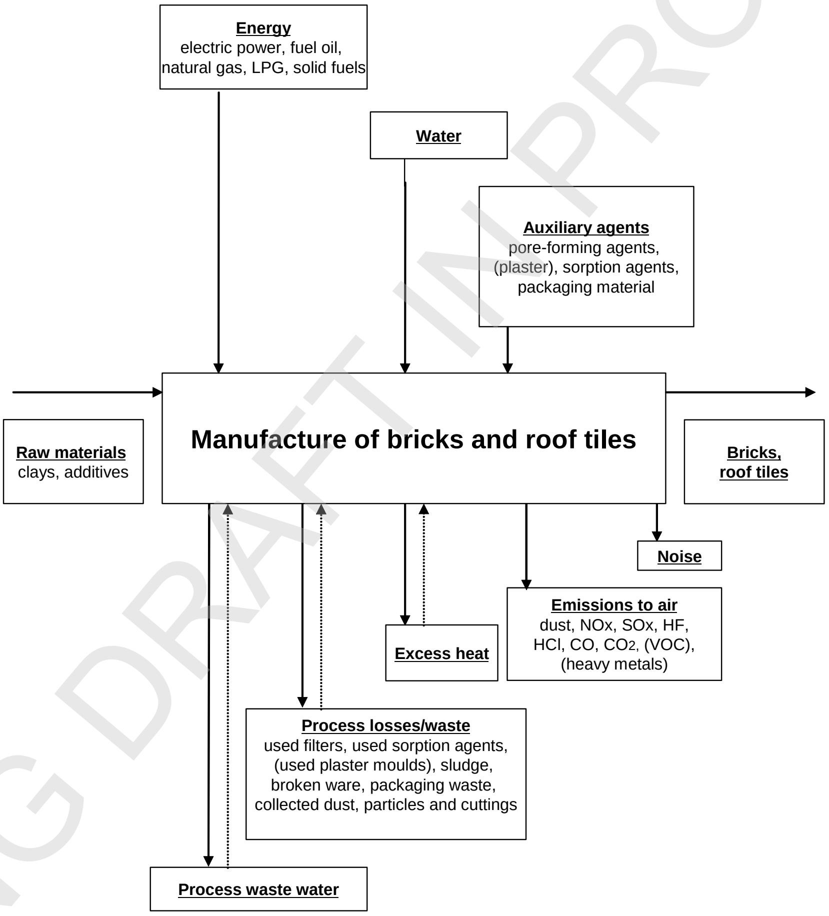
Some clay blocks are filled with mineral wool to improve isolation properties [38, COM 2022].

Roof tiles are packed and palletised for transportation to a shipping unit. A layer of paper, cardboard or wooden veneer is placed between each layer of tiles, and full pallets are shrunk in or wrapped in tight-pack film. The products are handled by forklifts, mobile and portal cranes.

~~2.3.1.7 Input and output flows in the manufacture of bricks and roof tiles~~

[Note to the TWG: this Section (2.3.1.7 of the CER BREF2007) has been merged with Section 2.3.1]

~~Important input and output flows of the brick and roof tile manufacturing process are presented in the following figure [4, UBA 2001], [23, TWG 2005].~~



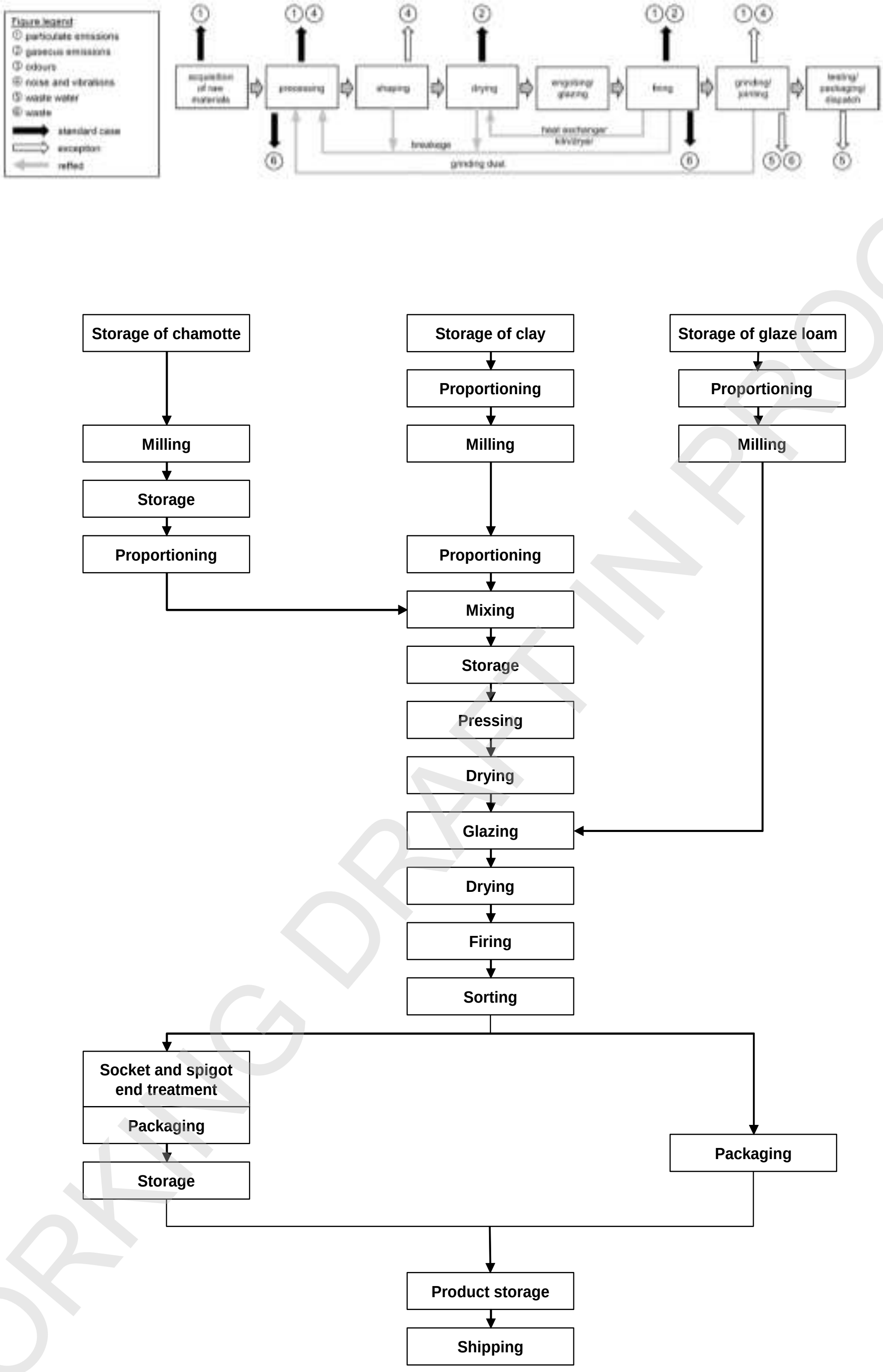
Source: [9, COM 2007]

~~Figure 2 20:Input and output flows in the manufacture of bricks and roof tiles~~

2.3.2 Vitrified clay pipes

Vitrified clay pipes are manufactured using the following process steps: storage of raw materials, preparation of raw materials, shaping, drying, glazing, firing and subsequent treatment. ~~The~~

~~following figure~~Figure 2-19 shows a schematic view of the manufacture of vitrified clay pipes [4, UBA 2001].

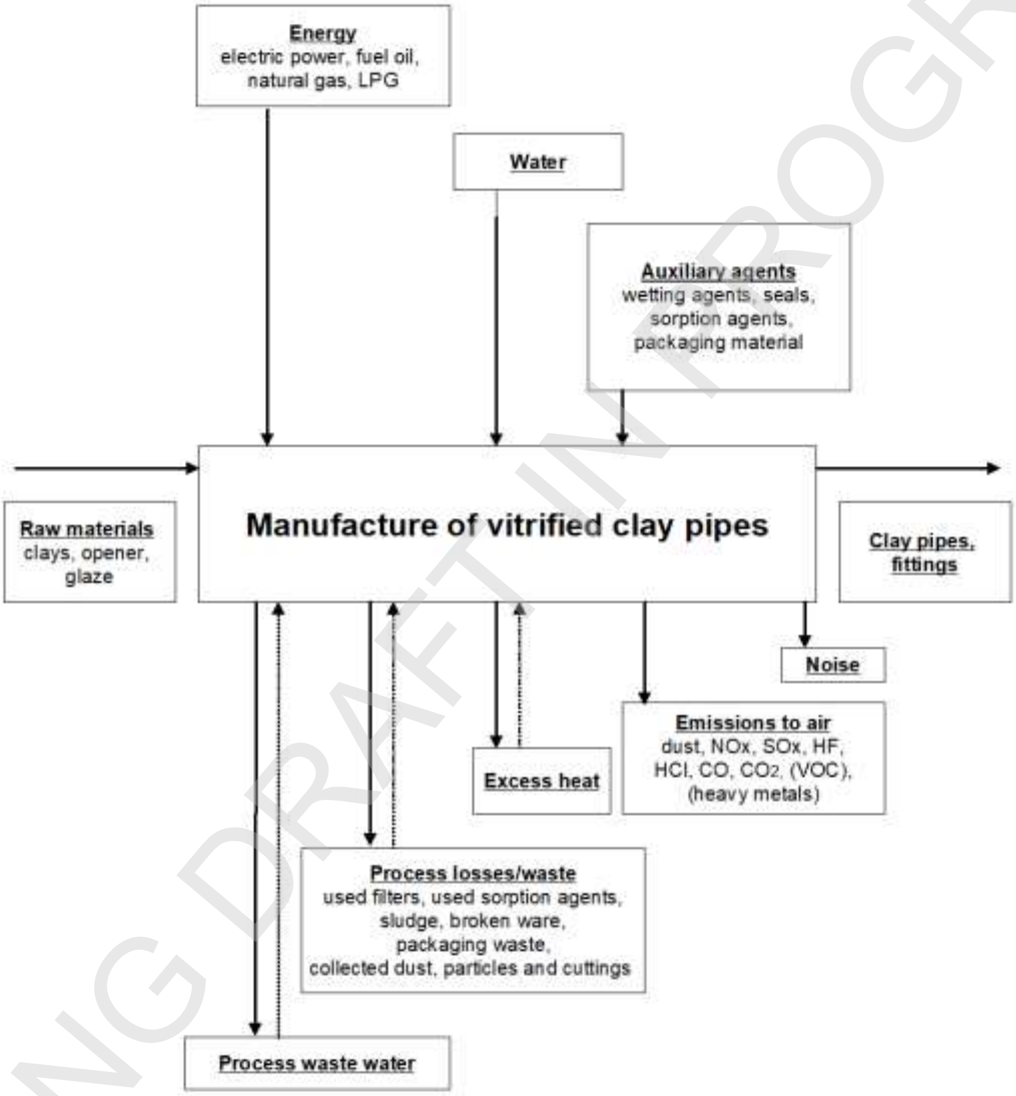


Source: [52, VDI 2018], [9, COM 2007]

Figure 2-19: Schematic view of the manufacture of vitrified clay pipes

[Note to the TWG: this section has been moved from Section 2.3.2.7 of the 2007 CER BREF]

Important input and output flows of the vitrified clay pipe manufacturing process are presented in ~~the following figure~~ Figure 2-20 [9, COM. 2007].



Source: [9, COM. 2007]

Figure 2-20: Input and output flows in the manufacture of vitrified clay pipes

2.3.2.1 Raw materials

Clay, chamotte and glaze are employed as raw materials in the manufacture of vitrified clay pipes. To ensure the stability of the pipe wall during production and use, the clays selected as raw materials do not contain gypsum. Glaze consists of a mixture of loam, clay, chalk, dolomite, quartz and metal oxides. Chamotte raw materials~~,~~ mainly consist~~ing~~ of reused material from the ceramic production process~~,~~. Depending on the preparation process, the clay components are stored in the open air or in boxes. Chamotte raw materials and loam for the glaze are stored under a roof. ~~Depending on the preparation process, the clay components are stored in the open air or in boxes.~~

Table 2.6 and Table 2.7 show typical ~~the~~ ranges of mineralogical and chemical compositions of clays used in the manufacture of vitrified clay pipes [3, Ceram-Unie 2003].

[Note to the TWG: please provide information to update and complete the information with MS not mentioned in Tables 2.7 and 2.8 below]

Table 2.6: Mineralogical composition of clay in the manufacture of vitrified clay pipes

Parameter (wt-% ~~weight~~)	BE	DE	IT	NL	~~UK~~
Quartz ~~min~~ ~~max~~	24–45	8–25	35–50	40–50	~~21~~ ~~33~~
Feldspar ~~min~~ ~~max~~	11–18	1–4	1–24	~~0~~ ~~0~~	~~0~~ ~~0~~
Kaolinite ~~min~~ ~~max~~	24–32	30–60	5–20	20–25	~~8~~ ~~20~~
Illite ~~min~~ ~~max~~	16–37	10–40	12–30	20–25	~~40~~ ~~56~~
Montmorillonite ~~min~~ ~~max~~	0–8	2–10	0.5–1	~~0~~ ~~0~~	~~0~~ ~~0~~

Source: [9, COM. 2007]

Table 2.7: Chemical composition of clay in the manufacture of vitrified clay pipes

Parameter (wt-% ~~weight~~)	BE	DE	IT	NL	~~UK~~
S ~~min~~ ~~max~~	0.02–0.05	0.0–0.2	0.01–0.62	0.01–0.05	~~0.01~~ ~~0.10~~
F ~~min~~ ~~max~~	0.03–0.05	0.02–0.06	0.04–0.13	0.02–0.04	~~0.02~~ ~~0.05~~
CO_2 ~~min~~ ~~max~~	0.1–0.3	ND	ND	0.05–0.25	~~0.50~~ ~~1.50~~
SiO_2 ~~min~~ ~~max~~	60–81	55–70	60–75	65–72	~~55~~ ~~63~~
Al_2O_3 ~~min~~ ~~max~~	15–27	20–35	15–23	18–23	~~17~~ ~~22~~

Parameter (wt-% ~~weight~~)	**BE**	**DE**	**IT**	**NL**	**~~UK~~**
Fe$_2$O$_3$ ~~min~~ ~~max~~	1.0–7.4	1.0–10	5.0–7.0	1.5–4.5	~~6.0~~ ~~8.0~~
MgO ~~min~~ ~~max~~	0.2–1.0	0.0–1.5	0.7–1.5	0.5–1.4	~~1.7~~ ~~2.2~~
CaO ~~min~~ ~~max~~	ND	0.0–0.8	ND	0.2–0.5	~~0.3~~ ~~0.6~~
Na$_2$O ~~min~~ ~~max~~	0.1–0.3	0.0–0.4	3.0–7.0	0.1–0.6	~~0.3~~ ~~1.1~~
K$_2$O ~~min~~ ~~max~~	1.0–2.6	1.0–4.0	1.0–3.0	1.8–2.6	~~2.8~~ ~~3.9~~
TiO$_2$ ~~min~~ ~~max~~	1.3–1.8	1.0–2.5	0.5–1.0	0.7–1.3	~~0.9~~ ~~1.0~~

NB: ND: No data.
Source: [9, COM. 2007]

2.3.2.2 Preparation of raw materials

Different processes are used for clay preparation, e.g. the slip process. The clay is passed in the required quantities by box feeders into the preparation process. Fine grinding is performed by different types of mills, e.g. wet drum mills and roller mills. Wet drum mills are also used for the fine grinding process of loam glaze components. The components are milled to a fineness of 0.06 mm. Following this step, coarser particles are removed by screening. The fine components are suspended in water and stored in stirred tanks.

Raw chamotte is crushed and milled in jaw crushers, cone crushers, beater mills or ball mills. The fraction with a maximum particle size of 2.5 mm is screened out and stored. Chamotte is used as an opener and provides the mass with the necessary strength and stability during firing. Clay and chamotte fractions are fed to the mixing unit gravimetrically via a conveyor belt and chamotte scales, or volumetrically by box feeders, belt feeders or rotary feeders.

In the mixing unit the components are mixed and watered to an approximate pressing moistness with a water content of between 15 % and 20 %. Organic and inorganic pressing agents and plasticisers are added to the press mass if needed. The prepared, moist mass is stored and homogenised in large volume feeders, clay silos, storage sheds or ageing and souring facilities with adequate mechanisation.

2.3.2.3 Shaping

The green clay pipes are shaped in horizontal and vertical de-airing extruders. The press mass is compressed and de-aired in the de-airing chamber of the extruder followed by the shaping of the pipe and the socket and spigot end. After this step, the socket and spigot end are cleaned.

The pipes are usually extruded with a firing ring (buffer zone) of 20-50 cm. This firing ring is needed because the placing on the drying/kiln cars causes some deformation due to the weight of the pieces. This ring is removed after the firing process [56, COM 2023].

The green pipe bodies are handled by special appliances such as vacuum adhering robots. The robots place the green ware on dryer cars. A speciality of the clay pipe shaping process is the stiffness of the press mass, the different pipe diameters and the periodically operated extruder.

2.3.2.4 Drying ~~and glazing~~

The ~~rupture-free~~ drying of the green ware takes place in chamber or tunnel dryers at temperatures of up to 100 ºC to about ~~two per cent~~ 2 % remaining humidity. The drying time of the fittings is between 70 and 100 hours, the drying time of the pipes is between 30 hours (small pipes) and ~~nine~~9 days (large pipes). Climate control (temperature, humidity) is necessary to avoid distortion of the pipes by unequal shrinkage.

2.3.2.5 Glazing

[Note to the TWG: the text below was part of Section 2.3.2.4 in the 2007 CER BREF. The numbering of the following sections has been updated]

Suitable gripping and holding robots dip the dried green ware into the glaze tank to cover the bodies with loam glaze and also glazing by spraying is possible. In the firing process, the glaze merges with the body surface, encloses it and covers it with a smooth surface. If parts of the surface are not to be glazed, they have to be covered with paraffin before the glazing process.

The glazed green ware is set on tunnel kiln cars. Afterwards, they are finally dried to less than ~~one per cent~~ 1 % remaining moisture in tunnel dryers~~, which are situated in front of the tunnel kilns~~.

2.3.2.6 Firing

Firing takes place in gas-heated tunnel kilns predominantly in an oxidising atmosphere. The green ware is fired in a vertical position fixed on firing auxiliaries. Conventional firing temperatures are between 1 150 ºC and 1 250 ºC~~,~~ and the firing time is between 30 and 80 hours. ~~The following table~~ Table 2.8 presents ranges of operating data of tunnel kilns used for the manufacture of vitrified clay pipes [4, UBA 2001].

Table 2.8: Ranges of operating data of tunnel kilns

~~Tunnel kilns~~	~~Unit~~	~~Vitrified clay pipes~~
~~Throughput~~	~~t/h~~	~~1 – 6~~
~~Kiln length~~	~~m~~	~~80 – 180~~
~~Cross-section~~	~~m²~~	~~6 – 10~~
~~Setting density~~	~~kg/m³~~	~~150 – 300~~
~~Firing temperature~~	~~ºC~~	~~1100 – 1200~~
~~Specific energy requirement (drying + firing)~~	~~kJ/kg~~	~~3000 – 4000~~
~~Flue-gas volume flow~~	~~m³/h~~	~~4000 – 18000~~
~~Flue-gas temperature~~	~~ºC~~	~~160 – 200~~

Tunnel kilns	**Unit**	**Stoneware (pipes/fittings)**
Capacity	t/d	24-144
Kiln length	M	80-180
Setting density	kg/m³	150-400
Firing temperature	°C	1 100-1 200
Specific energy requirements (a)	kJ/kg	3 000-4 000 (b) 7 000 (c)
Waste gas volumetric flow (d)	M³/h	4 000-18 000
Waste gas temperature	°C	160-200

(a) Energy requirements for drying and firing.
(b) Pipes of up to 600 mm in diameter.
(c) Pipes of 600 mm in diameter and greater, up to approximately 1 400 mm in diameter.
(d) Gas volume under standard conditions.
Source: [52, VDI 2018]

An alternative to the conventional firing process is the fast firing method ~~of vitrified clay pipes~~. ~~Vitrified clay pipes are dried in ten hours and glazed by spraying. Then t~~They pass through the kiln for a period of ~~eight~~8 hours. The pipes are fired while they are moved by horizontal rolling. Fittings, e.g. branches and arcs, are also manufactured in the fast firing process. Similar to the fast fired pipes, they pass through the roller hearth kiln in a period of ~~eight~~8 to ~~eleven~~11 hours. Transport of the fittings takes place on special firing auxiliaries which are moved back in a cycle below the kiln.

2.3.2.7 Subsequent treatment

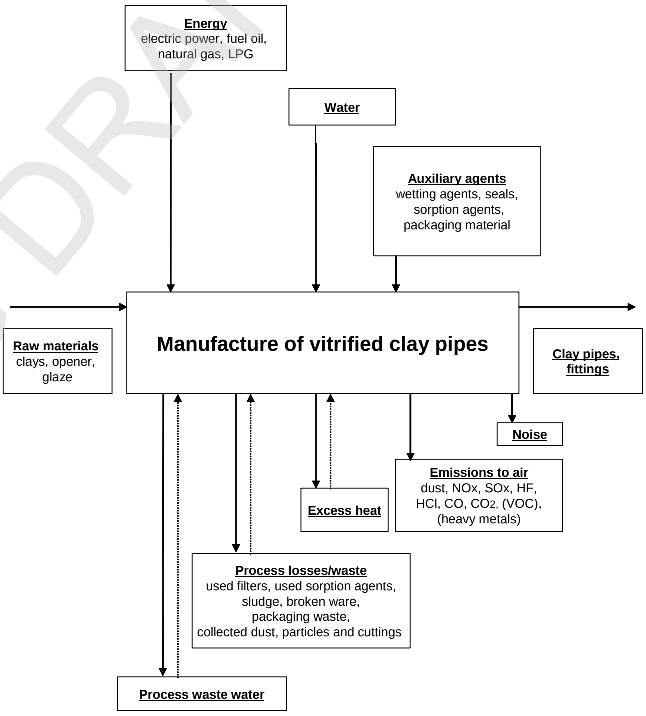
Following the firing process all products are inspected. Polymer seal elements or prefabricated seals are added to the socket and spigot end if necessary. After this step, the pipes and fittings are packed.

After attaching the seal elements, pipes with a certain dimension (DN 250 to DN 600) are treated by grinding to guarantee high precision of the socket and spigot ends.

~~2.3.2.8 Input and output flows in the manufacture of vitrified clay pipes~~

[Note to the TWG: this Section (2.3.2.7 of the CER BREF2007) has been merged with Section 2.3.2]

~~Important input and output flows of the vitrified clay pipe manufacturing process are presented in the following figure [4, UBA 2001], [23, TWG 2005].~~



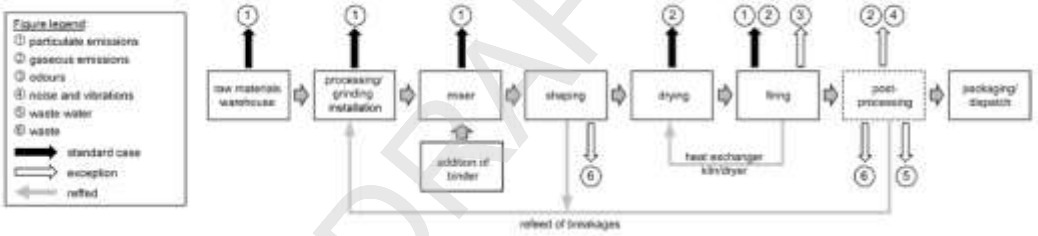
~~**Figure 2 23: Input and output flows in the manufacture of vitrified clay pipes**~~

2.3.3 Refractory products

Refractory products are classified according to their principal constituent. The main groups are:

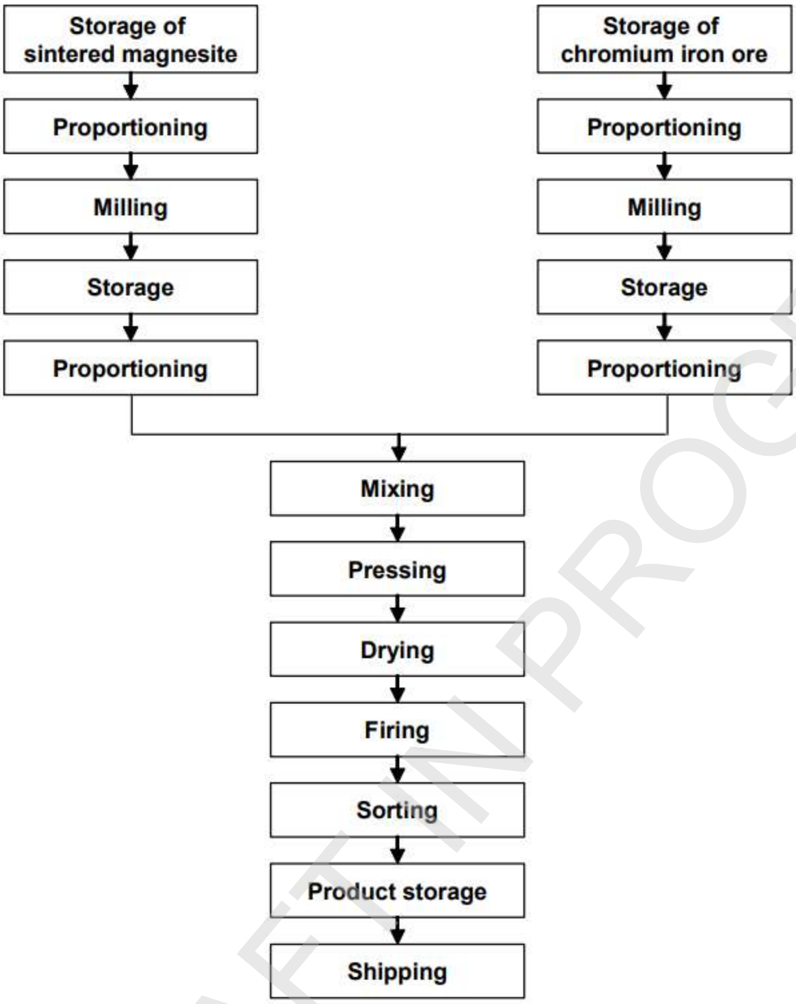
- high-alumina products, group 1 ($Al_2O_3 > 56$ %);
- high-alumina products, group 2 (45 % < $Al_2O_3 < 56$ %);
- fireclay products (30 %-< $Al_2O_3 < 45$ %);
- low-alumina fireclay products (10 % < $Al_2O_3 < 30$ %, $SiO_2 < 85$ %);
- siliceous products or semi-silica products (85 % < $SiO_2 < 93$ %);
- silica products ($SiO_2 > 93$ %);
- basic products, based on magnesia, magnesia-chrome, chrome-magnesia, chromite, forsterite, dolomite;
- special products, based on carbon, graphite, zircon, zirconia, silicon carbide, carbides (other than silicon carbide), nitrides, borides, spinels (other than chromite), fused-lime.

Various methods are employed by the refractory industry in the manufacture of bricks. The simplest procedure is to saw shapes from natural or artificially produced raw materials. Fusion cast products are manufactured by casting melts in moulds in order for the melt to solidify into blocks or bricks. Highly refractory materials are nowadays manufactured increasingly by fine crushing and wet mixing and afterwards the refractory materials are formed by means of extrusion, slip casting or isostatic pressing. However, the so-called heavy clay ceramic method is now preferred for the manufacture of refractory bricks. The production process passes the stages storage of raw materials, raw materials preparation, shaping, drying, firing and subsequent treatment. Figure 2-21 ~~The following figure~~ shows a schematic view of the manufacture of ~~basic bricks containing chromium ore [4, UBA 2001]~~ refractory products [52, VDI 2018].



Source: [52, VDI 2018]

Figure 2-21: Schematic view of the refractory making process

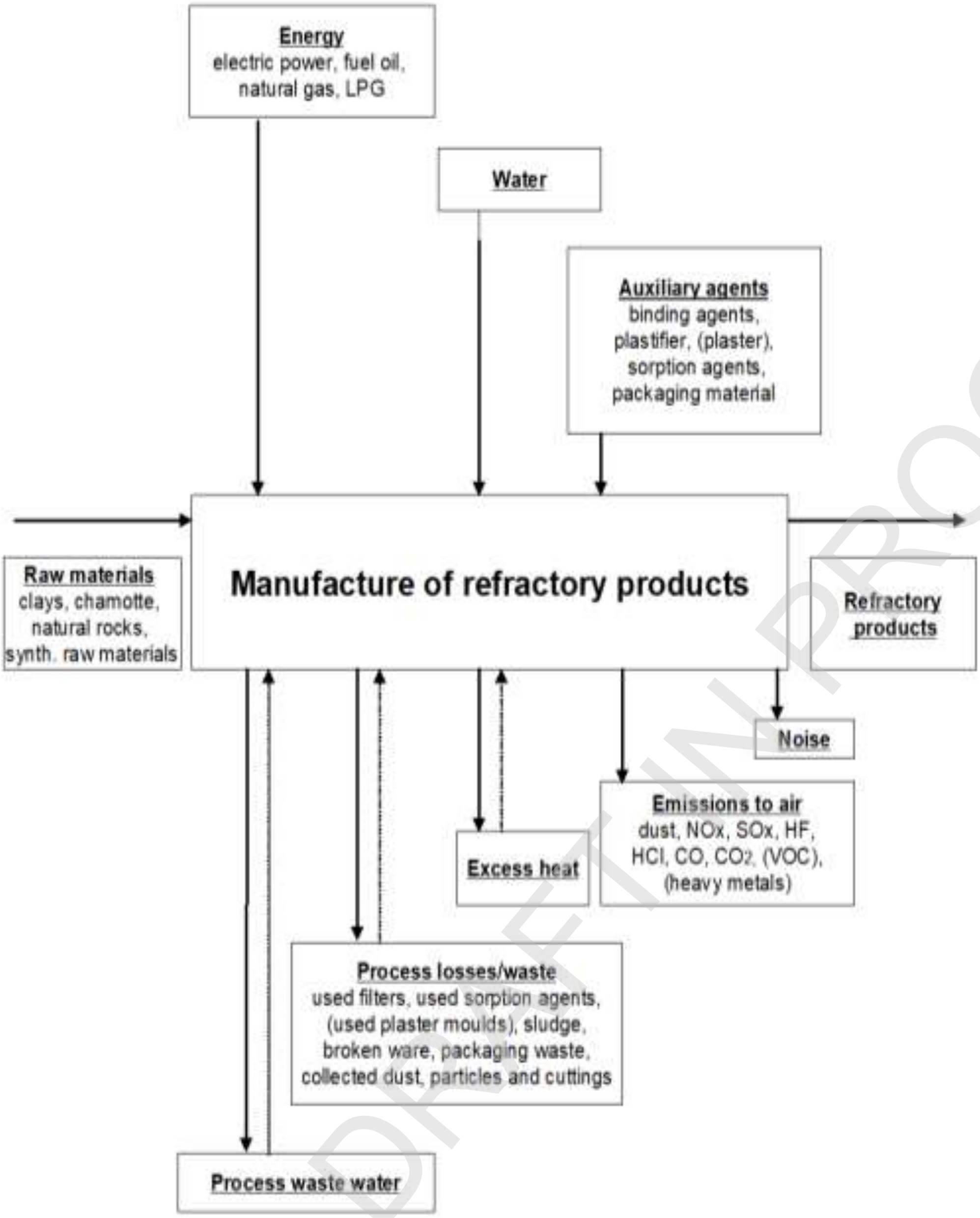


Source: [9, COM 2007]

Figure 2-22: Schematic view of the manufacture of basic bricks containing chromium ore

[Note to the TWG: this section has been moved from Section 2.3.3.8 of the CER BREF 2007]

Important input and output flows in the manufacture of refractory products are presented in Figure 2-23 ~~the following figure~~ [4, UBA 2001], [23, TWG 2005].



*Sourc*e: [9, COM 2007]

Figure 2-23: Input and output flows in refractory manufacture

2.3.3.1 Raw materials

Clay, chamotte and natural rocks such as quartzite, dolomite, magnesite and bauxite, which can be calcined (see Section 2.2.2.8), and also synthetic base materials such as~~, e.g.~~ sintered corundum, silicon carbide, fused mullite or spinel~~,~~ serve as raw materials for refractory products. In order to produce compressible masses, binders and aggregates are added to the milled raw materials. There are very different types of binders and aggregates used such as clay slip, sulphite lye, coal tar pitch, naphthalene, synthetic resin, milk of lime, wax, phosphoric acid, soot, graphite and sulphur. The raw materials are stored in roofed boxes. Pre-crushed delivered raw materials are stored in silos to avoid a reaction between water and raw materials.

~~The following table~~ shows the most commonly used oxides in melting/casting operations for refractory products with their corresponding melting temperatures [3, Ceram-Unie 2003]

Table 2.9: Most commonly used oxides in melting/casting operations

Name	Formula	Melting temperature (ºC)
Alumina	Al_2O_3	2050
Chromium(III) oxide	Cr_2O_3	2275
Magnesia	MgO	2830
Dolomite	$CaO + MgO$	2700
Silica	SiO_2	1725
Zirconia	ZrO_2	2700
Zircon	$ZrSiO_4$	1770
Source: [9, COM 2007]		

2.3.3.2 Preparation of raw materials

Raw materials are mostly crushed in a coarse and then a fine crushing process. Coarse crushing is performed by jaw crushers, impact crushers, roller crushers and cone crushers. Fine grinding is carried out in ring-roll mills, ball mills and vibratory mills. The crushed and milled raw materials are classified in different fractions by vibration screens. Oversized material is fed back to the milling units. The fractions are stored temporarily in silos, which are depots between the preparation step and the brick production. Proportioning is carried out using weighing scales. Binders, pore-forming agents, antitack agents and mould lubricants are added if necessary. The components are fed into mixers (mainly in periodically operated mixers), homogenised and pre-densified. Muller mixers, counterflow mixers and double shaft pug mills have proved satisfactory.

Casting slip is produced by mixing the raw materials with a dispersing agent such as water. ‘Dust pressing powder’ is manufactured in a dry process or in a wet or semi-wet process followed by spray drying.

2.3.3.3 Shaping

Casting slip and ‘dust pressing powder’ are employed in the shaping process. The casting slip is ~~filled~~poured into moulds in the casting process. After adequate body formation time, the green ware is removed from the mould.

~~Formerly, ‘dust pressing powder’ was formed into the desired shape by toggle presses. These days~~, ~~toggle presses have been replaced~~ ‘Dust pressing powder’ is formed into the desired shape by hydraulically operated presses equipped with modern electronic control units. The presses continuously check the bricks and make adjustments if required. A specific press force of 80 MPa to 200 MPa is standard today. Using the different press programmes, refractory bricks can comply with customers’ requirements.

The isostatic pressing method ~~has been accepted~~ is applied for the manufacture of high-quality special refractory products. In this method, flexible plastic moulds are filled with a fine ceramic powder mix. After closing the mould, the mix is subjected to pressure usually in a hydraulic autoclave. The pressure is applied uniformly in all directions to the pressed shape via a compressive liquid, so that uniform densification is achieved. Pressures of up to 300 MPa are applied to manufacture large ~~sized~~ blocks and special shapes with this process.

Various grades of ceramic mixes can be compacted to shapes with relatively low pressure in conjunction with mechanical oscillations created by vibrators. ~~Recently, t~~ The traditional shaping process has been supplemented by a ~~new~~ process where~~. T~~ the mixes to be shaped are mixed with a binder sensitive to cold. Next, the mixes are poured into moulds and harden at temperatures of below -30 °C.

2.3.3.4 Drying

Some raw materials for refractory products are not mixed with water before shaping, so drying is not always necessary [38, COM 2022].

The drying process takes place in chamber or tunnel dryers and lasts, depending on the size of the bricks, between ~~one~~ 1 day and several weeks. Large shapes are dried under controlled humidity of the drying air. The remaining moisture should be less than ~~one per cent~~1 % before the firing process starts. ~~The following table~~ Table 2.10 presents examples of operating data of periodically operated dryers, the significance of which is decreasing in the refractory industry [4, UBA 2001].

[Note to the TWG: please provide information to update Tables 2.10 and 2.11 below]

Table 2.10: Operating data of periodically operated dryers (chamber dryers)

Chamber dryers	Unit	Fireclay products	Silica products
Throughput	t/cycle	18	10
Drying chamber volume	m^3	171	56
Setting density	kg/m^3	105	180
Drying temperature	°C	80	100
Drying time	h	44	24
Specific energy requirement	kJ/kg	350	300
Flue-gas volume flow	m^3/h	1 600	15 000
Flue-gas temperature	°C	60	60

Source: [9, COM 2007]

~~The following table~~ Table 2.11 shows the operating data of two tunnel dryers and a climate controlled dryer [4, UBA 2001].

Table 2.11: Operating data of two tunnel dryers and a climate controlled dryer

	Unit	Tunnel dryer	Tunnel dryer	Climate controlled dryer
Product		Fireclay	Magnesite	High alumina
Throughput	t/h	2.1	4	3.5
Dryer length	m	80	51	36
Cross-section	m^2	1.65	2.5	2.7
Setting density	kg/m^3	1 000	1 800	1 000
Drying temperature	°C	100	150 – 180	30 – 200
Drying time	h	48	17	32 – 48
Specific energy requirement	kJ/kg	500	1 500	~~n.a.~~ ND
Flue-gas volume flow	m^3/h	800	11 000	5 410
Flue-gas temperature	°C	40	120	105

NB: ND: No data.
Source: [9, COM 2007]

2.3.3.5 Firing

Refractory products are fired at temperatures of between 1 250 °C and 1 850 °C. Maturing temperatures depend on the composition of the raw materials and reach the beginning of deformation. The firing temperatures for the most important material groups are in the following ranges:

- fireclay bricks 1 250-1 500 ºC;
- silica bricks 1 450-1 500 ºC;
- high-alumina bricks 1 500-1 800 ºC
- magnesia bricks 1 400-1 800 ºC.

The products are fired in tunnel kilns, shuttle kilns and hood-type kilns. ~~The following table~~ Table 2.12 shows examples of operating data of tunnel kilns used in the refractory industry [4, UBA 2001].

[Note to the TWG: please provide information to update Table 2.12 and Table 2.13 below]

Table 2.12: Operating data of tunnel kilns used in the refractory industry

Tunnel kilns	Unit	Magnesia bricks	Fireclay bricks	Bauxite bricks	Silica bricks
Throughput	t/h	2 – 8	4	4	2.1
Kiln length	m	150	113	116	180
Cross-section	m^2	1.3 – 3	2.4	2.2	2.8
Setting density	kg/m^3	1 000 – 2 500	600 – 1 500	600 – 1 300	700 – 10 00
Firing temperature	ºC	1 760 – 1 850	1 260	1 400	1 450
Specific energy requirement (drying + firing)	kJ/kg	6 000 – 9 700	3 200	4 500	9 050
Flue-gas volume flow	m^3/h	15 000 – 25 000	10 000 – 15 000	10 000 – 15 000	1 200
Flue-gas temperature	ºC	250 – 400	150 – 200	150 – 220	120
Source: [9, COM 2007]					

~~The following table~~ Table 2.13 shows examples of operating data of shuttle kilns used for firing silica, high-alumina and fireclay products [4, UBA 2001].

Table 2.13: Operating data of shuttle kilns

Shuttle kilns	Unit	Silica bricks	High-alumina bricks	Fireclay bricks
Throughput	t/cycle	153	40 – 50	18
Firing chamber volume	m^3	180	20	25
Setting density	kg/m^3	850 – 1 100	2 000 – 2 500	650 – 1 000
Firing temperature	ºC	1 540	1 340 – 1 650	1 430
Specific energy requirement	kJ/kg	4 500 – 7 000	4 500 – 8 000	7 600
Flue-gas volume flow	m^3/h	to 50 000	to 20 000	3 600 – 7 000
Flue-gas temperature	ºC	180 – 300	180 – 290	160 – 250
Source: [9, COM 2007]				

The setting of bricks, especially in tunnel kilns, is generally performed ~~increasingly~~ by automatic setting machines. The bricks coming from the presses are automatically handled and placed on the kiln cars according to programmed setting patterns. The setting pattern permits impingement by flame and hot gases on all sides in conjunction with a low energy requirement. ~~Modern k~~ Kilns are operated with fuel oil and natural gas. In some cases, electric heating is standard for a short run of special products.

2.3.3.6 Subsequent treatment

In some special cases it is necessary for the fired refractory products to be subsequently treated by grinding, polishing and turning in wet or dry processes. Some products are dipped after firing into a solution of $MgSO_4$ to tune the product resistance and avoid hydration and are afterwards dried [38, COM 2022]. Following this treatment, the products are palletised or packaged and covered with plastic foils to avoid any water soaking, because protection must be guaranteed for the entire transportation.

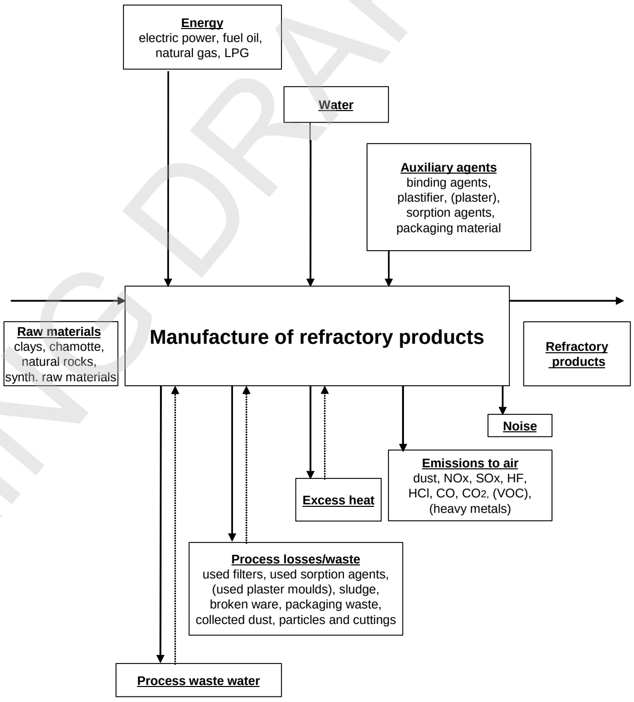
2.3.3.7 Special procedures

Special procedures are applied to manufacture refractory products with special characteristics. The formation of carbon bonding and pitch impregnation are procedures where special auxiliary agents are used. C-bonded bricks are predominantly used in the production of steel. The raw materials are often ~~hot~~ processed hot and pressed with coal tar, pitch or resins as binders. The bonding of the pressed parts is considerably reinforced by tempering and curing. The binding agent cokes during the tempering under the exclusion of air at temperatures of between 320 ºC and 550 ºC. During the hardening process, the products are heated to approx~~.~~imately 150 ºC to 220 ºC in electrical kilns. Refractory bricks are impregnated in some cases with coal-tar or bitumen to avoid 'open pores'.

~~2.3.3.8. Input and output flows in the manufacture of refractory products~~

[Note to the TWG: this section has been merged with Section 2.3.3]

~~Important input and output flows in the manufacture of refractory products are presented in the following figure [4, UBA 2001], [23, TWG 2005].~~



Source: [9, COM 2007]

~~**Figure 2-25: Input and output flows in the manufacture of refractory products**~~

2.3.4 Expanded clay aggregates

Expanded clay is a porous ceramic product with a uniform pore structure of fine, closed cells and has a densely sintered, firm external skin. It is produced from raw materials containing clay minerals and additives. The raw material is prepared, moulded and then subjected to firing processes at temperatures of between 1 100 ºC and 1 300 ºC, resulting in a significant increase in volume due to expansion.

For the industrial manufacture of expanded clay, certain material requirements have to be met. Another important factor is kiln design, which should match the characteristics of the raw material and the quantities being processed. The following parameters can influence the expansion process:
- raw material composition;
- additives;
- temperature curve;
- kiln atmosphere;
- viscosity as a function of the above-mentioned influence factors.

Practical experience during expanded clay manufacture has shown that the expandability of clay is determined by raw materials and additives and by the thermal process technology. The main technological factors influencing the expandability of raw materials are the heating rate and the kiln atmosphere.

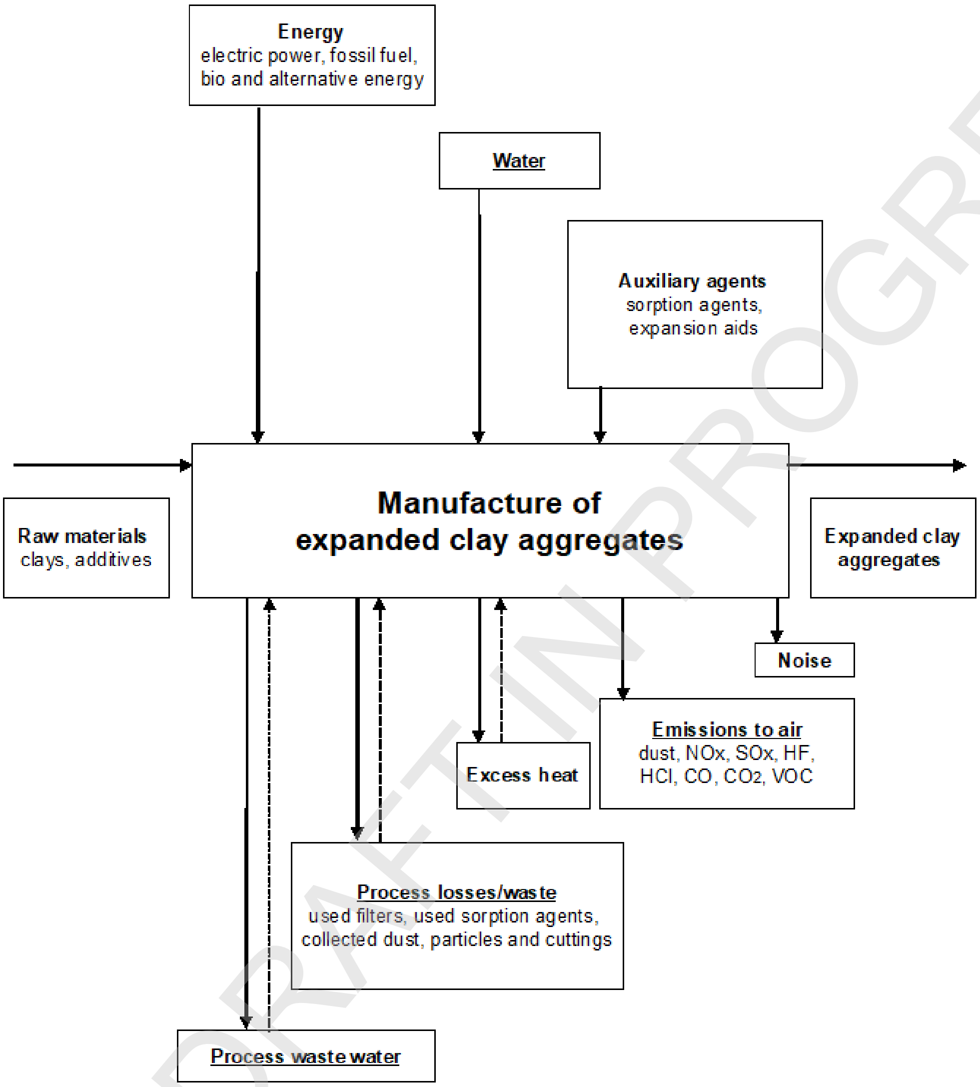
The manufacture of expanded clay involves the following steps: quarrying (this activity is not covered in this document), storage, raw material preparation, shaping, heat treatment (drying, firing), subsequent product treatment, product recovery and preparation for transport (bagging, loading). ~~The following figure~~ Figure 2-24 shows a schematic view of the manufacture of expanded clay aggregates [26, UBA 2005], [30, TWG 2005]. The shaping process step is not relevant for all plants.

Source: [52, VDI 2018], [9, COM 2007]

Figure 2-24: Schematic view of the manufacture of expanded clay aggregates

[Note to the TWG: this section has been moved from Section 2.3.4.3 of the CER BREF 2007]

Important input and output flows in the manufacture of expanded clay aggregates are presented in Figure 2-25 ~~the following figure~~ [17, Burkart, M. 2004], [23, TWG 2005], [26, UBA 2005], [28, Schorcht, F. 2005], [30, TWG 2005].



Source: [9, COM. 2007]

Figure 2-25: Input and output flows in the manufacture of expanded clay aggregates

2.3.4.1 Raw materials, additives and auxiliary agents

Raw materials for the manufacture of expanded clays are early sintering clays which have associated flux materials such as iron oxide, alkalis, alkaline earths as well as gas-forming substances, which are either already present or can be added in order for the expansion to occur [33, Ramboll 2019]. With a controlled heating rate and within a temperature range of between 1 100 °C and 1 300 °C, they experience a significant increase in volume. Only those raw materials that initially form a pyroplastic, dense sinter or melt coat when they are heated to these temperatures are suitable, and at the same time form gases inside the body (granule fragment) that are able to expand the viscous bodies. The presence of associated flux ~~media~~ materials in the clay such as iron oxides, alkalis, alkaline earths, as well as gas-forming substances that are either present in the raw materials or can be added during processing, ~~are~~ is necessary for this to occur.

Despite the example given above, p~~P~~revious studies showed that the expansion characteristics of a clay as a raw material cannot generally be derived from analysis. Certain general ~~statements~~ characteristics regarding the chemical/mineral composition and other ~~characteristics~~ features of materials with proven expandability are:

[Note to the TWG: please provide information to confirm if composition below refers to wt-% dry or other]

- relatively high plasticity, with a large fines content;
- relatively high content of layered silicates, particularly from the illite or mica group, more than 40 % is advantageous; the kaolinite content is usually low;
- calcite or dolomite content reduces the expansion time; lumpy lime is harmful, because it may subsequently lead to spalling;
- chemical composition:
    - Al_2O_3: 12 – 25 %;
    - SiO_2: 47 – 78 %;
    - flux (Na_2O, K_2O, CaO, MgO, Fe_2O_3, FeO): 8 – 29 %;
    - $C_{organic}$: 0 – 2.5 %;
    - FeS_2: should be fine-grained (residue in the finished product ≤1.0 or 1.5 % SO_3);
- mineralogical composition:
    - quartz: 7 – 45 %;
    - carbonates: 0.1 – 17 %;
    - clay minerals: 40 – 80 %;
    - feldspar: 5 – 25 %;
    - other: 3 – 17 %;
- pyroplastic softening of the mass or the granules should occur during the most favourable stage of the gas formation process; this offers the most advantageous expansion range of at least 50-100 K.

Clays that are naturally inadequate for expansion can be made expandable by adding appropriate additives and auxiliary agents, which make the manufacture of expanded products with special characteristics easier (for instance if the aim is to maximise the thermal insulation characteristics, expansion aids are often added to the expanded clay) and often also safer. Expansion additives are carbon compounds and can range from fossil or virgin additives to waste and biomass clay additives (e.g. waste water, sawdust or sugar molasses) [33, Ramboll 2019].

The examples of additives (fluxes and release agents) and auxiliary agents (expansion aids) shown in ~~the following table~~ Table 2.14 have proven to be particularly reliable~~:~~.

Table 2.14: Examples of expansion-promoting additives and auxiliary agents

Fossil/virgin additives	Waste organic clay additives	Waste inorganic clay additives	Biomass clay additives
• Heavy oil • Lignite fine fractions • Waste water • Iron oxides minerals • Coal/anthracite	• Waste oil • Mill scales with oil • Organic sludge • Waste from the petrochemical industry	• Waste water • Iron sludge • Alumina waste sludge • Waste from stone or glass wool • Waste from mineral production processes	• Fine sawdust • Wet sewage sludge • Waste from vegetable oil production, bleaching soils • Sludge from paper production

Fossil/virgin additives	**Waste organic clay additives**	**Waste inorganic clay additives**	**Biomass clay additives**
			• Biofuel production wastes • Sugar molasses • Tall oil/Tall oil products
Source: [65, EXCA 2020]			

~~**Flux**~~	~~**Expansion aids**~~	~~**Release agents**~~
~~Iron oxides~~	~~Heavy oils~~	~~Lime compounds~~
~~Iron hydroxides~~	~~Lignosulphonates~~	~~Dolomite~~
~~Illitic clays~~	~~Ultrafine coke/coal~~	
	~~Bituminous clays~~	

The types of additives and auxiliary agents depend on the composition of the raw material, the manufacturing process technology (processing of moist or dry clays, see Section 0), the economic availability and the characteristics of the emission. The dosage is usually between 0 and 10 % by weight.

[Note to the TWG: the numbering of the sections below has been updated]

~~**2.3.4.2 General system and process technology**~~

2.3.4.2 Preparation of raw materials and ~~S~~shaping

Two basic techniques are used for the preparation of raw material and the shaping depending on the moisture content in the clay.

Wet process
For clays with a relatively high moisture content, the use of the wet process is the most common technique: in mechanical processing and homogenisation in clay storage, pan mills, disintegrators, dual-shaft mixers and kneaders, the ductile clays (with additives) are fed to a rotary dryer. Through a suitable sequence of drying kiln fixtures such as chains, crossed bars and plates, the clay fragments are broken down further.

Source: [56, COM 2023]

Figure 2-26: Example of extrusion in expanded clay production

Dry process

For rather dry clays, the use of the semi-dry process is the most common technique: a primary crusher is used for crushing large pieces of raw material to a grain size of less than 100 mm. The material can be homogenised during automatic storage and retrieved via a bucket-conveyer excavator. In the dry grinding unit, the raw clay is crushed between the rotating grinding track and grinding rollers. The powdered clay is fed to the slanting dish granulator, with water being added. The rotary motion of the dish causes spherical granules to form, which are discharged via the lower edge of the dish and the rolling movement has a certain granulating effect. Suitable reagents are added ~~for~~ to reduc~~ing~~e the surface tension of the added water. The size of the granules is influenced and their characteristics adapted to the respective raw material by changing the speed and inclination of the dish and the height of the dish edge. The granules pass through a ‘powder drum’, where limestone powder is applied to the granule surface. This prevents bonding of the unfired granules and subsequently protects them in the expansion kiln.

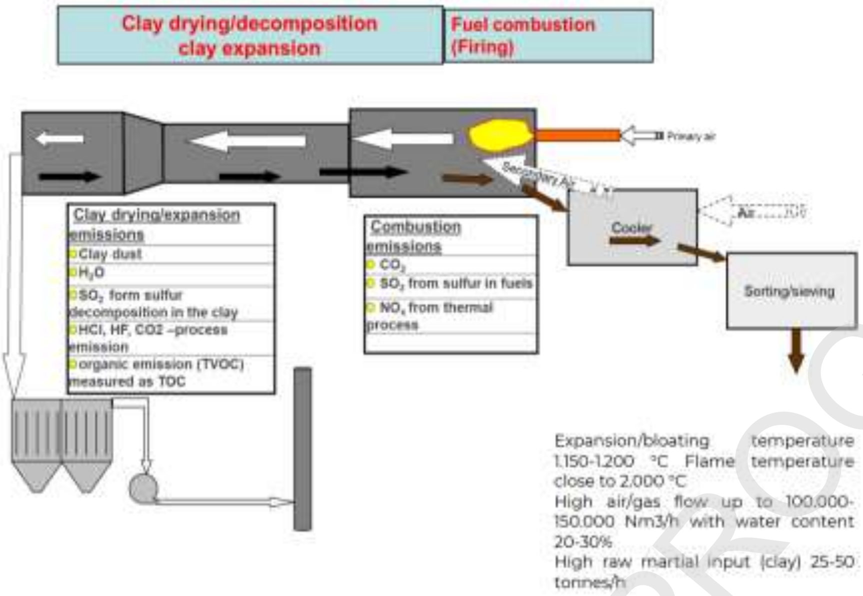
Other processes

In some cases, the raw material can also be dried before shaping (i.e. Liapor process).

2.3.4.3 Thermal process technology

Drying and firing processes occur in the kiln together. The drying part are directly connected to the expansion part of the firing kiln, with only one main burner in front of the inlet of the firing kiln. There are cases where additional burners between drying and firing kilns are in place to enhance the drying; however, in all kilns, there are no outputs of waste gases between drying and firing. All hot gases from the firing kiln are subsequently used for the drying process with only one flue-gas exit point throughout [33, Ramboll 2019].

Figure 2-27 and Figure 2-28 show a schematic of flows in rotary kilns and an example of a rotary kiln.



Source: [66, EXCA 2023]

Figure 2-27: Schematic of production of expanded clay in rotary kilns

Source: [56, COM 2023]

Figure 2-28: Example of a rotary kiln for the production of expanded clay

Trends in kiln design are characterised by efforts to develop systems with simple and flexible adaptability both in terms of the raw materials and the required product characteristics. One route for achieving this is variable firing and air control, combined with different transfer times for the individual thermal stages. The optimal temperature curve for reaching the desired density of the product depends upon the raw material mixture and additives. For optimising the procedure, preheaters are located upstream of the actual expansion kiln. The most common preheater type is a drum preheater (drying kiln). For cooling, devices such as shaft coolers, rotary coolers, satellite coolers, grate or hopper coolers are usually used.

Rotary kilns used for the manufacture of expanded clay are usually operated in a counterflow mode, i.e. the material and the heating medium move in opposite directions. The raw material is added on the cold side of the kiln. Due to the inclination of the drum and the rotation of the kiln, the material drifts to the hot end of the kiln, i.e. the high-temperature zone. The transfer time depends on the inclination of the kiln, its speed and the fixtures inside the kiln. Time has a significant influence on the product characteristics. In order to prevent the granules from sticking together, the kilns are sometimes equipped with appropriate fixtures such as suspended chains. The kiln dimensions vary depending on the technique used. Tube lengths vary between 4 m and 80 m, diameters between 1.0 m and 4.5 m. The most commonly used fuels used are oil, coal, gas and the alternative/secondary fuels are of organic origin (e.g. biofuels, biomass) and non-organic origin (e.g. waste oil, solvents). The system design aims to optimise the thermal balance, utilising a wide range of temperature and heating time options. In theory, expanded clay kilns can utilise up to 100 % alternative fuels. Nevertheless, there are certain fuel characteristics like the calorific value and the particle size that limit this. Table 2.15 shows fuels typically used in expanded clay manufacturing plants.

Table 2.15: Examples of fuels used in expanded clay manufacturing

Fossil fuels	Fossil-based alternative fuels	Recovered organic alternative fuels	Biomass fuels
• Hard coal • Lignite • Heavy oil • Light oil • Natural gas • Diesel • Propane/butane mix	• Waste oil • Solvents • Coal dust • Eco asphalt • Pet coke	• Animal meal • Sewage sludge • Waste wood • Paper and board • Grain rejects	• Natural wood, lignin • Straw or grass • Biofuel residues, e.g. shea meal, olive pomace • Rapeseeds • Sugarcane • Biogas • Sawdust, wood pellet • Bark • Tall oil/Tall oil products
Source: [65, EXCA 2020]			

Lime compounds such as dolomite or limestone are injected in the burning zone to reduce the sticking effects of the pellets during the expansion process [33, Ramboll 2019].

2.3.4.3.1 Chemical reaction during expansion

During the heating of the granules, water vapour is formed from residual water, as well as oxygen, water vapour from constitution processes, decomposition gases from organic substances, sulphur dioxide and carbonic acid from carbonate. At the same time, the pores on the surface begin to close. The expanded product (with a more or less fine cellular internal structure) is formed due to the fact that the gases expand with increasing temperature.

The expansion of the clays is the result of a carbothermic reaction, where carbon is the reduction agent and iron oxide the oxidiser. Organic carbon is mainly added as an additive for expansion and is oxidised to CO and CO_2. At the same time, iron oxides are reduced. This redox-type reaction leads to the generation of clay expansion gases. Iron is usually naturally present in the clay whereas organic carbon needs to be added to the process as a ‘clay expansion’ additive in a form that can be well mixed into the clay, to achieve a uniform distribution in the prepared raw material. Some clays have a lower iron oxides content and for these iron, mostly in the form of metallic iron, needs to be added to the process [56, COM 2023] [70, COM 2018].

The main reactions occurring during expansion are the following:

$3\ Fe_2O_3 = 2Fe_3O_4 + 0.5\ O_2$ (magnetite formation)
$2Fe_2O_3 = 4FeO + O_2$
$2Fe_3O_4 = 6FeO + O_2$
$1Fe_2O_3 + SiO_2 = 2FeO*SiO_2 + 0.5\ O_2$ (fayalite formation)
$3Fe_2O_3 + C = 2Fe_3O_4 + CO$
$1Fe_3O_4 + C = 3FeO + CO$ (wuestite formation)
$3Fe_2O_3 + CO = 2Fe_3O_4 + CO_2$
$1Fe3O_4 + CO = 3FeO + CO_2$
$1Fe2O_3 + CO = 2FeO + CO_2$
$1FeS + 1.5\ O_2 = 1FeO + SO_2$
$1CaCO_3 = 1CaO + CO_2$
$1MgCO_3 = 1MgO + CO_2$

Consequently, the main gaseous elements and compounds that are released are therefore oxygen, carbon monoxide, carbon dioxide and/or sulphur dioxide, of which one or more have to be available for the expanding process. This principally occurs in the extended temperature range of approximately 750 °C to 1300 °C.

2.3.4.4 Subsequent treatment~~sieving and crushing~~

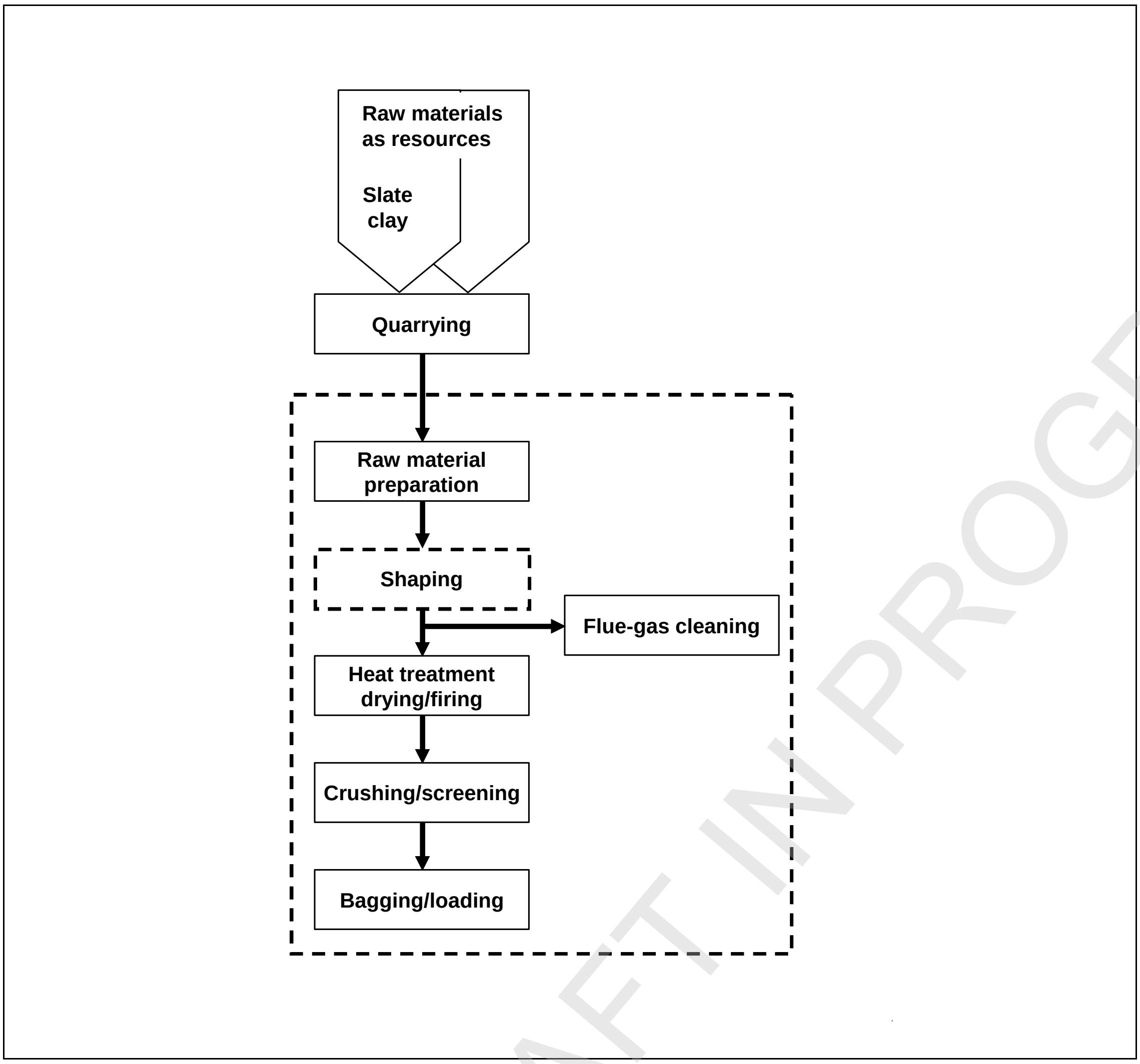
In the manufacture of expanded clay aggregates, after the heat treatment process, the aggregates go through a sieving and crushing process to obtain the desired granulometry and quality. Dry sieving and sand crushers are normally used.

The product is mostly stored and transported in bulk (trucks or vessels). The distribution to the customers is also possible in big bags or small bags [56, COM 2023].

~~2.3.4.5 Input and output flows in the manufacture of expanded clay aggregates~~

[Note to the TWG: this section has been merged with Section 2.3.4]

~~Important input and output flows in the manufacture of expanded clay aggregates are presented in the following figure [17, Burkart, M. 2004], [23, TWG 2005], [26, UBA 2005], [28, Schorcht, F. 2005], [30, TWG 2005].~~



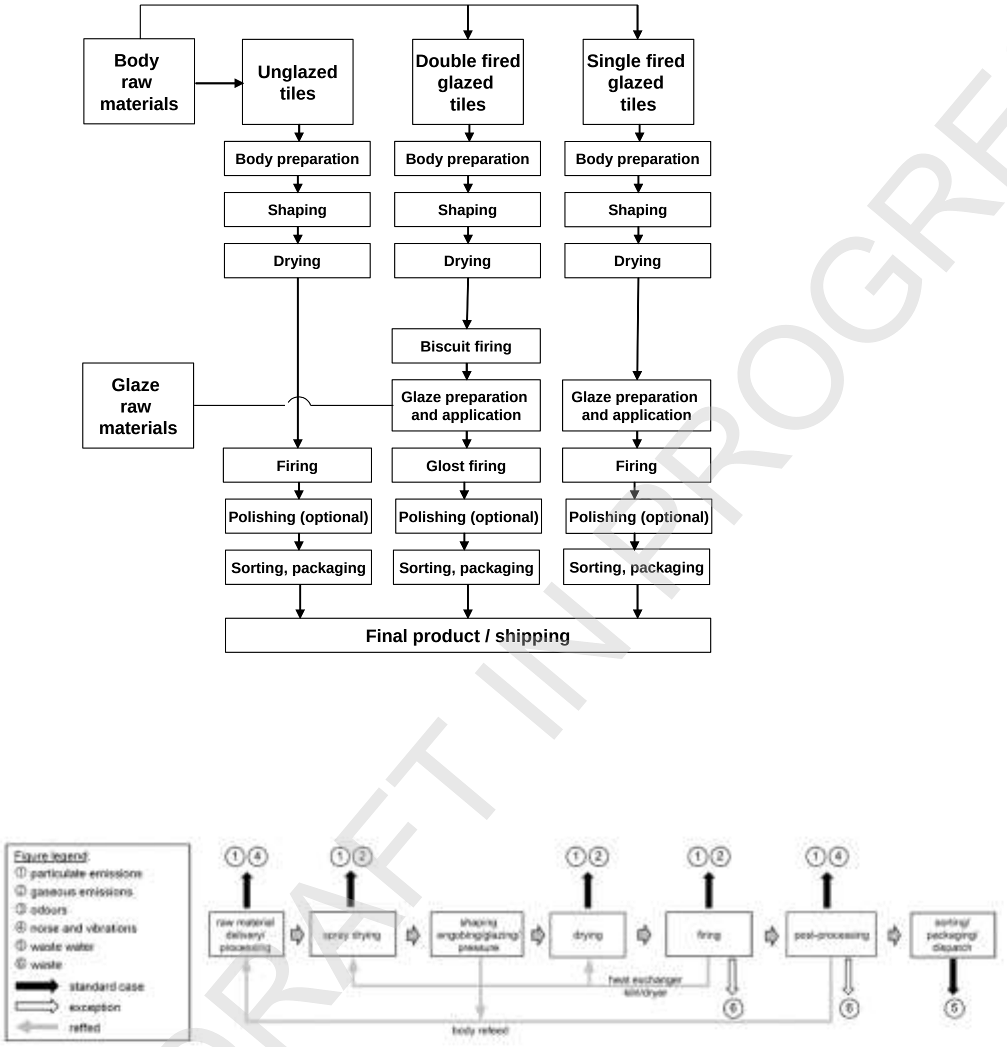
~~**Figure 2-31: Input and output flows in the manufacture of expanded clay aggregates**~~

2.3.5 Wall and floor tiles

The wall and floor tile manufacturing process consists of a series of successive stages which can be summarised as follows:

- storage of raw materials;
- body preparation (dust pressing powder (dry or wet process) or extrusion paste);
- shaping;
- drying of the green body;
- glaze preparation and glazing/inkjet printing;
- firing (with or without glazing);
- polishing/squaring;
- sorting and packaging.

Depending on whether the product to be made is glazed or not and whether single firing, double firing or ~~third~~ triple firing is involved, the tile will or will not be glazed in a given process, or the order of the glazing and firing stages will be suitably rearranged. ~~The following figure~~ Figure 2-29 shows a schematic view of the different possibilities for wall and floor tile manufacturing processes [3, Ceram-Unie 2003], [23, TWG 2005].

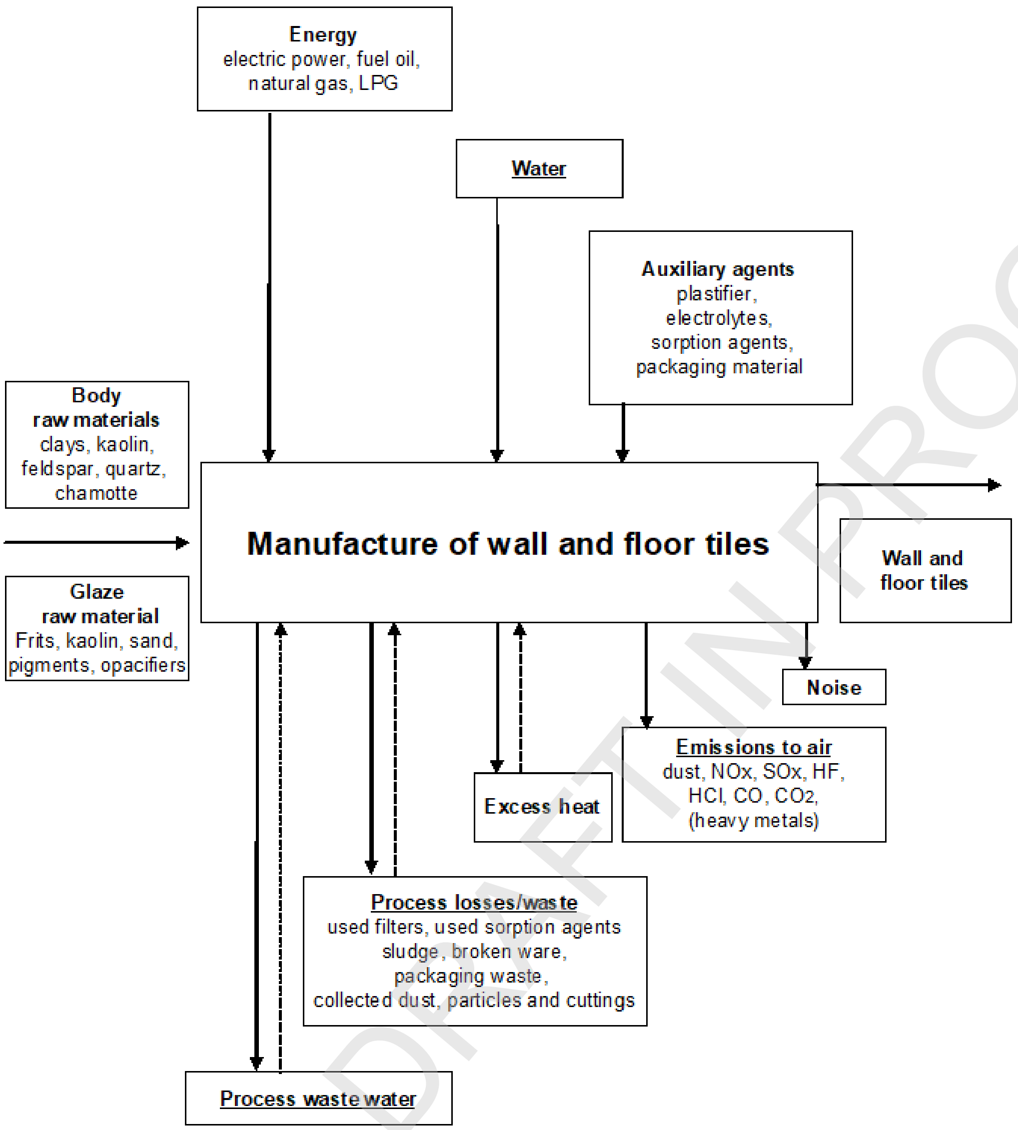


Source: [52, VDI 2018], [9, COM 2007]

Figure 2-29: Schematic view of wall and floor tile manufacturing

[Note to the TWG: this section has been moved from Section 2.3.5.7]

Important input and output flows of the wall and floor tile manufacturing process are presented in Figure 2-30 ~~the following figure~~ [4, UBA 2001], [23, TWG 2005], [30, TWG 2005].



Source: [9, COM. 2007]

Figure 2-30: Input and output flows in the manufacture of wall and floor tiles

2.3.5.1 Raw materials

Clays and kaolins are typical plastic raw materials used in the manufacture of wall and floor tiles. Chamotte, quartz, feldspars, calcium carbonate (calcite), dolomite and talc are non-plastic raw materials with different functions in the body composition (for instance feldspars act as fluxing agents, while calcite enables the formation of crystalline phases). The same raw materials combined with glaze frits, metal oxides and colo~~u~~rants are also used for glazes. Electrolytes such as sodium silicate or diphosphate are added to reduce the energy consumption in the drying process by water reduction. Organic binders such as lignosulphonates and acrylates are added in some of the compositions to increase mechanical strength [49, TWG ES 2021].

Body components are delivered to the raw material storage area mainly as bulk material. The materials are stored in the open air, in storage sheds, boxes or silos. Smaller masses are delivered and stored in bags and containers, and fluid materials in closed tanks.

2.3.5.2 Preparation of raw materials

Preparation of raw materials includes different operations and techniques, according to the type or form of body to be produced.

The proportioning of raw material is performed gravimetrically taking into consideration the moisture of the raw materials. Small masses of pigments, metal oxides or colo~~u~~rants are added to ~~stain~~ colour the body components. Larger pieces are pre-crushed in roller mills or auger machines. After weighing, the pre-crushed materials are milled (including water and electrolytes) in wet drum mills, which may be batch or continuous mills. An additional variation is the elutriation and homogenising process of the batched raw materials in large tanks. The suspension is pumped from the tanks to wet drum mills. The water content of the suspension is about 35 wt-%. Continuous mills are generally more efficient than batch mills [49, TWG ES 2021].

After fine grinding (to a particle size < 0.1 mm), the suspension is screened step by step and stored in stirred storage tanks. The suspension is processed either to a plastic body (‘extrusion paste’) or to ‘dust pressing powder’. The production and processing of casting slip is unusual in the manufacture of wall and floor tiles.

‘Extrusion pastes’ are usually prepared in pan mills or lamination units. To produce ‘extrusion paste’, the suspension is dewatered in filter presses or rotation filters to a water content of between 20 % and 25 %. Organic or inorganic substances are added to the plastic compound to maximise the plasticity. These substances are, for example, alginate, dextrin, lignin, methyl cellulose, ethyl cellulose and paraffin.

A special process to prepare raw materials for plastic shaping is fine grinding in dry mills, mixing and then adding about 20 % ~~of~~ water ~~(Buchtal process)~~ [23, TWG 2005].

Tiles are predominantly manufactured by the use of ‘dust pressing powder’. Dust pressing powder can be produced through a wet or dry process. The production of ‘dust pressing powder’ is often outsourced. Some wall and floor tile manufacturing installations include the full production cycle and others start the process directly shaping the powder produced off site [37, COM 2022].

In the wet process, the suspension is pumped from the stirred storage tanks by pumps to spray or flash dryers. Drying is performed at temperatures of between 350 ºC and 450 ºC to a water content of between ~~five~~ 5 % and ~~nine per cent~~9 %. ~~The required heat in the spray dryer is produced by natural gas or fuel oil firing.~~ The required heat is produced by natural gas or fuel oil firing or by using cogeneration gas turbines typically fuelled by natural gas. Organic slip additives are added to maximise the sliding characteristic of the powder. The slip additives may be organic or inorganic; the most widely used additives in body composition preparation are sodium silicate, sodium tripolyphosphate, lignosulphonates and acrylates. The use of binding agents such as carboxymethyl cellulose, methyl cellulose~~,~~ and polyvinyl alcohol~~, etc.~~ in body composition preparation is usually unnecessary due to their significant content in clays, except in special cases (e.g. big sizes) [23, TWG 2005] [49, TWG ES 2021].

The dry process includes dry grinding in cone, hammer and ring mills, followed by a suitable wetting of the ground powder, to achieve an average moisture content of around 5-7 %. An alternative dry process consists of dry milling in pendular mills followed by granulation with 11-

13 wt-% water and subsequent drying in fluidised beds to reach a moisture content of around 6-7 wt-% [49, TWG ES 2021].

2.3.5.3 Shaping

‘Extrusion paste’ is shaped in an extruder to the right geometry and cut into pieces. Typical products manufactured from these plastic compounds are cleaving tiles. Earthenware and stoneware tiles are mainly made of ‘dust pressing powder’. The powder is shaped to press bodies in impact toggle presses, screw presses, continuous presses or hydraulic presses with a pressure of about 35 MPa. Normally multi-tool presses~~, which are able to form four tiles per cycle,~~ are employed. ~~Pressed green ware is polished and put into the tunnel kiln car or roller dryer either automatically or manually.~~

2.3.5.4 Drying

The pressed bodies are dried mainly in roller or vertical dryers, and to a lesser extent in tunnel dryers. The thermal energy for drying comes mainly from natural combustion and recovery of heat from the cooling zone of the kiln [49, TWG ES 2021]. ~~The pressed bodies are dried mainly in tunnel dryers, roller dryers or vertical dryers.~~ ~~Waste heat from the kiln or natural gas and fuel oil firing burners are operated to heat the dryer.~~ Drying is performed at temperatures that vary depending on the type of technology, e.g. in vertical dryers between 200 ºC and~~–~~ 220 ºC and in tunnel dryers between 300 ºC and~~–~~ 350 ºC. Drying time is between ~~one~~ 1 and ~~four~~ 4 hours depending on the water content of the green ware. The required residual moisture content is less than ~~one per cent~~ 1 % to avoid fissures and glazing errors in the firing process.

2.3.5.5 ~~Firing and glazing~~ Decoration and firing

Traditionally, t~~T~~iles are made as glazed or unglazed single fired products or as glazed double or even triple fired products. In the double firing process, the tiles pass the biscuit firing first. Biscuit firing is performed at temperatures of between 1 050 ºC and 1 150 ºC in classic tunnel kilns (in 20-50 hours) or in modern roller hearth kilns in ~~one to two~~ 1-2 hours. Periodically operated kilns are used rarely in the ceramic biscuit process. Following this step, the tiles are sorted automatically and transported to the engobing/glazing process. ~~G~~ Engobe/glaze is applied to the tiles by spraying or watering. ~~G~~ Engobing/glazing machines are equipped with dabbing units to marble the tiles. Additionally, silk screen printing machines can be used for decoration purposes and decoration can also be carried out with gravure or flexography techniques. Ceramic ink-jet printing is replacing some of the traditional techniques. Digital ink-jet printers place the decoration on the dry pieces and minimise the amount of glaze or engobe used. Further details can be found in Section 2.2.6.3.

Engobe consists of a clay mixture with metal oxides, which is deposited as a thin film on the surface of the unfired ceramic body. Glaze has a greater glass content and builds up a thicker layer on the surface of the unfired ceramic body [56, COM 2023].

Glazing raw materials are often drawn as frits. All components in a frit are already batched, fired and milled. Substances such as lead are bound in frits in a molecular form, so water cannot wash them out in this process step.

The final firing takes place in roller hearth kilns, tunnel kilns or periodically operated kilns. Glazed tiles are put on firing auxiliaries and are fired at temperatures of between 1 050 ºC and 1 300 ºC in tunnel kilns or in roller heath kilns without firing auxiliaries. Specially formed tiles are fired in shuttle kilns or tunnel kilns at temperatures of up to 1 100 °C. ~~The following table~~ Table 2.16 and Table 2.17 show~~s~~ examples of operating data of tunnel kilns and roller hearth kilns.

[Note to the TWG: please provide information to update the two tables below]

Table 2.16: Operating data of tunnel kilns and roller hearth kilns firing tiles with higher water absorption

	Unit	Tunnel kiln	Roller hearth kiln	
		biscuit firing	final firing	single firing
~~Product~~		**~~Tiles with higher water absorption~~**		
Throughput	t/h	2.8	1.2	1.6
Kiln length	m	120	60	80
Cross-section	m^2	1.5 – 2.0	0.8 – 1.2	0.5 – 1.0
Setting density	kg/m^3	500 – 700	10 – 30	10 – 30
Firing temperature	ºC	1 100	1 250	1 300
Specific energy requirement	kJ/kg	3 500	2 900	2 200
Flue-gas volume flow	m^3/h	15 000	10 000	13 000
Flue-gas temperature	ºC	180	160	200
Source: [9, COM 2007]				

Table 2.17: Operating data of tunnel kilns and roller hearth kilns firing tiles with lower water absorption

	Unit	Tunnel kiln	Roller hearth kiln	
Product		**~~Tiles with lower water absorption~~**		
		unglazed	unglazed	glazed
Throughput	t/h	1.2	2.1	2.1
Kiln length	m	130	80	60
Cross-section	m^2	1.5 – 2.0	1.2	0.8 – 1.0
Setting density	kg/m^3	700 – 1 000	20 – 30	20 – 30
Firing temperature	ºC	1 200	1 220	1 230
Specific energy requirement	kJ/kg	3 900	2 900	2 500
Flue-gas volume flow	m^3/h	15 000	10 000	13 000
Flue-gas temperature	ºC	220	160	160
Source: [9, COM 2007]				

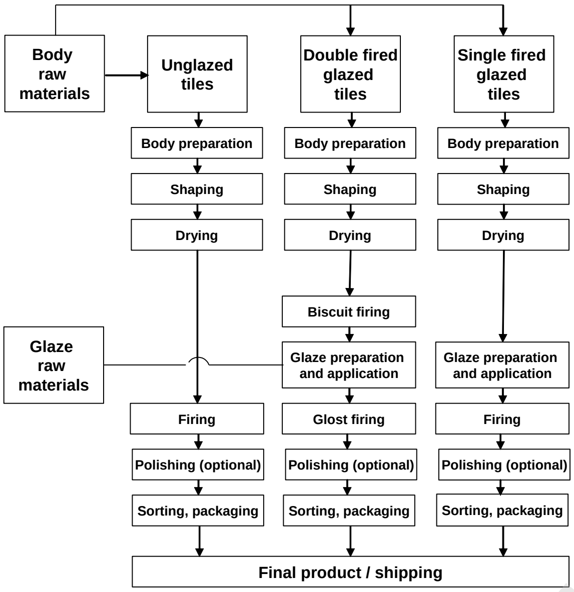
2.3.5.6 Subsequent treatment

After the final firing, some types of tiles ~~(mainly unglazed porcelain stoneware tiles)~~ can be ground, ~~or~~ polished or rectified. Finally tiles are manually or automatically sorted, packed and palletised. The pallets are coated with a foil in a tight-packing machine.

~~2.3.5.7 Input and output flows in the manufacture of wall and floor tiles~~

[Note to the TWG: this section has been merged with Section 2.3.5]

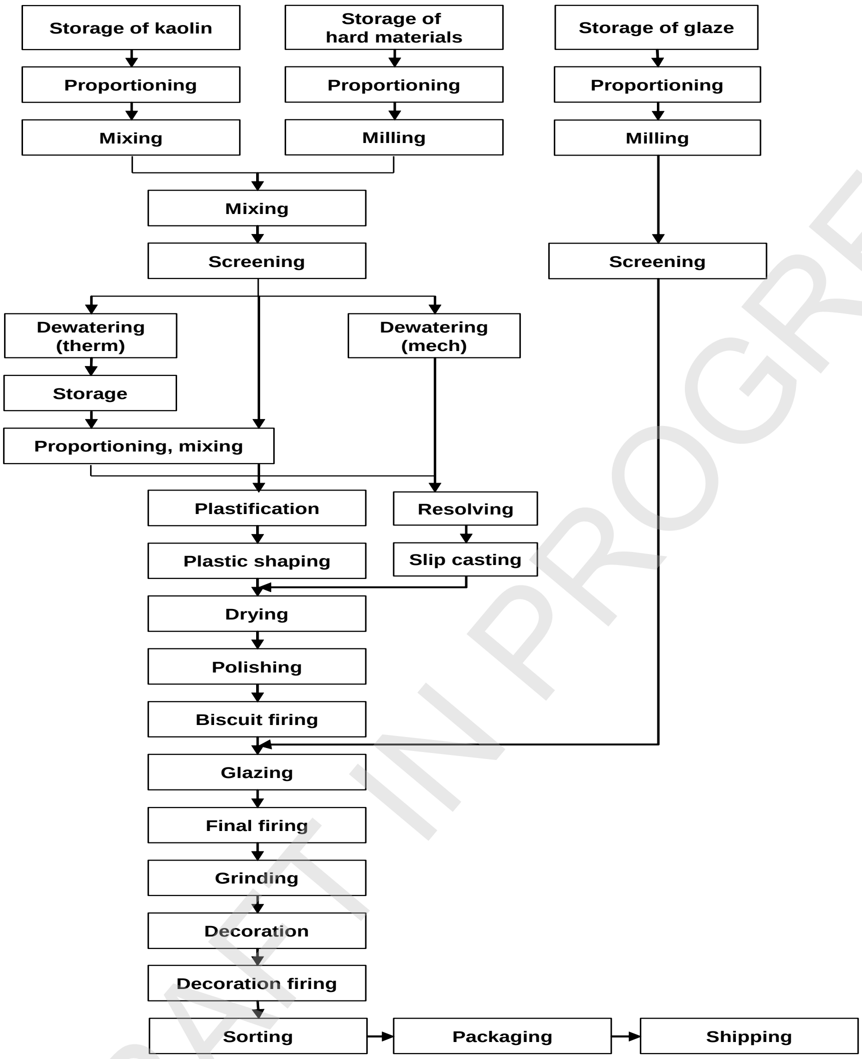
~~Important input and output flows of the wall and floor tile manufacturing process are presented in the following figure [4, UBA 2001], [23, TWG 2005], [30, TWG 2005].~~



~~Figure 2 36: Input and output flows in the manufacture of wall and floor tiles~~

2.3.6 Table- and ornamentalware (household ceramics)

The process of household ceramics manufacture is made up of the following main steps: storage of raw materials, preparation of raw materials, shaping, drying, firing, glazing, decoration and subsequent treatment. As a typical example of household ceramics manufacturing, ~~the following figure~~ Figure 2-31 shows the stages of the manufacture of table porcelain [4, UBA 2001] [52, VDI 2018].



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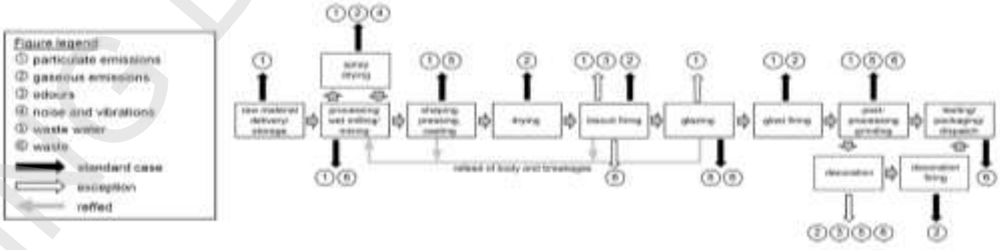
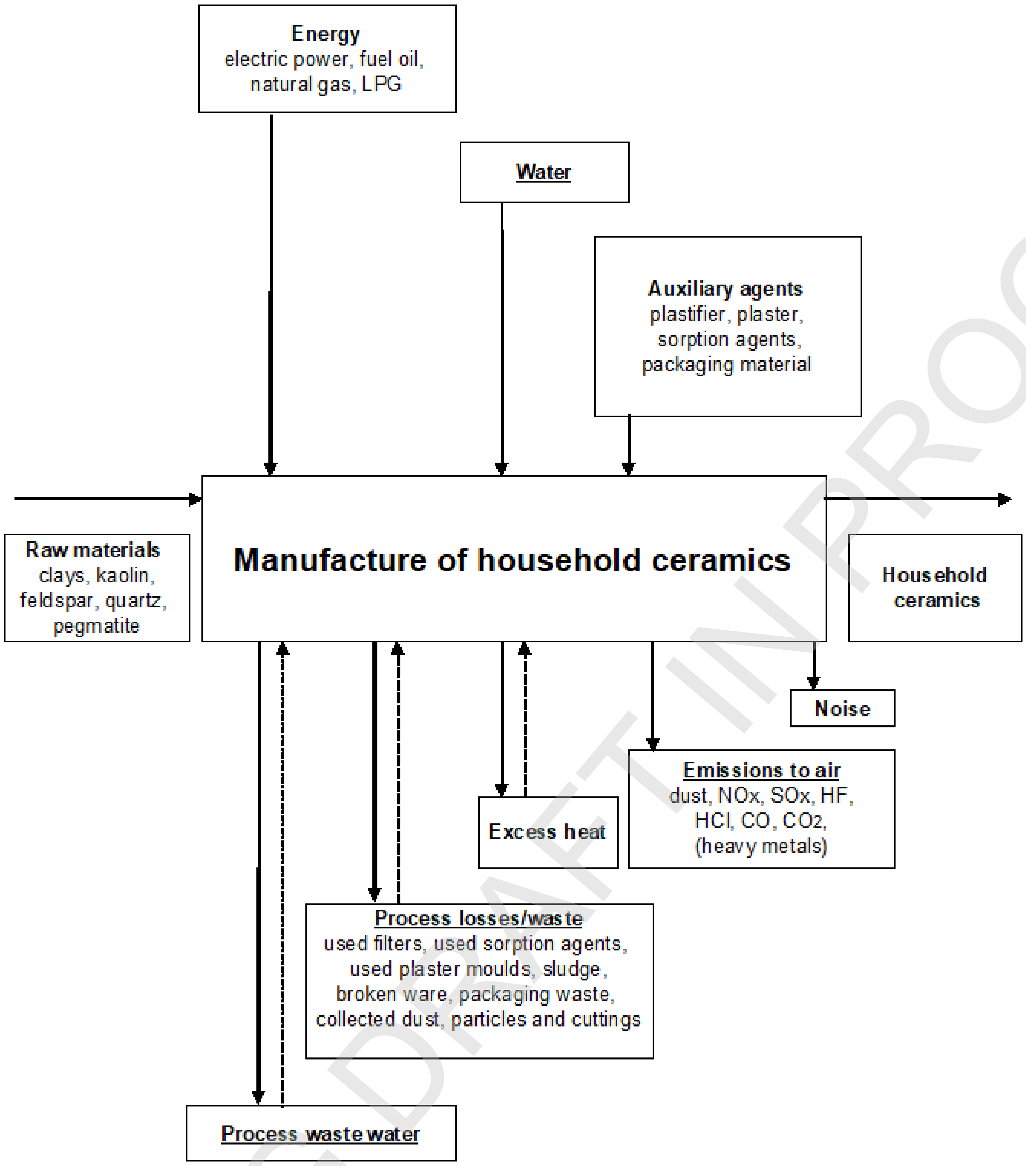


Source: [4, UBA, 2001] [52, VDI 2018]

Figure 2-31: Schematic view of the manufacture of table porcelain

[Note to the TWG: this section has been moved from Section 2.3.6.7 of the CER BREF 2007]

Important input and output flows of the household ceramics manufacturing process are presented in Figure 2-32 ~~the following figure~~ [4, UBA 2001], [23, TWG 2005].



Source: [9, COM. 2007]

Figure 2-32: Input and output flows in the manufacture of household ceramics

2.3.6.1 Raw materials

Plastic clays, feldspar and quartz are used as the main raw materials for the manufacture of household ceramics. The different compounds for the body batch and the glaze batch are delivered to the factory and are stored in silos, bags and containers depending on the moisture content of the raw material, the storage method and the particle size. To achieve a good body characteristic, several raw materials with different parameters are used.

Table 2.18 and Table 2.19 show typical ranges of the mineralogical and chemical compositions of raw materials used for the manufacture of household ceramics [3, Ceram-Unie 2003].

[Note to the TWG: please provide information to update the two tables below]

Table 2.18: Typical ranges of the mineralogical composition of raw materials for the manufacture of household ceramics

Mineral (%)	Earthenware	Vitrified	Porcelain	Bone china	Stoneware
China clay	25	25	55	25	0
Ball clay	15 – 25	25	0	0	0
Feldspar*	0 – 15	20	15	25	30
Talc	0 – 35	0	0	0	0
Silica	20 – 35	0	30	0	70
Flint	0	30	0	0	0
Bone ash*	0	0	0	50	0

*Nepheline syenite: normally an alternative to feldspar and bone ash
Source: [9, COM 2007]

Table 2.19: Typical ranges of the chemical composition of raw materials for the manufacture of household ceramics

Mineral (%)	SiO_2	Al_2O_3	Other
China clay (kaolin)	55	35	10
Ball clay	75	20	5
Feldspar	70	20	10
Nepheline syenite	60	25	15
Talc	60	0	40 (MgO)
Silica	95	0	5
Flint	90	0	10
Bone ash	0	0	100 ($Ca_5(PO_4)_3OH$)

Source: [9, COM 2007]

2.3.6.2 Preparation of raw materials

The preparation of raw materials for the manufacture of household ceramics is performed in a wet or a dry process. ‘Extrusion paste’ and ‘dust pressing powder’ are predominantly produced. Body components are mainly metered gravimetrically. If kaolin compounds are dissolved in water, volumetric apportioning also takes place. In general, glazing raw materials are dosed gravimetrically. The plastic body compounds are suspended in water in stirred tanks to prepare the compounds for the mixing process. The following wet milling is performed in drum mills or in stirrer mills. Hard body compounds are often delivered with the correct particle parameters, so that no additional milling is necessary. Plastic body compounds and hard body compounds are mixed in stirrers or mixers. The compounds are screened to remove impurities followed by deferrisation which removes foreign iron compounds. Deferrisation is performed in electromagnetic fields.

The body slip is dewatered mechanically in filter presses or thermally in spray dryers. For the production of ‘extrusion paste’, the water content of the slip is reduced from 65 % down to 20-25 % in filter presses or in rotation filters. The filter cake is homogenised and formed into clots in extrusion presses. For the production of ‘dust pressing powder’, the slip cast is dewatered down to 5-8 % water content in spray dryers. The slip cast is pumped into the spray dryer by a special slip cast pump. The water content is reduced by a hot gas stream. The flue-gas of the gas-heated dryer and the vaporised water leaves the spray dryer at the top.

Organic slip additives and binding agents are added to the ‘dust pressing powder’ to give the powder fluidity ~~achieve soft and slide characteristics of the powder~~. Carboxymethyl cellulose, methyl cellulose, cellulose ether, polyvinyl alcohol, polyvinyl acetate and polysaccharide are used for this purpose. Olein, mineral oil, stearic acid and wax are added. The share of slip additives and binding agents in the ‘dust pressing powder’ is between 0.2 % and 0.4 wt-%. ‘Dust pressing powder’ produced in the fluidised bed process can be used with a reduced share of slip additives and binding agents, thus providing better deformation characteristics.

Fluidised bed granulation on the one hand and non-thermal granulation processes on the other ~~hand,~~ are future alternatives in the production of ‘dust pressing powder’ in spray dryers. The specific energy consumption of fluidised bed granulation is higher than in the normal spray drying process but the specific thermal energy consumption is lower.

If ‘extrusion paste’ for soft plastic shaping is produced by the use of ‘dust pressing powder’, the powder and returning slip cast is mixed until the water content is about 20-25 %. The extruded cylindrical sections are stored for some time to guarantee even moistness and tension. Organic additives and agents and inorganic binding agents such as magnesium chloride, magnesium sulphate, phosphate or borax are used to increase the strength of the plastic compounds for soft-plastic shaping.

Filter cake, waste from plastic compounds for hard-plastic shaping or ‘dust pressing powder’ are dissolved in water to produce casting compounds (casting slip). The water content of the casting slip is between 25 % and 35 %. To ensure a good slip characteristic, even with lower water contents, additives such as soda, sodium or potassium silicate, caustic or humic acid are used.

2.3.6.3 Shaping

There are three different types of shaping processes in the manufacture of household ceramics. Flatware such as plates and dishes are predominantly manufactured in the dry pressing process. Hollow wares, e.g. vases, are manufactured in the slip casting process, while cups and jugs are manufactured in the plastic shaping process.

In the dry pressing process, ‘dust pressing powder’ (water content of around 5 %) is pressed isostatically with auxiliary agents. The ‘dust pressing powder’ is filled into a press. The press consists of an upper and a lower part. In the lower part, the isostatic membrane works as the main ~~part~~point of compression. Depending on the product, the upper part of the press is designed in various shapes. Horizontal presses using multi-form heads are able to produce various products with a high output. Double head presses produce up to 1 200 pieces per hour. The powder is pressed into the form with a pressure of 30 MPa. The advantage of this process is the low water content of the green ware.

[Note to the TWG: please provide information to update the figures in the two paragraphs below]

In the plastic shaping process, the ‘extrusion paste’ (water content of between 20 % and 25 %) is formed in jiggering machines with the aid of profile tools. Dynamically balanced goods are produced in plaster moulds, which are manufactured in special facilities. The cylindrical plastic body is cut into similar slices. In the next step, the slices are mechanically apportioned to the plaster moulds of the jiggering machines. The lifetime of the plaster moulds is very short. Plaster moulds are often used for only a 100 to 150 pieces. Recently, porous moulds made of polymer materials have been employed to achieve a longer lifetime.
Non-dynamically balanced goods are produced in the slip casting process. Body formation takes place by dewatering the slip cast in plaster moulds. The solid casting process is used mainly for the production of flatware. Vases and jugs are manufactured in the drain casting process. Casting machines are used for manufacture on an industrial scale. Production on a small scale is carried out by hand-casting. The body formation time can be reduced under pressure. Pressure casting

takes place in porous polymer moulds under pressures of up to 4 MPa. Pressure casting is much faster than the conventional casting process, so that the casting cycles last for ~~two~~2 or ~~three~~3 minutes only.

Plastic pressing is an additional process used for the manufacture of household ceramics. Goods are manufactured in two-part plaster moulds or polymer moulds. Compared with the slip casting process ~~by~~ using a plastic body, this process reduces the body formation time considerably.

2.3.6.4 Drying

Goods produced in the slip casting process or in the plastic shaping process have to be dried in special dryers to a water content of ~~less than two per cent~~ < 2 %. Chamber and tunnel dryers heated with kiln waste heat, natural gas or extra light fuel oil ~~EL~~ is used for this dewatering. Infrared dryers and microwave dryers are an alternative to the conventional drying process. These dryers are employed for the pre-drying of the casting compounds and also for the drying of used and new plaster moulds. Microwave dryers are built as chamber, tunnel and chamber-passage dryers.

Surface roughness and mould marks resulting from the shaping process are removed in the dressing process. Dressing is carried out with knives and by subsequent treatment with a wet sponge rubber. Pressed and jiggered goods are cleaned predominantly by machines~~,~~; other goods are treated manually. For manufacturing on an industrial scale, the shaping, drying and dressing processes are united in one ~~stage of~~ manufactur~~e~~ing stage.

2.3.6.5 Firing, glazing and decoration

Household ceramics are fired between one and four times, depending on the material and the production technique. In the first step, biscuit firing gives the pieces ~~semi-product~~ the strength and absorbency needed for the glazing. Biscuit firing temperatures are between 900 ºC and 1 050 ºC, the firing time in classic tunnel kilns is between 18 and 30 hours. Fast firing kilns achieve firing times of between ~~three~~3 and ~~seven~~7 hours.

Glazing follows biscuit firing. The glaze consists of glassy compounds with a higher share of fluxing agents dispersed in water. Hollow goods (except for cups) are glazed by manual dipping. Flatware and cups are glazed mechanically in a pouring-glazing process, whereas small-scale production is glazed manually by dipping. Flatware is also glazed by spraying. Adhesive agents (for example polyamine or dextrine) are used as organic binding agents and glues. Electrolytes are mixed with the glaze to achieve faster drying.

The glost firing that follows is performed in an oxidising or reducing atmosphere at temperatures of between 1 320 ºC and 1 430 ºC. Glost firing kilns are tunnel kilns with tunnel kiln cars, (multi-rack) roller hearth kilns, fast firing tunnel kilns with moving firing tables, slab kilns or belt conveyer kilns. Periodic kilns such as chamber kilns, shuttle kilns and hood-type kilns are operated at lower feed rates. The ware to be fired is set on fireproof firing auxiliaries (~~so called~~ ‘kiln furniture’). Glost firing time varies between 25 and 36 hours in the tunnel kiln and between ~~three and a half~~3.5 and ~~five~~5 hours in fast-firing kilns without firing auxiliaries.

Table 2.20~~ 17 ~~and Table 2.21~~ 18~~ show examples of operating data of shuttle and tunnel ~~periodically and continuously operated~~ kilns [4, UBA 2001].

[Note to the TWG: please provide information to update the tables below]

Table 2.20: Operating data of a shuttle kiln

Shuttle kiln	Unit	Porcelain
Throughput	t/cycle	0.91
Firing chamber volume	m^3	7.0
Setting density	kg/m^3	12.8
Firing temperature	ºC	1 400
Specific energy requirement	kJ/kg	20 000
Flue-gas volume flow	m^3/h	12 500
Flue-gas temperature	ºC	800
Source: [9, COM 2007]		

Table 2.21: Operating data of tunnel kilns

Firing in ~~T~~tunnel kilns ~~Firing~~	Unit	Porcelain		Porcelain	Porcelain
		Biscuit	Glost	Glost fast	Glost fast
Throughput	t/h	0.3 – 0.7	0.2 – 0.4	0.58	0.47
Kiln length	m	60 – 100	80	70	56
Cross-section	m^2	0.5 – 1.0	0.5 – 1.0	0.7	0.94
Setting density	kg/m^3	60 – 70	60 – 70	<100	<100
Firing temperature	ºC	850 – 1 260	1200 – 1400	1 420	1 420
Specific energy requirement (drying + firing)	kJ/kg	25 000	20 000	12 500 without drying	19 700
Flue-gas volume flow	m^3/h	3 500 – 5 000	3 500 – 5 000	n.a.	n.a.
Flue-gas temperature	ºC	120 – 170	120 – 170	n.a.	n.a.
Source: [9, COM 2007]					

The glaze melts during the firing process and seals the porous ceramic body. The surface becomes watertight and smooth. After the glost firing, the goods are divided into corresponding quality grades. Areas with no glaze are ground and polished to maximise the value of the products.

Bone china is a speciality for traditional tableware and tea services. Important raw materials for bone china are Cornish clay, Cornish stone and up to 50 % calcined bovine bones. The glos~~s~~t firing temperatures are between 1 250 ºC and 1 350 ºC, and biscuit firing temperatures are between 1 100 ºC and 1 150 ºC. A kiln atmosphere with glaze vapour ensures a very smooth surface.

The decoration process which follows~~,~~ maximises the value of the product and permits customisation. On-glaze colours, in-glaze colours, under-glaze colours and metal compounds are used for the decoration. In the on-glaze decoration process, glazed and already fired goods are decorated. On-glaze decoration is melted into the glaze by an additional firing process. In the in-glaze decoration process, the coloured pigments sink into the glaze. In the under-glaze decoration process, the goods are decorated before the glazing process starts. Typical decoration processes are the slide-off transfer, reprinting, direct silk screen printing, offset printing, lining, banding, stamping, powdering, painting, spraying, stencilling and etching. Besides manual decoration, machines for silk screen printing and coloured printing are employed. Numerous oxides are set in as fluxing agents, opacifiers and for direct colouring in the glazing and decoration processes. The glaze and decoration colours consist of complex systems of numerous pigments. In the following list, the elements and their chemical valence (in brackets), in which they appear as oxide compounds in the pigments, are mentioned: Cu (1, 2), Ca (2), Zn (2), Al (3), In (3), Si (4), Sn (4), Pb (2), Ti (3, 4), Zr (4), Ce (4), Pr (4), V (4, 5), Sb (3, 4, 5), Cr (3, 6), Mo (4, 6), Mn (2, 4), Fe (2, 3), Co (2), Ni (2) ~~u~~and Cd (2).

In addition to the decoration process, examples of operating data of different kilns are presented in Table 2.22 ~~19~~ and Table 2.23 ~~20~~ [4, UBA 2001], [21, Almeida, M., Vaz, S., Baio, D. 2004].

[Note to the TWG: please provide information to update the tables below]

Table 2.22: On-glaze decoration operating data

Type of kiln	Process	Firing temperature (ºC)	Firing time
Electric melting kiln with basket transportation	Melting decoration	760 – 840	2 – 4 h
Fast firing tunnel kiln (sledge or firing table)	On-glaze decoration	850 – 950	40 – 70 min
Roller hearth kiln with firing auxiliaries	On-glaze decoration	850 – 950	40 – 70 min
Roller hearth kiln with quartz goods	On-glaze decoration	1 080	40 – 70 min
Double track belt conveyer kiln	On-glaze decoration	850 – 950	40 – 70 min
Double track belt conveyer kiln (special belt)	On-glaze decoration	1 050	40 – 70 min
Tunnel kiln with plate transportation	Hard-firing decoration	1 300 – 1 400	7 – 16 h
Shuttle kiln	On-glaze decoration	850 – 950	8 – 10 h
Source: [9, COM 2007]			

Table 2.23: In-glaze and under-glaze decoration operating data

Type of kiln	Process	Firing temperature (ºC)	Firing time
Shuttle kiln	Hard-firing decoration	1 300 – 1 400	14 – 24 h
Fast firing tunnel kiln (sledge or firing table)	Hard-firing decoration	1 350 – 1 420	2 – 4 h
Fast firing tunnel kiln (sledge or firing table)	In-glaze decoration	1 200 – 1 280	60 – 90 min
Roller hearth kiln with special rolls	In-glaze decoration	1 200	60 – 90 min
Shuttle kiln	Under-glaze decoration	1 370 – 1 420	18 – 30 h
Tunnel kiln with kiln car	Under-glaze decoration	1 370 – 1 420	18 – 30 h
Tunnel kiln with firing table	Under-glaze decoration	1 370 – 1 420	12 – 16 h
Fast firing tunnel kiln (sledge or firing table)	Under-glaze decoration	1 370 – 1 420	3 – 4 h
Roller hearth kiln with special rolls	Under-glaze decoration	1 350	2 - 4 h
Source: [9, COM 2007]			

Another household ceramics manufacturing process, which is applied in a few cases, involves only one firing process without prefiring. This one-time firing process suffices for undecorated products and for products with decorations applied prior to the glazing. The firing takes 20 hours in shuttle kilns, at a temperature of 1 260 ºC. Gold, platinum and other metallic colours have to be fired at the lower temperature of 890 ºC [17, Burkart, M. 2004] [22, SYKE 2004]

In the household ceramics manufacturing process, mainly natural gas and liquefied petroleum gas are used as fuels in the different types of kilns. Fuels such as extra light fuel oil ~~EL~~ are rarely used in this sector.

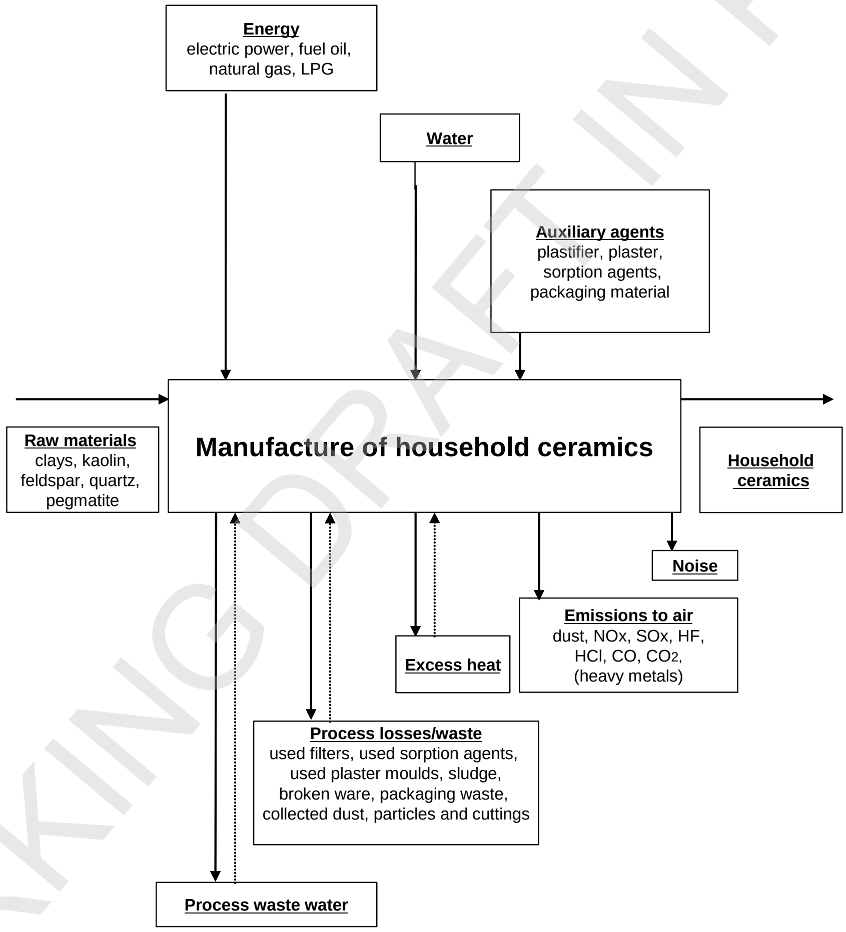
2.3.6.6 Subsequent treatment

After decoration and quality control, the products are sorted. The ~~wet~~ subsequent wet treatment is carried out by grinding and polishing machines to smooth the surface of the products. Certain products are pre-packed mechanically. Then the sets for sale and dispatch are put together and manually packed. For the manufacture of modern tableware, pieces ~~semi-products~~ are handled automatically by robots between the shaping, drying, firing and subsequent treatment stages.

~~2.3.6.7 Input and output flows in the manufacture of household ceramics~~

[Note to the TWG: this section has been merged with Section 2.3.6]

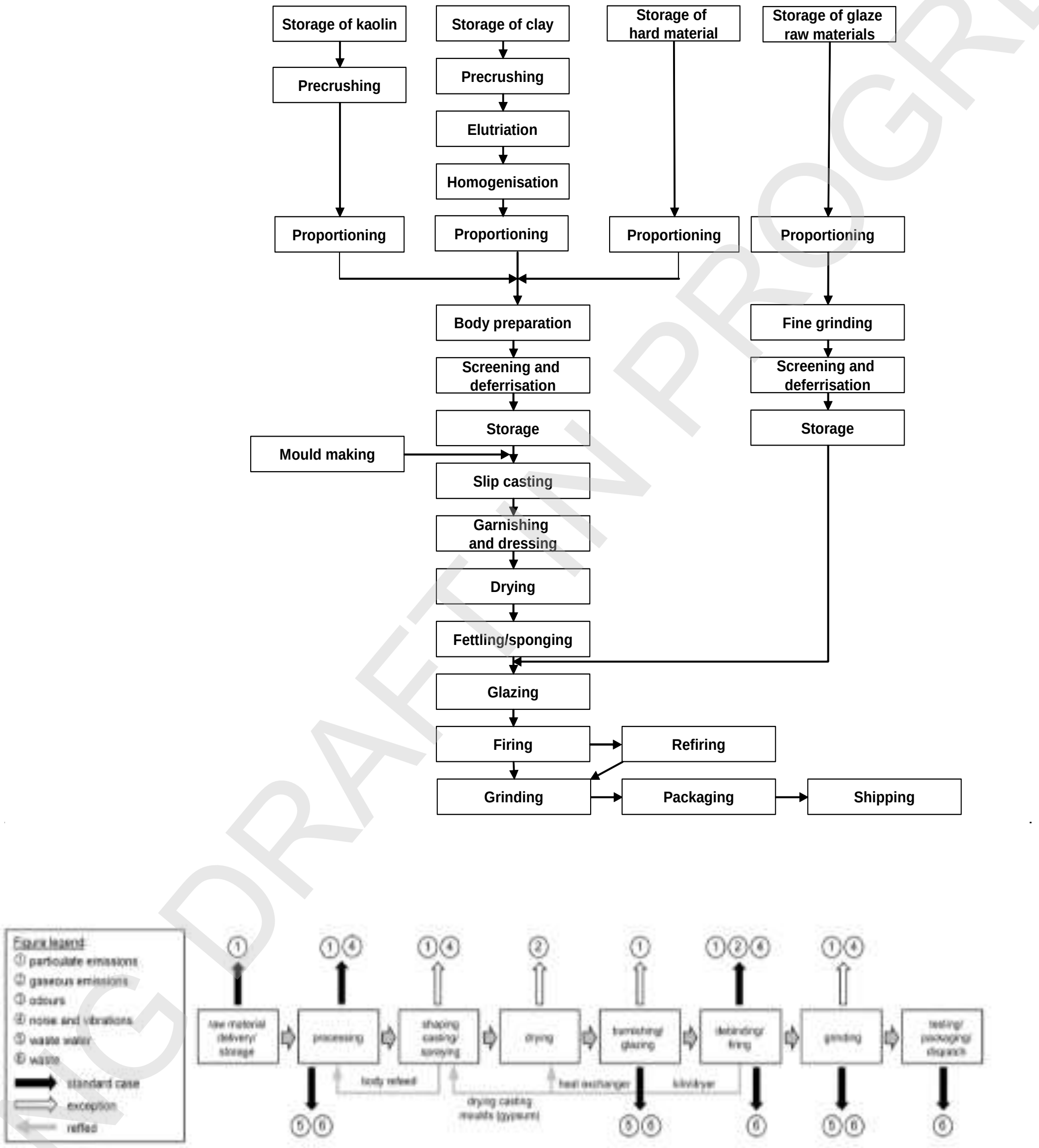
~~Important input and output flows of the household ceramics manufacturing process are presented in the following figure [4, UBA 2001], [23, TWG 2005].~~



~~Figure 2 39: Input and output flows in the manufacture of household ceramics~~

2.3.7 Sanitaryware

The main process steps in the manufacture of sanitaryware are storage of raw materials, preparation of raw materials, shaping, drying and glazing, firing and subsequent treatment. ~~The following figure~~ Figure 2-33 shows a schematic view of the sanitaryware manufacturing process [4, UBA 2001], [23, TWG 2005].

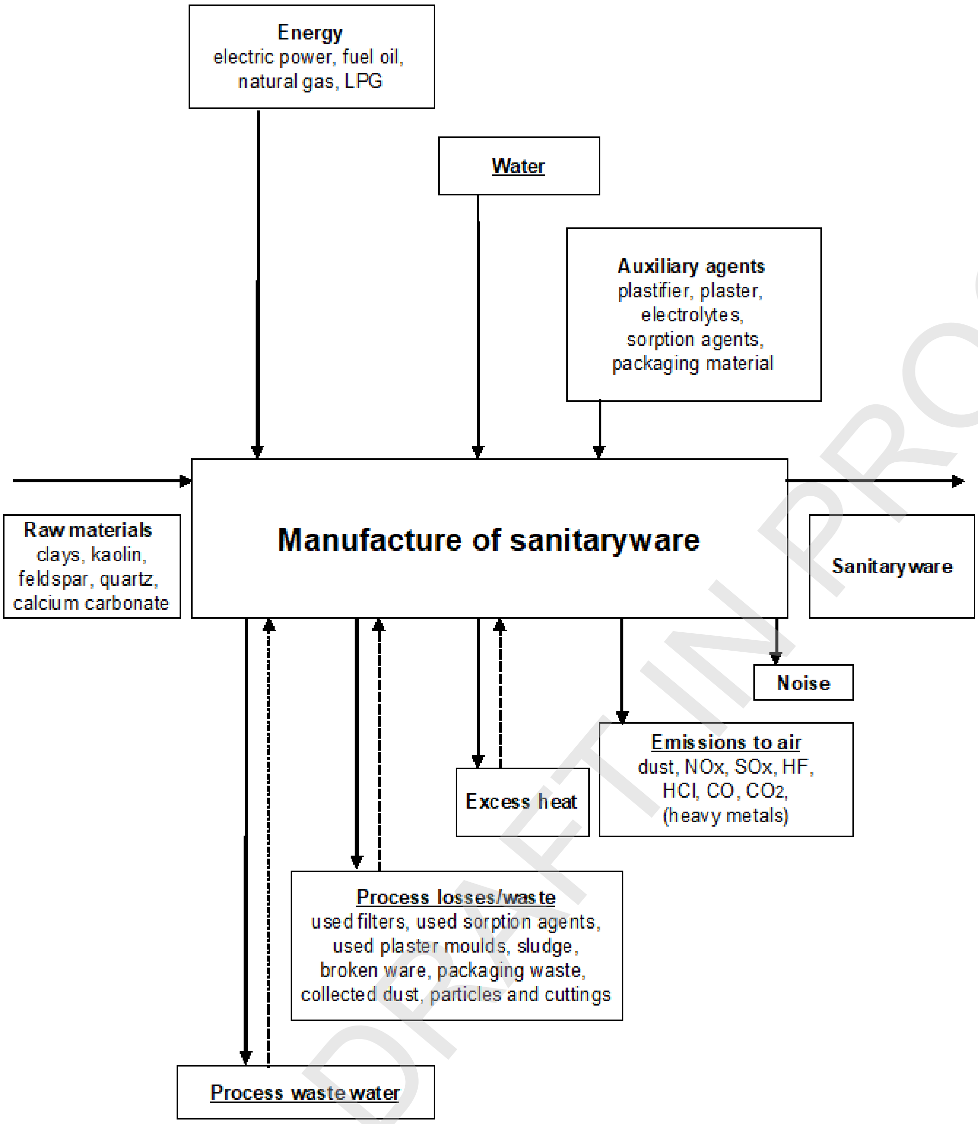


Source: [9, COM 2007] , [52, VDI 2018]

Figure 2-33: Schematic view of the manufacture of sanitaryware

[Note to the TWG: this section has been moved from Section 2.3.7.7]

Important input and output flows of the sanitaryware manufacturing process are presented in Figure 2-34 ~~the following figure~~ [4, UBA 2001], [23, TWG 2005].



Source: [9, COM. 2007]

Figure 2-34: Input and output flows in the manufacture of sanitaryware

2.3.7.1 Raw materials

The applicable raw materials are kaolin, clay, quartz, feldspar and calcium carbonate. A typical batch consists of 40-50 % kaolin and clay, 20-30 % quartz, 20-30 % feldspar and between 0 % and 3 % calcium carbonate. Kaolin is ~~stored~~ preferably stored in lumps with a maximum water content of 15 %~~ per cent~~. Hard materials such as quartz and feldspar are ground to small particles and applied with a water content of ~~less than one per cent~~ < 1 %. The raw materials are stored in silos or boxes to avoid any atmospheric influence.

2.3.7.2 Preparation of raw materials

The preparation of raw materials for sanitaryware is performed predominantly in a wet preparation process. Kaolin and clay are hackled in toothed roll crushers or similar units. After this step, the materials are reduced to a particle diameter of less than ~~five millimetres~~ 5 mm in the fine grinding process. The material is elutriated in water and impurities are removed from the slurry by screening. Following this step, the screened clay suspension is homogenised in tanks by slow stirrers. The proportioning of hard materials is performed gravimetrically and electrolytes are added.

~~This preparation of the raw materials is not often performed by the ceramic manufacturer~~ The ceramic manufacturer does not usually prepare the raw materials. The delivered raw materials are often only proportioned by the manufacturer, followed by the real production of slip in blungers [23, TWG 2005].

The subsequent storage in stirred tanks over a couple of days increases the shaping characteristics of the casting slip. Liquefactions and stability agents such as soda, water glass, caustic, potash and humic acid compounds are employed to achieve castability connected with a low water content. The glaze materials are proportioned and then mixed and ground in ball mills (batch) or in horizontal or annual gap mills (continuous). Binding agents such as carboxymethyl cellulose or polyamine are added to the glaze to maximise adhesion and gripping strength after the grinding. Deferrisation of body and glaze is carried out by permanent magnets to avoid colouring the products through magnetic impurities.

2.3.7.3 Shaping

Most ceramic goods are still shaped in plaster moulds today. The development trend is towards a plaster-free shaping process performed in porous polymer moulds. The casting process normally takes place in plaster moulds. Water leaves the casting slip through the porous areas of the plaster moulds to form the body. The body formation time is reduced by pressure. Complex sanitary goods are produced in the drain casting process. Additional solid casting parts are manufactured in a parallel process and are added and connected to the main body. In this ~~garnishing~~ process, the final shape of the product is created. After the separation of body and mould, the mould marks are fettled and further treated. The handling and dressing of the body is performed mostly automatically.

[Note to the TWG: please provide information about the use of plastic moulds]

Bodies of sanitary ceramics are increasingly formed ~~more and more~~ by machines with multi-piece polymer moulds in combination with pressure casting. Depending on the article, four- or five-piece polymer moulds are used. Pressure of up to 3 MPa minimises the body formation time. The shaping cycle of lavatory bowls is reduced to ~~five to eight~~ 5-8 minutes. Fettling and garnishing is usually performed while the body is fixed in the mould. The advantages of polymer moulds compared with plaster moulds are that they are easier to clean and have a longer lifetime.

2.3.7.4 Drying and glazing

The green ware is dried in two stages. After the leather-hard drying, the green ware is perfectly treated. The following white drying minimises the water content down to less than ~~one per cent~~1 %. The drying process takes place in tunnel or chamber dryers. Microwave dryers are built as tunnel dryers and are also used for leather-hard and white drying. ~~The following table~~ Table 2.24 shows examples of operating data of periodically operated dryers [4, UBA 2001], [21, Almeida, M., Vaz, S., Baio, D. 2004].

[Note to the TWG: please provide information to update the table below]

Table 2.24: Operating data of periodically operated dryers (chamber dryers)

Chamber dryers	Unit	Lavatory bowls and wash basins
Throughput	t/cycle	4 – 45
Drying chamber volume	m^3	30 – 375
Setting density	kg/m^3	30 – 200
Drying temperature	ºC	60 – 90
Drying time	h	8 – 20
Specific energy requirement	kJ/kg	300 – 1 400
Flue-gas volume flow	m^3/h	2 000 – 20 000
Flue-gas temperature	ºC	60 – 150
Source: [9, COM 2007]		

After white drying, the green ware is inspected and the surface is cleaned of dust and foreign particles. The glaze is applied to the surface of the ware by spraying, performed by robots and hand spraying. The thickness of the glaze is between 0.3 mm and 0.5 mm, depending on the colour of the body and the share of opacifiers ~~share of~~ in the glaze. Spraying in an electric field maximises the quality of the glaze.

2.3.7.5 Firing

Sanitaryware is fired in tunnel kilns and roller hearth kilns at temperatures of between 1 250 ºC and 1 290 ºC in an oxidising atmosphere. Small-scale production is carried out in flexible periodically operated kilns such as shuttle kilns. Shuttle kilns are operated to change the product-specific firing curve in very short cycles. Ranges of operating data of kilns for the manufacture of sanitaryware are presented in Table 2.25 ~~22~~ and Table 2.26 ~~23~~ [23, TWG 2005], [21, Almeida, M., Vaz, S., Baio, D. 2004], [30, TWG 2005].

[Note to the TWG: please provide information to update the two tables below]

Table 2.25: Operating data of tunnel kilns

Tunnel kiln	Unit	Sanitaryware
Throughput	t/h	1.5 – 2.0
Kiln length	m	70 – 110
Cross-section	m^2	1.5 – 2.5
Setting density	kg/m^3	100 – 150
Firing temperature	ºC	1 250 – 1 290
Specific energy requirement	kJ/kg	8 300
Flue-gas volume flow	m^3/h	12 000
Flue-gas temperature	ºC	150 – 550
Source: [9, COM 2007]		

Table 2.26: Operating data of shuttle kilns

Shuttle kiln	Unit	Sanitaryware
Throughput	t/cycle	5 – 15
Firing chamber volume	m^3	50 – 150
Setting density	kg/m^3	100
Firing temperature	ºC	1 210 – 1 250
Specific energy requirement	kJ/kg	8 300 – 11 300
Flue-gas volume flow	m^3/h	up to 50 000
Flue-gas temperature	ºC	150 – 550
Source: [9, COM 2007]		

In the sanitaryware manufacturing process, natural gas and liquefied petroleum gas are mainly used as fuels in the different types of kilns. Fuels such as extra light fuel oil ~~EL~~ and heavy fuel oil are rarely used in this sector. Broken fired ware and refractory waste arise in the firing process. Broken fired ware consists of faulty goods after the firing process. Refractory waste results from broken parts of the kiln or from broken firing auxiliaries or tunnel car parts.

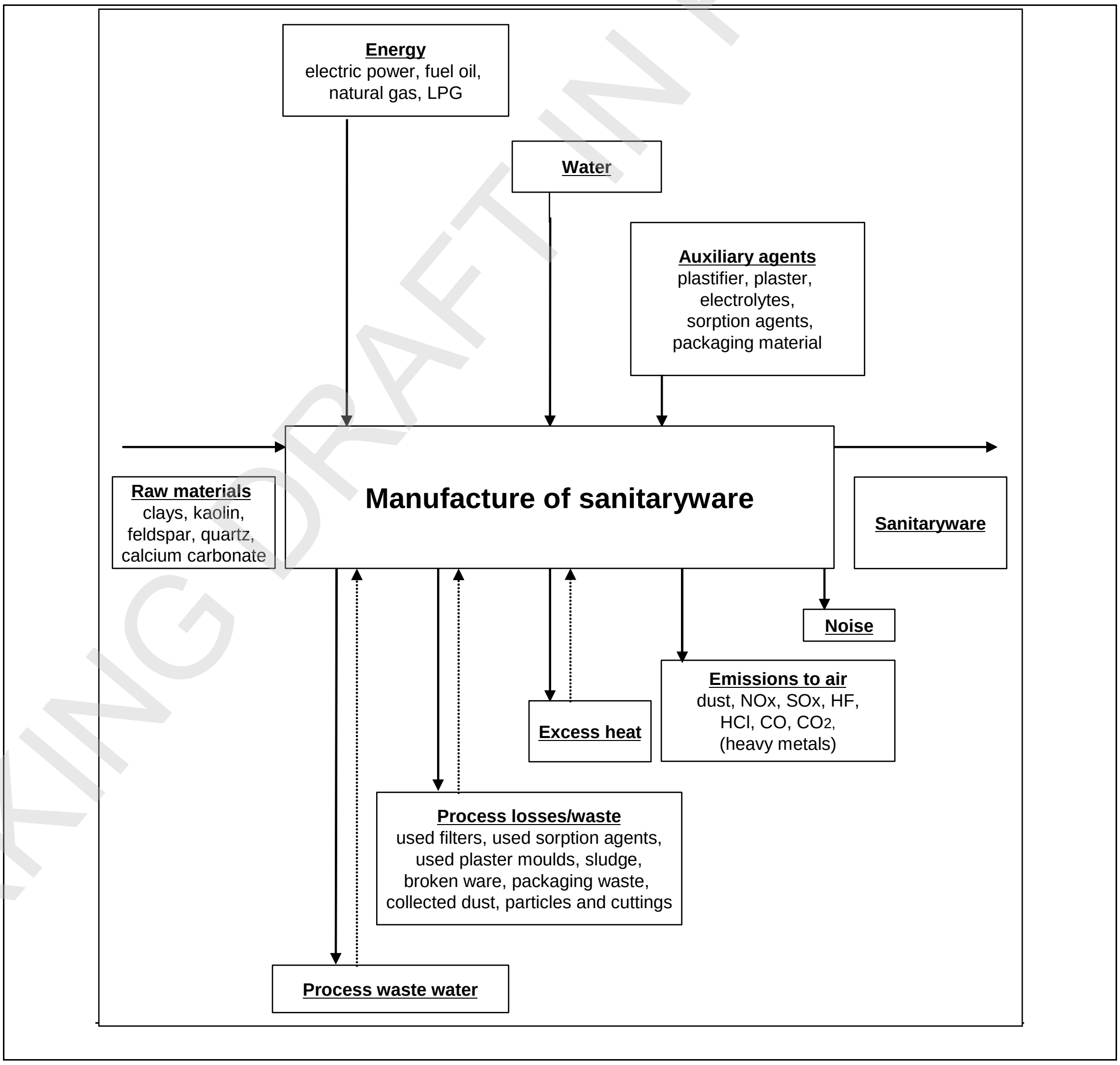
2.3.7.6 Subsequent treatment

After the final sorting, mounting surfaces are abraded by wet grinding and polishing. In special cases, fittings are added to lavatory bowls and cisterns followed by the final packaging.

~~2.3.7.7 Input and output flows in the manufacture of sanitaryware~~

[Note to the TWG: this section has been merged with Section 2.3.7]

~~Important input and output flows of the sanitaryware manufacturing process are presented in the following figure [4, UBA 2001], [23, TWG 2005].~~



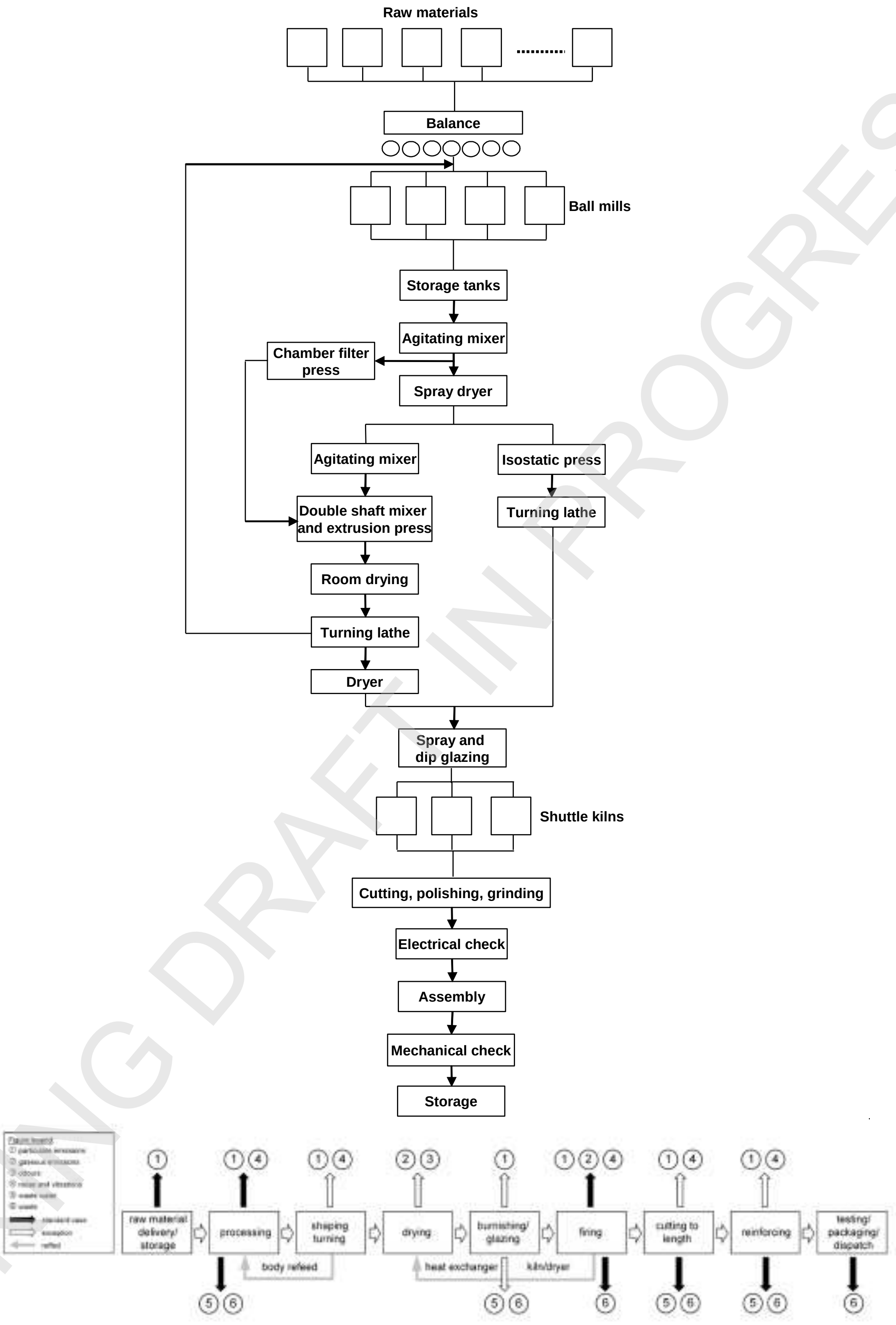
~~**Figure 2 42: Input and output flows in the manufacture of sanitaryware**~~

2.3.8 Technical ceramics

Technical ceramics are not only based on clays, but also on synthetic raw materials. Like the other ceramic sectors, the raw materials are fired in kilns, using mainly natural gas, but also electrical energy ~~for the firing process~~.

Because of the wide variety of technical ceramics and manufacturing process variants involved, a general schematic view of the manufacturing process cannot easily be defined, but examples of schematic views of different manufacturing processes can be shown.

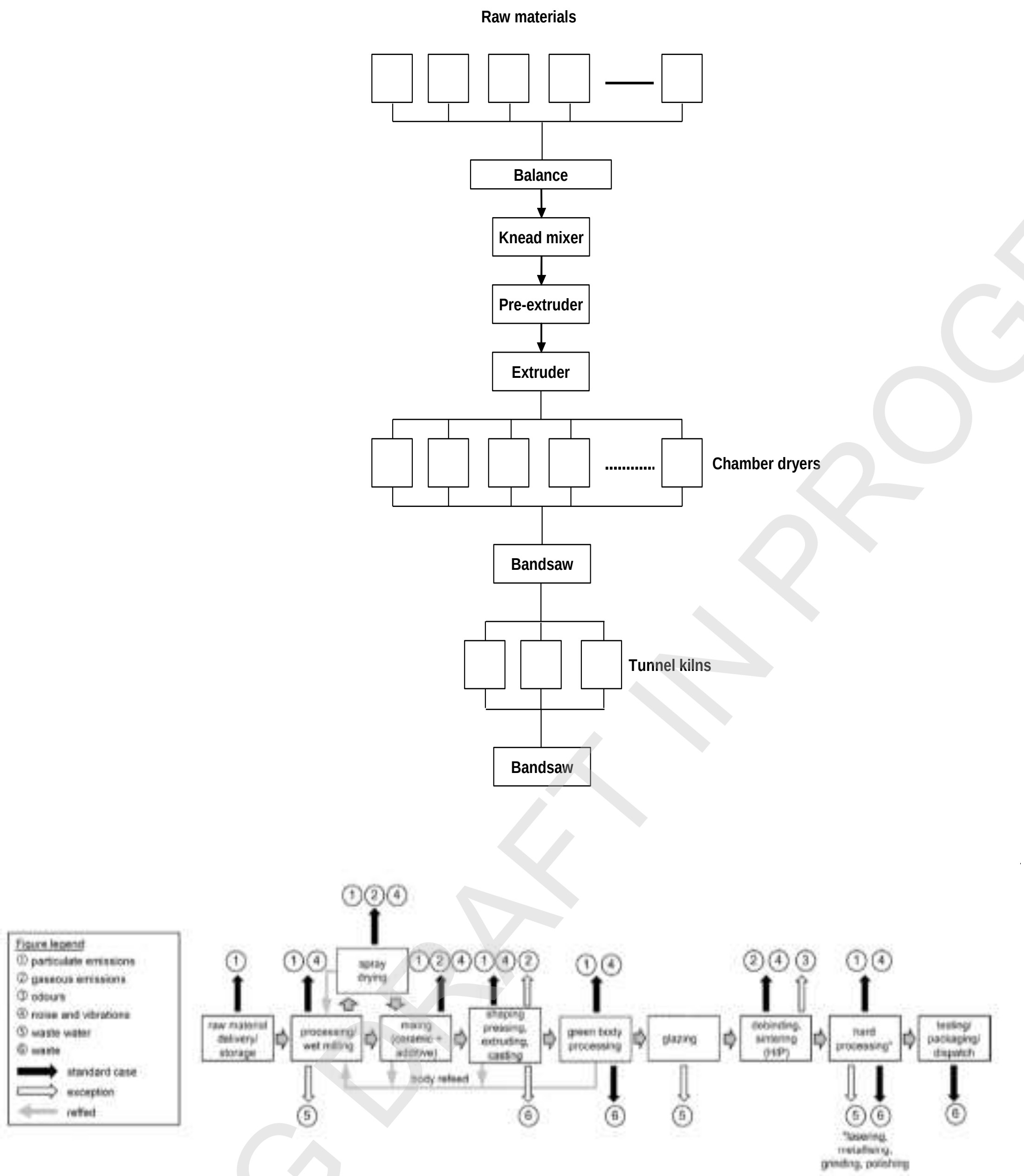
~~The following figure~~ Figure 2-35 shows the schematic view of an electrical insulator manufacturing process [1, BMLFUW 2003].



*Sourc*e: [9, COM 2007], [52, VDI 2018]

Figure 2-35: Schematic view of an electrical insulator manufacturing process

~~The following figure~~ Figure 2-36 shows the schematic view of a technical ceramic ~~catalyst~~ manufacturing process of components for high-performance electronics ~~[1, BMLFUW 2003]~~.

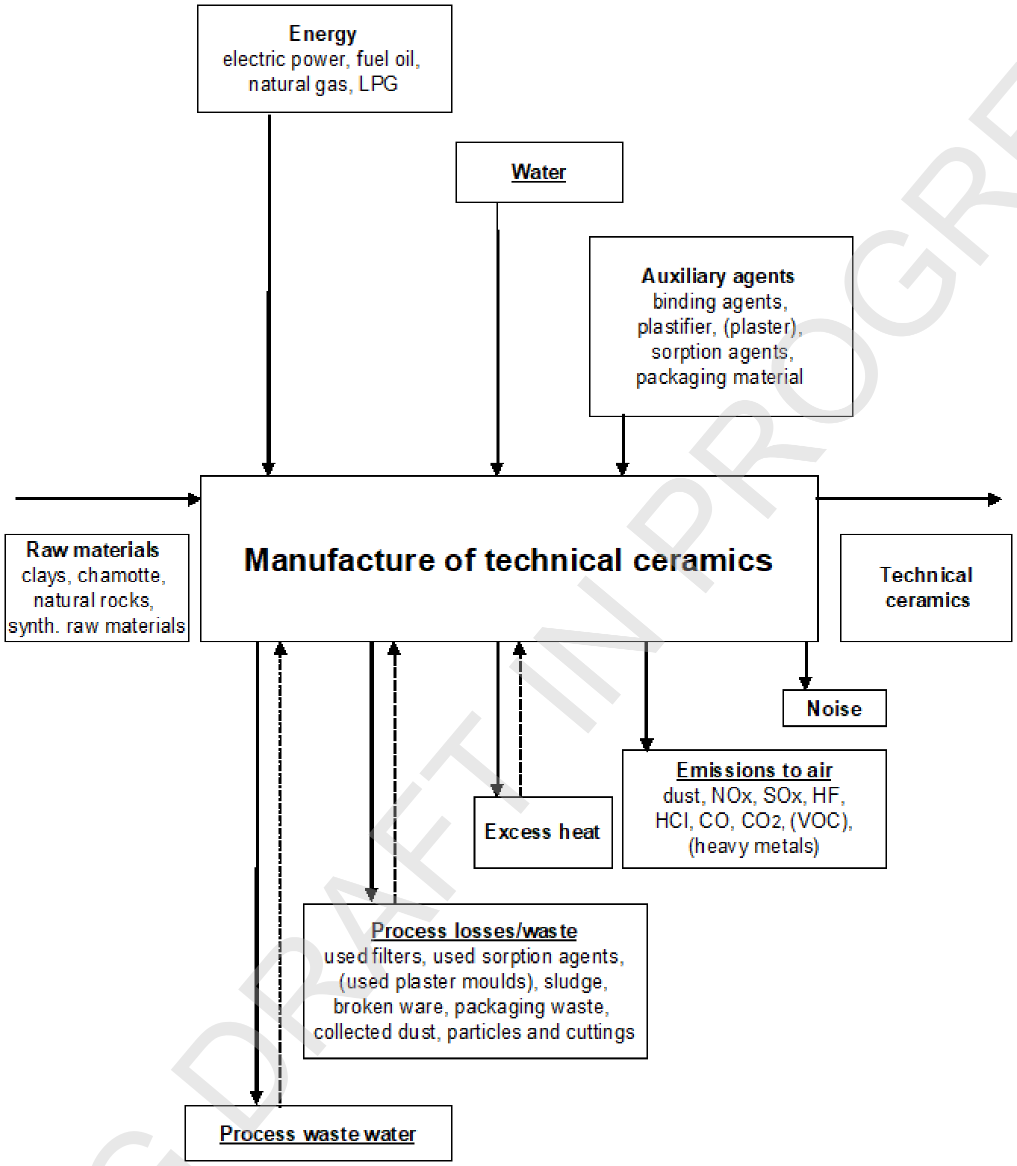


Source: [9, COM 2007], [52, VDI 2018]

Figure 2-36: Schematic view of a ceramic catalyst manufacturing process of components for high-performance electronics

[Note to the TWG: this section has been moved from Section 2.3.8.7]

Important input and output flows of technical ceramics manufacturing processes are presented in ~~the following figure~~ Figure 2-37 [23, TWG 2005], [24, VKI-Germany 2004].



Source: [9, COM. 2007]

Figure 2-37: Input and output flows in the manufacture of technical ceramics

2.3.8.1 Raw materials

Technical ceramics, which contain only a small fraction of clay or none at all, are based on the following materials: oxides, carbides, nitrides and borides of Al, Mg, Mn, Ni, Si, Ti, W, Zr and other metal ions. Typical examples are Al_2O_3 (alumina), MgO (periclase or dead-burned magnesia), SiC (silicon carbide), TiN (titanium nitride) and WB_2 (tungsten boride) [8, Ullmann's 2001].

However, plastic clays (e.g. kaolin), feldspar and quartz can also serve as raw materials for technical ceramics, for example for the manufacture of electrical insulators [1, BMLFUW 2003].

Additionally, additives (auxiliary agents) such as (inorganic) sintering aids and (usually organic) forming aids, such as liquefaction agents, plasticisers or binders are applied, which are as significant as the raw materials themselves [24, VKI-Germany 2004].

2.3.8.2 Preparation of raw materials

There are two possibilities for the preparation of raw materials:

a) The technical ceramics manufacturer acquires the necessary raw materials and carries out all further processing tasks. Specific preparations of unfired material are required for the different shaping processes:
   - granulates – for pressing;
   - plastic material – for extrusion;
   - slips – for casting.

b) The technical ceramics manufacturer acquires ready-prepared unfired material, and begins at the proportioning or shaping stage of the ceramics process [24, VKI-Germany 2004].

Technical ceramics often require chemical conversion of raw materials into intermediate compounds. These intermediates lend themselves to purification and eventual chemical conversion into a final form. For some technical ceramics, specialised powders have to be synthesised and a variety of chemical routes can be used to synthesise these powders. Chemical routes, such as sol-gel processing, can also bypass the powder stage.

Requirements for high strength and smooth finishes, particularly of small parts, necessitate fine-grained powders. Thus, one line of technical ceramics research aims at producing very fine essential spherical, monosized particle powders. These are typically made by colloidal chemistry for oxides. The above-mentioned nitrides and carbides involve controlled nucleation and growth in gas-phase reactions. However, most high-technology ceramics are still made from powders ~~a~~ with a broad size distribution in the submicromet~~e~~re range [8, Ullmann's 2001].

Some raw materials are calcined (‘dead-burned’ at high temperatures), in order to make them suitable for the manufacture of technical ceramics. For more information on this, see Section 2.2.2.8.

~~Also t~~The spray drying process is also employed in the manufacture of technical ceramics. The aqueous suspension of raw material resulting from wet ball milling (solids content ~ 60-70 %) is sprayed under pressure to produce fine droplets which come into contact with a stream of hot air. Drying of the droplets produces highly uniform, more or less spherical hollow granules (moisture content typically 5.5-7 %). This form of ‘dust pressing powder’ ~~has high flowability~~ flows easily, facilitating accurate filling of the press dies and the subsequent pressing of technical ceramic products [3, Ceram-Unie 2003].

It should be noted that especially synthetic materials, such as silicon carbide, calcined raw materials and also spray-dried ‘dust pressing powder’ are often manufactured by specialist suppliers, but may still need to go through a comminution process.

However, not only is ‘dust pressing powder’ produced, but also ‘extrusion paste’~~ is produced~~, particularly if plastic clays serve as the raw materials for technical ceramics (e.g. for the manufacture of electroporcelain or ceramic catalysts) [1, BMLFUW 2003]. To produce ‘extrusion paste’, the ground suspension is dewatered in filter presses or rotation filters to a water content of between approx~~.~~imately 20 % and 25 %.

Another possibility for raw materials preparation is the production of casting slip in a wet preparation process. The delivered raw materials are often only proportioned by the manufacturer, followed by the step of slip production in blungers [23, TWG 2005].

2.3.8.3 Shaping

Methods of shaping technical ceramic parts can be divided into the following basic types [24, VKI-Germany 2004]:

- pressing (0-15 % moisture; dry, isostatic, moist and wet pressing);
- plastic shaping (15-25 % moisture; extrusion);
- casting (> 25 % moisture; injection moulding, slip casting, tape casting).

Dry pressing
Dry pressing is used to manufacture mass-produced precision products. Non-clumping granulates are compressed in steel dies designed appropriately for the part to be manufactured. The high cost for the dies (sometimes made of carbide) can only usually be justified for large runs.

Dry pressing is the most economic process for large production runs, and is suitable for both simple and complex geometries. Depressions and holes are normally only designed in the pressing direction. Depending on the design of the dry pressing machine, components ranging in size from tiles down to match-heads can be manufactured. Small discs or plates can be pressed with thicknesses of around 0.8 mm or 1.0 mm. It is still possible to manufacture fine ridges or similar structures on the component if the granulate being pressed can effectively fill hollows in the pressing tool, and provided it is possible to create the necessary tool.

Isostatic pressing
Isostatic pressing is suitable for the manufacture of uniformly compressed blanks and large parts, which are appropriate for machining in the green state. High-quality products of the technical ceramics sectors require uniform densification of ‘dust pressing powder’, which can be achieved by applying pressure equally on all surfaces. In the isostatic press, rubber or polyurethane moulds are filled with ceramic powder and placed in a liquid-filled vessel. A high hydrostatic pressure is then applied, followed by de-moulding of the objects.

This type of forming is well suited to the manufacture of ambitious prototypes and small series, but for some products isostatic pressing can also be fully automated (spark plugs, grinding balls, small pistons, welding nozzles).

Wet pressing/moist pressing
Wet pressing/moist pressing allows the manufacture of parts with complex geometries such as screw threads, side holes, recesses and undercuts. The unfired material used for this purpose usually has moisture levels in the range of ~~between~~ 10 % to 15 %. Compressing with a single axis makes these materials able to flow freely, so that relatively even compression can be achieved. The disadvantage of this, however, is that wet pressing materials can accept only low compressive strains. This also means that the degree of compression is limited. It depends heavily on the moisture content of the unfired material, and is lower than in the case of dry pressed parts.

Under some circumstances, moreover, it is necessary to dry the pressed parts before firing. Mean tolerances in accordance with DIN 40680-1 are based on this.

Extrusion
Extrusion is carried out using piston extruders or vacuum screw presses. In the plastic shaping process, for example for the manufacture of electrical insulators, the ‘extrusion paste’ (water

content of between 20 % and 25 % or between 19 % and 23 % in high-voltage insulator extrusion) is shaped in an extruder to the right geometry, cut into pieces and additional shaping with turning lathes is carried out [1, BMLFUW 2003], [23, TWG 2005].
Extrusion is also suitable for manufacturing other rotationally symmetrical parts such as axles or pipes. Complex profiles can additionally be made with the aid of appropriate nozzle designs. The lengths of the billets to be manufactured depend to a large extent on the tendency of the processed material to warp.

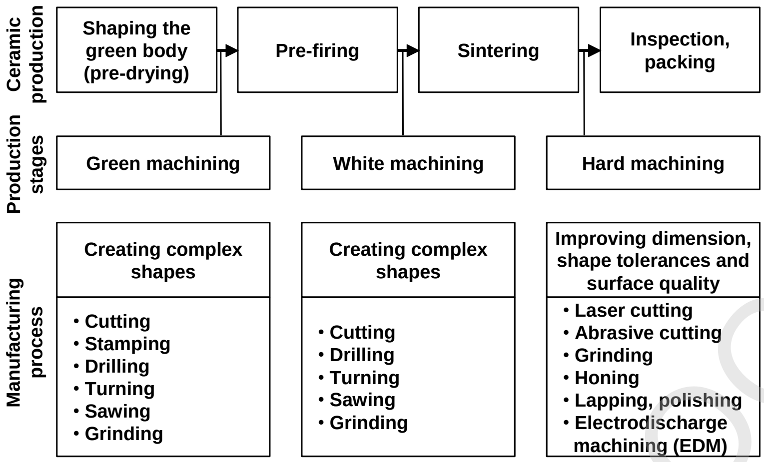
Injection moulding
Injection moulding is principally suited to the mass production of complex products. It is limited by relatively high costs and the complex burnout of organic additives. The conveying capacity ('shot weight') of large injection moulding machines is typically up to about 70 g. Generally, the part should be designed so that thicknesses are as consistent as possible, having an upper limit of approx~~.~~imately 12 mm.

Slip casting
Slip casting is a simple method for the manufacture of prototypes, parts with complex geometries and relatively large items. It can be used to manufacture both thin-walled and solid objects. Ceramic slip casting involves a stable suspension, referred to as the slip, being poured into a porous, absorbent plaster mould. Extraction of the suspending liquid causes a layer of particles to develop on the mould wall. This layer develops, in solid casting, to create the fully moulded body. In the case of hollow casting, the superfluous slip is poured out once the desired wall thickness has been achieved.

Tape casting
Tape casting means that a ceramic slip containing various organic additives is poured onto an endless steel strip carried by rollers. The slip flows continuously from a reservoir through an adjustable slot onto the strip. Hot air is blown over the strip in the opposite direction to dry it, so that at the end of the strip, because of the organic additives, a flexible tape of green ceramic is obtained. This can either be wound up and stored for further processing at a later time, or maybe processed immediately through cutting, punching, stamping or other similar methods. Tape casting is typically used to manufacture ceramic parts with thicknesses ranging from 0.25 mm to 1.0 mm. The formed products are suited for the manufacture of substrates, housings, capacitors and multilayer transducers.

2.3.8.4 Machining

As shown in ~~the following figure~~ Figure 2-38, green machining (after drying), white machining (after burning out and prefiring) and hard machining (after firing/sintering) can be distinguished [24, VKI-Germany 2004].



Source: [9, COM 2007]

Figure 2-38: Green, white and hard machining in the manufacture of technical ceramics

Green machining is performed on the dry parts while they still contain organic additives. It is well suited to the manufacture of individual parts and small series. It is also used with large series to manufacture shapes that cannot be ~~realised~~ obtained directly by initial shaping procedures, such as holes transverse to the direction of dry pressing.

White machining is performed on the prefired parts, now free from organic additives. The strength depends on the prefiring. In this way, extremely high removal rates can be achieved with relatively low tool wear, using conventional, ceramic or diamond~~-~~–coated tools. This process is used by manufacturers both for making prototypes and for mass production.

Hard machining is carried out on fully fired/sintered items that have been brought as close as possible to the final dimensions through forming, or through green or white machining. The closest possible tolerances can be achieved through a final machining procedure involving material removal. Tight requirements for dimensional precision and the wide variety of geometries and surface qualities require the use of modern machine tools for processing ceramic components. Due to the ~~high~~ extreme hardness of ceramic materials, diamond tools (bonded or pastes) are used here almost exclusively.

2.3.8.5 Glazing, engobing and metallisation

Glazing and engobing

By applying a glaze, surfaces are made smooth and visually more attractive, but, above all, the glaze may noticeably improve many technically important properties of the ceramic product (for example, electrical behaviour, mechanical strength, resistance to chemicals~~, etc.~~). A wide variety of glaze colours can be created by mixing in colo~~u~~rants (metal oxides). In order to achieve a possible increase in strength, the thermal expansion coefficient of the glaze must be matched to that of the body very precisely. A slight compressive stress in the glaze increases the strength of the finished product, but tensile stress reduces this effect, and is thus undesirable.

In contrast to glazes~~ing~~, an engobe is porous and largely free from glass phase material. It usually consists of fire-resistant oxides (Al_2O_3, SiO_2, MgO, ZrO_2), mixtures of these, or of fire-resistant minerals such as mullite, spinel, zircon silicate, or even kaolin or clay. Engobes are used in furnace engineering to protect ceramic surfaces from mechanical or corrosive attack. Applied to fire-resistant kiln furniture such as plates, beams or cases, engobes prevent both contact reactions with the supported firing materials and adhesion ~~from~~ of any glaze running off the fired items that are standing on the coated kiln furniture [24, VKI-Germany 2004]

A thin mineral glaze or engobe layer is applied to ceramic surfaces by dipping, rolling, spraying or brushing.

Metallisation

Some manufacturers of technical ceramics offer metallised ceramics. Aluminium oxide and aluminium nitride are available as substrate materials. The metallisation offered is suitable for brazing and also for soft soldering and consists of a base metallisation of tungsten ~~having~~ with a layer thickness of at least 6 µm, applied by a screen printing process. A layer of nickel, applied non-electrolytically, with a minimum thickness of 2 µm, is applied on top to assist the flow of solder. A gold layer with a thickness of approx~~.~~imately 1 µm can be deposited to protect against corrosion. Alternatively, the non-electrolytically applied nickel layer can be reinforced with a bondable gold layer. An additional layer of tin can also be applied if soft soldering is carried out [24, VKI-Germany 2004].

2.3.8.6 Drying, burning out and pre-firing

Drying

Depending on the wide variety of raw materials and process variants, which are tailor-made to ~~reach~~ achieve the specific product properties, different types of dryers are used, but often chamber dryers are applied, especially if small-scale production is undertaken.

Burning out

Green bodies shaped from plastic material are usually resistant to breakage in this state, but this resistance can still be improved with the aid of organic additives. Such additives are, however, indispensable when the unfired material is not plastic. Burning out the remaining plasticisers and binders along with other organic additives requires a carefully adapted temperature-pressure-atmosphere-time profile in order to achieve a non-destructive and reproducible removal of these additives from the finely porous green body. One variation of burning out is referred to as ‘carbonising’ or ‘coking’, for example with SiC. Here, organic components are converted to carbon, which remains in the structure and is converted, with the help of added reagents, to a ceramic matrix during the sintering reaction. After the drying and burning out (or carbonising/coking), the structure of the green body (pressed powder with the shape of the component) is held together only by weak cohesive forces, and requires particularly careful handling during the subsequent process steps. For this reason, drying and burning out are integrated with the firing/sintering wherever possible [24, VKI-Germany 2004].

Pre-firing

In order to reduce the level of risk during handling, and to allow the alternative white machining, the shaped green body can be strengthened by firing with relatively low shrinkage in preliminary firing. This requires strength and shrinkage to be made reproducible through control of the process parameters [24, VKI-Germany 2004].

2.3.8.7 Firing/sintering

For firing, depending on the wide variety of raw materials and process variants, different types of kilns are used. Small-scale production is carried out in flexible periodically operated kilns such as shuttle kilns, which are operated to change the product-specific firing curve in very short cycles.

Typical sintering temperatures for technical ceramic materials are shown in Table 2.27 ~~the following table~~ [24, VKI-Germany 2004].

Table 2.27: Sintering temperatures for technical ceramic materials

Technical ceramic material	Sintering temperature (ºC)
Alumina porcelain	Approx. 1 250
Quartz porcelain	Approx. 1 300
Steatite	Approx.1 300
Cordierite	1 250 – 1 350
Aluminium oxide	1 600 – 1 800
Recrystallised silicon carbide	2 300 – 2 500
Sintered silicon carbide	Approx. 1 900
Silicon nitride	Approx. 1 700
Source: [9, COM 2007]	

The energy required for the firing process increases disproportionately as the firing temperature rises. In addition to the energy input, the firing auxiliaries ('kiln furniture') used to stack the green bodies in the kiln ~~is~~ are made of refractory material which can withstand very high temperatures. Special varieties of material can be created from some ceramic materials with the aid of particular types of firing processes [24, VKI-Germany 2004]:

Hot pressing (HP)
Hot pressing is used to manufacture components with a density close to the theoretical maximum. It is a sintering process supported by uniaxial pressing.

Hot isostatic pressing (HIP)
Hot isostatic pressing allows small parts particularly to achieve the maximum density through the application of isostatic gas pressure of up to 3 000 bar at temperatures of up to approximately 2 000 ºC (usually within a collapsible silicate glass envelope).

One example for firing technical ceramics in large shuttle kilns is the manufacture of electrical insulators by employing a modulated temperature programme (kiln capacity 100 m^3 with a setting density of 260 kg/m^3, firing temperature of up to 1 300 ºC, firing time including a cooling phase of 80-105 hours) and using natural gas as the fuel [1, BMLFUW 2003].

Another example for the use of shuttle kilns is the manufacture of firing auxiliaries ('kiln furniture') [17, Burkart, M. 2004]:

- H-cassettes, which are shaped from special refractory clays, are fired in shuttle kilns (setting density below 300 kg/m3, kiln volume 12 m3) at a temperature of 1 360-1 390 ºC with natural gas as the energy source. They are used as firing auxiliaries in roof tile manufacturing processes.
- SiC firing auxiliaries, which are shaped from SiC powder and organic binders, are fired in electrical induction shuttle kilns (setting density below 300 kg/m3) at a temperature of 2 000-2 500 ºC under a hydrogen/nitrogen atmosphere. They are used in other manufacturing processes, in particular porcelain glost fast firing.

However, tunnel kilns are also employed for the manufacture of technical ceramics. An example is the firing of ceramic catalysts in a 63 m long tunnel kiln at a maximum temperature of 650 ºC and with a throughput of 0.76 m^3/h [1, BMLFUW 2003].

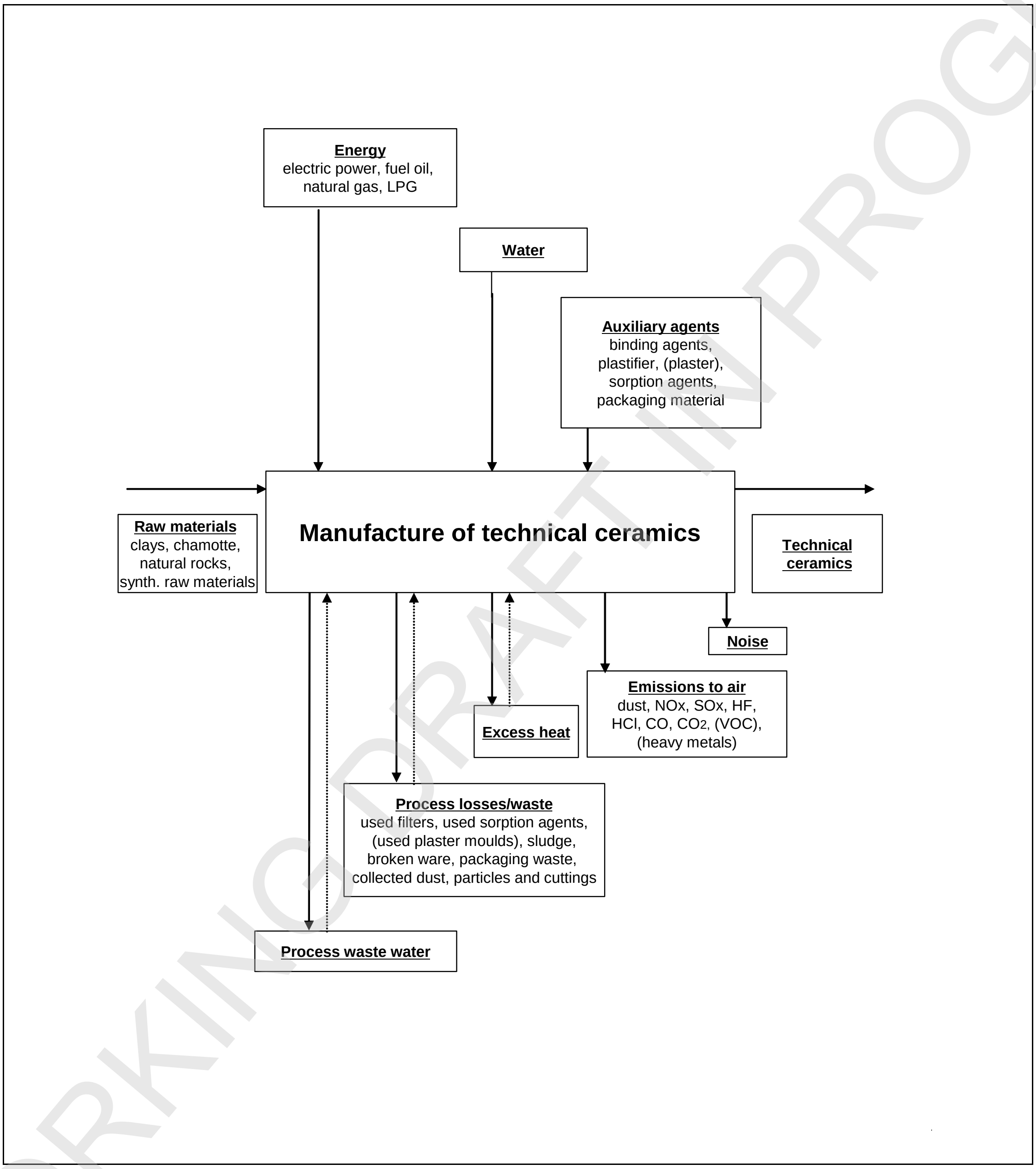
2.3.8.8 Subsequent treatment

Depending on the wide variety of technical ceramics, often subsequent treatment like cutting, sawing, grinding, polishing and assembling with other parts may be necessary. In this context, see Section 2.3.8.4, especially regarding hard machining. After final quality control, the products are sorted and packed.

~~2.3.8.9 Input and output flows in the manufacture of technical ceramics~~

[Note to the TWG: this section has been merged with Section 2.3.8]

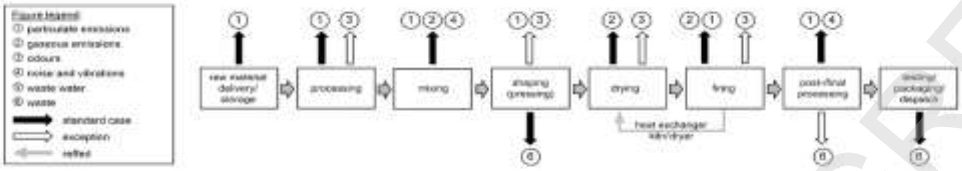
~~Important input and output flows of technical ceramics manufacturing processes are presented in the following figure [23, TWG 2005], [24, VKI Germany 2004].~~



~~Figure 2-42: Input and output flows in the manufacture of technical ceramics~~

2.3.9 Inorganic bonded abrasives

Figure 2-39 shows the schematic view of a vitrified bonded abrasives manufacturing process [52, VDI 2018].

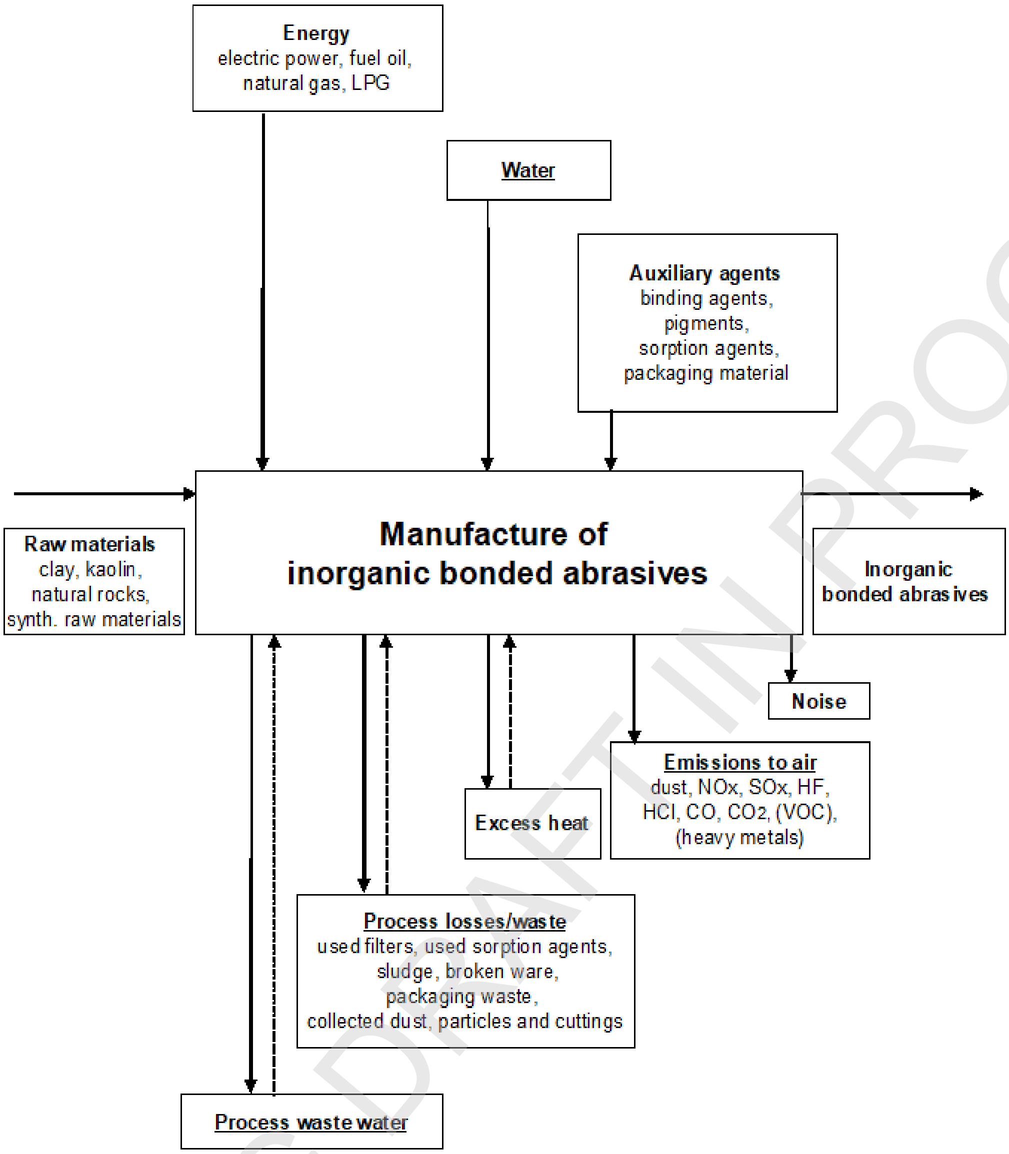


Source: [52, VDI 2018]

Figure 2-39: Schematic view of vitrified bonded abrasives production

[Note to the TWG: this section has been moved from Section 2.3.9.7]

Important input and output flows of inorganic bonded abrasives manufacturing processes are presented in Figure 2-40 ~~the following figure~~ [14, UBA 2004], [23, TWG 2005].



Source: [9, COM. 2007]

Figure 2-40: Input and output flows in the manufacture of inorganic bonded abrasives

2.3.9.1 Raw materials

Inorganic bonded ceramic abrasives consist of abrasive grains, binding agents and several additives, which are mixed, shaped, dried and fired [14, UBA 2004].

The most commonly used abrasive grains for the manufacture of inorganic bonded abrasives are special fused alumina, corundum~~,~~ and black and green silicon carbide. Cubic boron nitride (CBN) and diamond grains are also used.
The binding agent is typically made of the following components:

- feldspar;
- silicates;
- quartz;
- frits (glass with a defined composition);
- kaolin (china clay);
- clay;
- nepheline;
- pigments.

The composition varies depending on the application profile of the abrasives. Consequently, ~~also~~ pure frit binders or special binders with a defined thermal coefficient of expansion and/or melting point might also be applied. In some cases, frits might contain high shares of alkali and boron. Colouring metal oxides, colouring glass or colouring pigments might be added to obtain a specific colour.

Auxiliary substances are used during the manufacturing process of inorganic bonded abrasives to ~~realise~~ achieve required characteristics and shapes. However, these auxiliary substances are not ingredients of the final product.

Temporary binding agents are necessary for the manufacture of inorganic abrasives to keep the mixture of grains and binder in the right shape before the firing process. For temporary binders, water-soluble glues, wax emulsions, converted starch like dextrin, polyoxyethylene preparations, lignosulphonates, converted urea-formaldehyde condensation products, synthetic resins, etc. are alternatively used.

Pore-forming agents have the function of generating a defined pore profile in the abrasives. Pore-forming agents are added to the raw material and evaporate, sublimate, depolymerise, or incinerate, depending on the substance used, during the drying or firing process. Depending on the final product, different pore-forming agents are used. Naphthalene or other thermal calcinating substances are applied.

2.3.9.2 Preparation of raw materials

The first step of the manufacturing process of inorganic bonded abrasives is the weighing and the mixing (e.g. in a horizontal bed mixer) of the components according to the abrasive formulation.

2.3.9.3 Shaping

For the manufacture of inorganic bonded abrasives, the raw workpieces are mechanically compressed to a specific density according to the default form and weight requirements. For this purpose, hydraulic or eccentric presses with pressure ranges of up to 2 500 MPa are used [14, UBA 2004].

2.3.9.4 Drying

As the compressed material is moist~~urised~~ened with water containing glue, the raw workpiece has to be dried. Chamber dryers and vacuum dryers are applied, in which the products are dried at temperatures of between 50 ºC and 150 ºC. Long drying times of up to 45 hours are necessary for ~~a~~ crack-free drying and the dryers can also be air-conditioned (in particular, vacuum dryers are equipped with a humidity control) for ~~a~~ crack-free drying [14, UBA 2004] [28, Schorcht, F. 2005].

2.3.9.5 Firing

[Note to the TWG: please provide information to update figures given in the paragraph below]

The firing of inorganic bonded abrasives takes place in natural gas or electrically heated periodically or continuously operated kilns. Example plants operate kilns with capacities of more than 4 m^3 (up to 11 m^3), firing temperatures of between 850 ºC ~~to~~and 1 300 ºC and setting densities of between 360 kg/m^3 ~~to~~and 1 400 kg/m^3 [14, UBA 2004]. The share of the vitrified bond in the ware to be fired comes to about 10 % of the total mass of inorganic bonded abrasives in the kiln. Depending on the size of the abrasive wheel products, the firing cycles take between 40 ~~to~~and 120 hours [28, Schorcht, F. 2005], [30, TWG 2005].

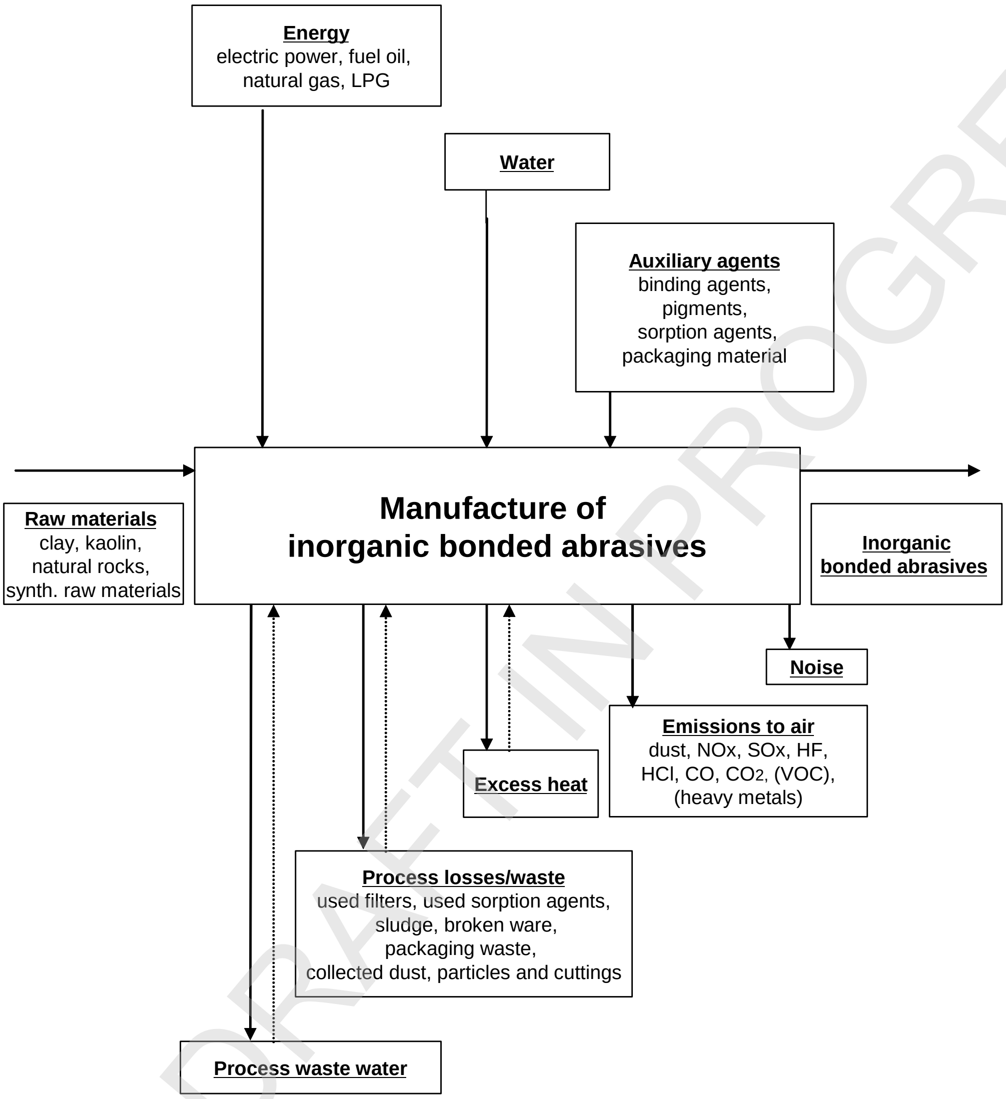
2.3.9.6 Subsequent treatment

After the determination of the quality (grade, density) of the abrasive, the finishing of the abrasives is carried out related to customer-specific requirements, for instance with computer-aided lathes or grinding machines. Afterwards, the final inspection which normally covers an out-of-balance check, dimensional, ring test and visual inspection, a safety speed and a bursting speed test take place conforming to standards. After the final inspection, the inorganic bonded abrasives are labelled as conforming to standards and packed for consignment [14, UBA 2004], [30, TWG 2005].

~~2.3.9.7 Input and output flows in the manufacture of inorganic bonded abrasives~~

[Note to the TWG, this section has been merged with Section 2.3.9]

~~Important input and output flows of inorganic bonded abrasives manufacturing processes are presented in the following figure [14, UBA 2004], [23, TWG 2005].~~



~~Figure 2 50: Input and output flows in the manufacture of inorganic bonded abrasives~~

2.4 Decarbonisation in the ceramic industry

[Note to the TWG: please provide additional information on this topic]

This section summarises the measures applied in the ceramic manufacturing industry for decarbonisation. The reported applied measures for decarbonisation vary widely among the different process steps.

At installation level, the measures applied for decarbonisation include the following [35, TWG 2023] [56, COM 2023]:

- Material and energy efficiency measures.
- Electrification for the transportation of products by automatic electric vehicles and packaging.
- Use of electricity from fossil-free energy sources (e.g. photovoltaic panels and windmills on-site).
- Dematerialisation of products by designing them to use less clay whilst maintaining the technical performance (e.g. thinner facing bricks, brick slips, design and orientation of the holes in clay blocks).
- Some companies establish internal group roadmaps and set intermediate goals towards decarbonisation, e.g. to reduce CO_2 emissions by 15 % by 2023 and by 40 % by 2030 as compared to 2020, and to achieve climate neutrality by 2050.
- Transportation of products and raw material by ship wherever possible as one ship may be equivalent to approximately 30 trucks.

For raw material preparation (crushing and milling, mixing and shaping), the following measures for decarbonisation are applied, among others:

- Choice of raw material with low carbon content.
- Electrification of processes and use of electricity from fossil-free energy sources.

For drying and spray drying, the following measures for decarbonisation are applied, among others [35, TWG 2023] [56, COM 2023]:

- Use of residual energy by heat exchange.
- Internal/external heat recovery.
- Use of alternative fossil-free fuels.
- Combined heat and power.
- Introduction of new technologies in the sector (e.g. heat pumps).

For firing, the following measures for decarbonisation are applied, among others [35, TWG 2023] [56, COM 2023]:

- Use of alternative fossil-free fuels.
- Process optimisation (e.g. extended tunnel kilns).
- Material and energy efficiency measurements.
- Choice of raw material with low carbon content.
- Introduction of new technologies in the sector (e.g. electric kilns).

2.5 ~~Recycling in the ceramic industry~~ Circular economy in the ceramic industry

[Note for the TWG; this section is partly from Section 2.2.12 of the CER BREF 2007, please provide further information]

This sections summarises the measures applied in the ceramic manufacturing industry to enhance circular economy.

Most sectors of the industry recycle materials such as off-cuts, trimmings and substandard articles back to the raw material preparation stage. Fired goods of lower quality may also be recycled within the factories, usually after crushing and screening to form granular ~~'grog'~~ chamotte. This is non-plastic~~,~~ and can confer benefits like easier drying and lower shrinkage when added as a controlled proportion of clay bodies due to the increase of permeability. Even if 'fired process loss' recycling is not suited to the process from which ~~it~~ the materials originated, it may find an outlet in a different ceramic process.

Used refractory products removed whilst relining a kiln may be contaminated by slags, salts, glass or metal, which could compromise the refractory properties of any body to which they were added. Similarly, ~~also~~ various other contaminated materials (e.g. with heavy metals contaminated materials, derived from glazes) may also be unsuitable for recycling.

The mechanical cleaning of the refractory material before and after breakout as well as the dry storage after breakout are crucial for the recyclability of these materials. If the breakout is done selectively, different grades of refractory can be separated. This separated breakout material can be reused as secondary refractory material whereas unsorted breakout material is not ready for reuse [47, Cerame-Unie 2021]. Manufacturers can produce refractories that contain between 20 % and 80 % recycled material [41, Cerame-Unie 2020].

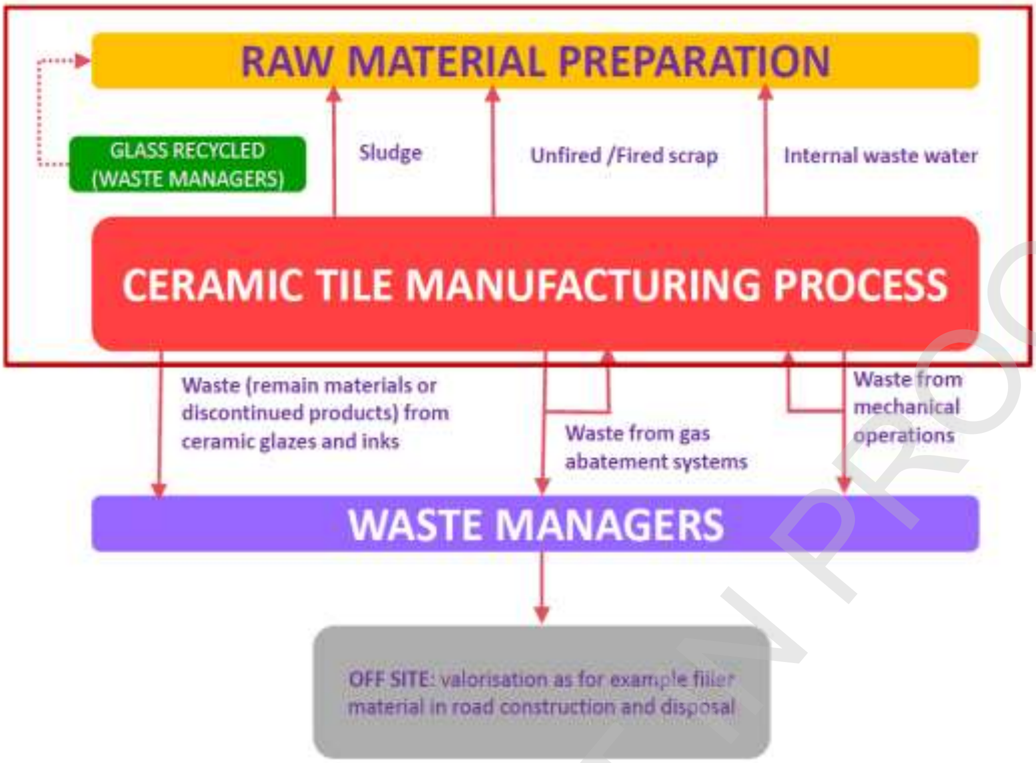
Plaster moulds which reach the end of their functional life represent another process loss which cannot be reused, but in some cases they can be used as raw material in the cement industry.

However, in other cases – notably facing bricks and clay roof tiles – recovery and reuse is widely practised, and recovered bricks are in ~~a~~ great demand. Throughout Europe, large numbers of Roman bricks are still found in masonry structures. It should be noted that some of the uses of granular or finely ground bricks or roof tiles would be applicable to similar size gradings of fired ware from other sectors. Also, crushed and graded 'ceramic process loss material' finds use as a partial aggregate in concrete for construction purposes, or as a filler in asphalt for road construction.

In the brick and roof tiles sector, the recycled content of the product depends on the type of product manufactured. For bricks and clay blocks, it can be up to 20-40 % whereas for facing bricks the maximum recycled content may be up to 5-10 % [35, TWG 2023], [56, COM 2023].

The recycled content of products in the wall and floor tiles sector varies depending on the type of product and can reach 40-60 % [35, TWG 2023].

Figure 2-41 shows an example of residues flow for the production of wall and floor tiles.



Source: [57, Cerame-Unie 2022]

Figure 2-41: Residues flow in the wall and floor tiles sector

For vitrified clay pipes, the minimum share of external recycled content in the raw materials used has increased on average to over 20 %. The internal recycled content from scrap and auxiliary materials leads to a recycled content of over 60 % [41, Cerame-Unie 2020].

The main techniques applied by the ceramic manufacturing industry towards circular economy are the following:

- reintroduction of residues in the raw material mixture, such as the dust generated from grinding of clay blocks or ground fired product;
- use of secondary raw materials from other processes (e.g. sawdust, rice husks or sunflower seed shells) as pore-forming agents in the manufacture of bricks;
- use of sludge from ceramic manufacturing processes or from other industries (e.g. paper, oil extractive industries, power plants, sewage sludge) as secondary raw material;
- use of spent silica sand from foundries as secondary raw material;
- use of residues from ash products, hydrocarbons and minerals as secondary raw material for bricks and clay blocks;
- crushing of broken clay blocks to be used as lightweight aggregate in the production of concrete blocks;
- advanced product design (e.g. use of connection systems with clicks or holes for bricks to be easily reused (see Figure 2-42);
- crushing of broken products to be used for backfilling in pits and quarries, road construction or tennis courts;
- dry milling technology in the production of tiles to recycle all type of ceramic residues;
- use of clay from construction and infrastructure works;
- collection of plastic packaging film and pallets from construction sites;

- use of banners containing only small areas of colour in the packaging instead of using coloured plastic for the full package to reduce the amount of coloured plastic and enhance the recyclability of the packaging material;
- reintroduction of lime mortar in building to facilitate the reuse of demolition waste;
- dematerialisation of products by designing products to use less clay whilst maintaining the technical performance (e.g. thinner facing bricks, brick slips, design and orientation of the holes in clay blocks);
- selective breakout and storage of refractories to increase recycling rates;
- separate collection of process waste water and use of run-off water.

[35, TWG 2023], [41, Cerame-Unie 2020], [56, COM 2023]

Source: [57, Cerame-Unie 2022]

Figure 2-42: Click systems for facing bricks

In the expanded clay sector, kilns can use residues as substitutes for fossil fuels or raw material/additive. The organic compounds needed in the raw material for the expansion can be substituted by different waste streams from food and biomass processing like waste flour, wood fines and sewage sludge. Conventional fossil fuels can be replaced by alternative fuels for energy recovery (e.g. waste oil, spent solvents) [58, EXCA 2020].

3 CURRENT EMISSION AND CONSUMPTION LEVELS

The following sections present the emission and consumption data reported by the ceramic manufacturing plants/installations across the European Union (EU) that took part in the CER BREF review data collection.

[Note to the TWG: Most of the information contained in this section of the old BREF has been removed and replaced with up-to-date information obtained from the data collection. Some relevant elements of the old information have been kept when considered relevant for this BREF (following the fonts colouring code). Information from the old BREF can still be integrated into this section provided that the members of the TWG kindly update the content of the old BREF with new information, where necessary.]

3.1 Introduction

The data for emission and consumption levels presented were collected from 199 plants/installations across the EU. The participating plants are located in 16 Member States (AT, BE, BG, CZ, DK, FI, FR, DE, EL, ES, HU, IT, NL, PL, PT and SK).

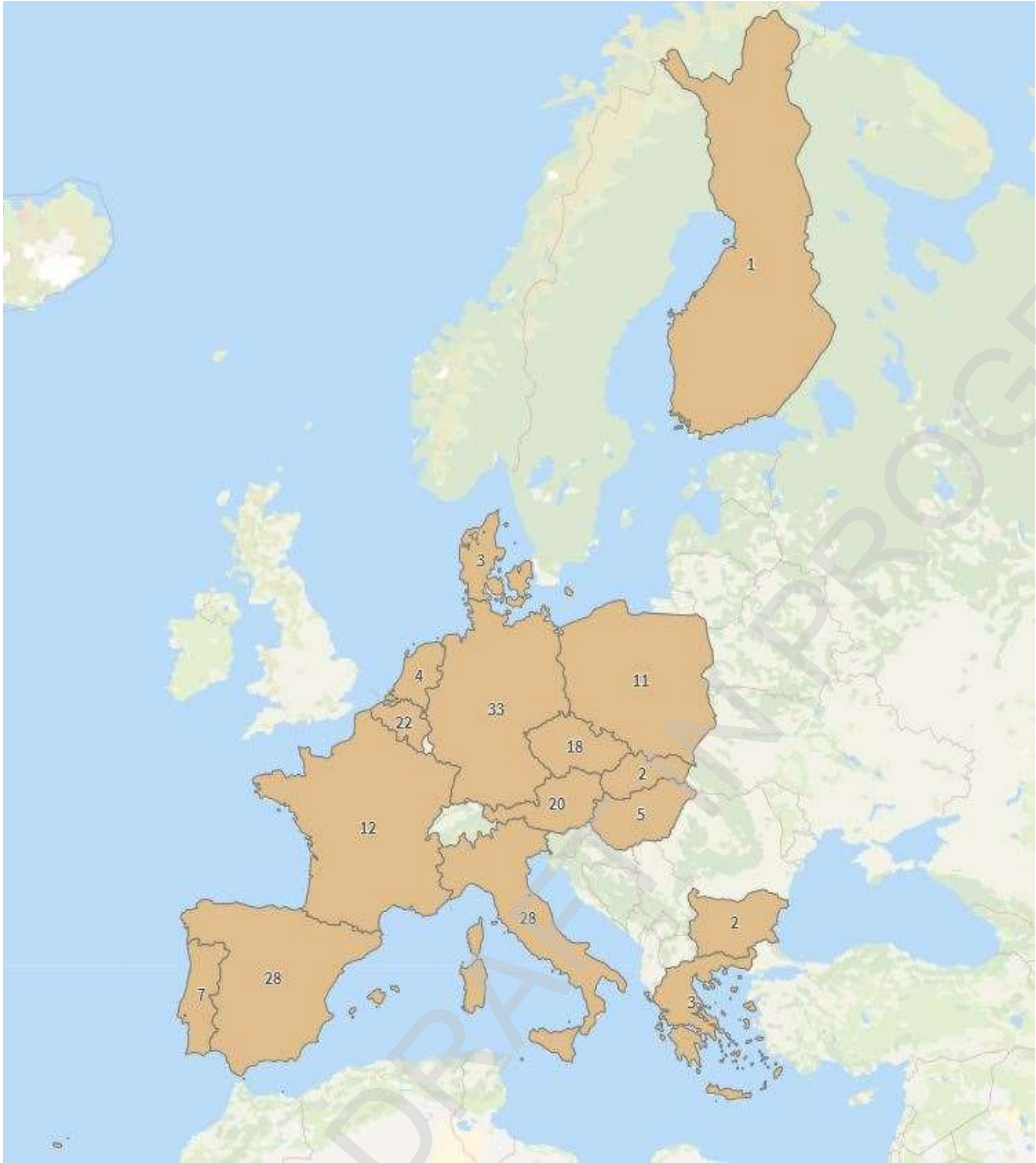
The geographical distribution of plants/installations is shown in Figure 3-1. The data refer to a 3-year reference period covering 2017, 2018, 2019 or, if representative, 2020 and 2021. The list of plants that participated in the data collection are listed in the Annex, Section 4.1, Table 4-1.

The data collection for the CER BREF review focused on information gathering using a standardised questionnaire for the following topics:
- identification and description of the plant/installation;
- processes and emission sources;
- channelled and diffuse emissions to air;
- channelled emissions to water;
- energy consumption;
- waste and residue generation;
- water consumption and discharge;
- material and chemical consumption;
- circular economy and decarbonisation.

Handling of Confidential Business Information (CBI)

During the data collection, the following data were considered CBI:
- energy consumption;
- water consumption;
- hazardous chemical consumption;
- specific emission of carbon dioxide (CO_2).

In order to maintain data confidentiality, plant names are not directly mentioned in the graphs or figures. The plant names are replaced with anonymised and randomly attributed plant CBI codes. In addition, no contextual information (e.g. process parameters or techniques applied) is included as this could reveal the identity of the plant.

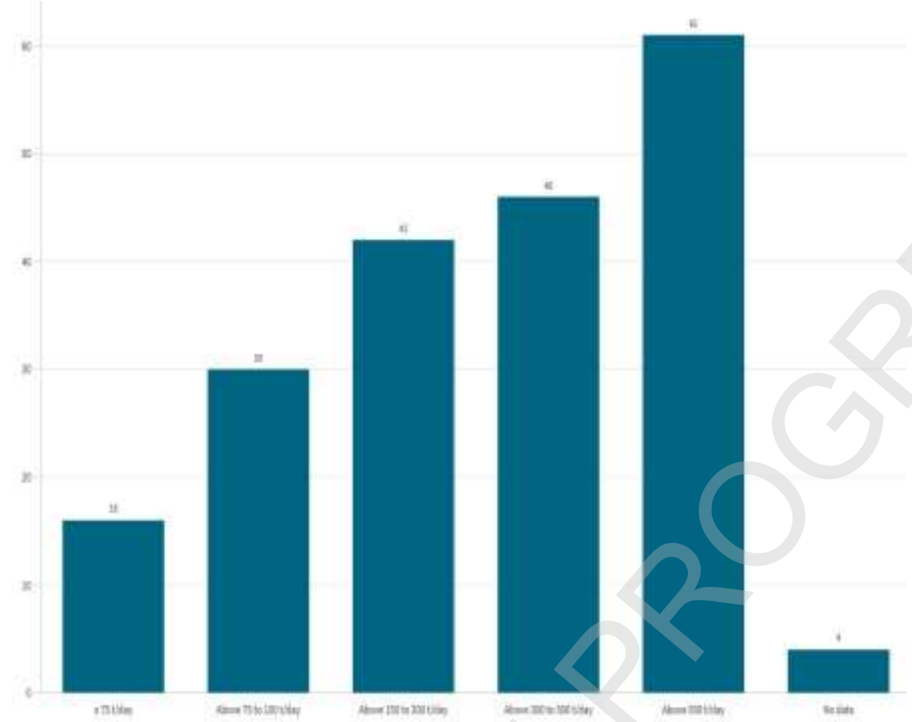


Source: [35, TWG 2023]

Figure 3-1: Geographical distribution of participating plants

3.1.1 Plant characteristics

Figure 3-2 shows the distribution by the production capacity range of the ceramic manufacturing plants/installations participating in the data collection.



Source: [35, TWG 2023]

Figure 3-2: Capacity production range reported for the plants

Several installations reported other activities covered by Annex I to the Industrial Emissions Directive. These different activities are included in Table 3-1.

Table 3-1: Other Annex I IED activities at the installation or directly associated with it

Other Annex I IED activities at the installation or directly associated with it	Number of plants
1 Energy industries	1
1.1 Energy – Combustion	10
2.6 Metals – Surface treatment of metals or plastic materials	1
3 Mineral industry	2
3.1c Mineral – Production – Magnesium oxide	1
3.4 Mineral – Melting mineral substances	1
5.1b Disposal or recovery of hazardous waste – Physico-chemical treatment	3
5.2a Disposal or recovery of non-hazardous waste - Incineration or co-incineration	2
5.2b Disposal or recovery of hazardous waste - Incineration or co-incineration	2
6.7 Other – Surface treatment of substances, objects or products using organic solvents	1
Source: [35, TWG 2023]	

According to the information reported in the questionnaires, the following installations would be below both IED Annex 3.5 thresholds (i.e. exceeding production capacity of 75 tonnes per day and/or with a kiln capacity exceeding 4 m^3 with a setting density per kiln exceeding 300 kg/m^3): AT_026, CZ_068, DE_080, DE_087, DE_089, DE_090, DE_094, DE_096, DE_098 and DE_099. These installations have been identified with the '@' symbol following the plant number to allow the reader to distinguish their data.

Table 3-2 shows the number of EMAS and ISO standards certifications reported by installations in the data collection.

Table 3-2: EMAS or ISO certification

EMAS or ISO certification	Number of plants
EMAS	13
ISO 9001 – Quality management systems	111
ISO 14001 – Environmental management systems	90
OSHA 18001 – Health and safety	12
ISO 50001 – Energy management	64
Other	30 (17 correspond to ISO 45001)

Source: [35, TWG 2023]

3.1.2 Overview of plants by sector

The distribution of the number of plants by country and sector is shown in Table 3-3.

Table 3-3: Number of plants by country and sector

Country	Brick and roof tiles	Expanded clay	Refractory products	Sanitary ware	Tableware and household ceramics	Technical ceramics	Vitrified clay pipes	Wall and floor tiles	Total
T	15	-	3	1	-	1	-	-	20
BE	20	1	-	-	-	-	1	-	22
BG	1	-	-	1	-	-	-	-	2
CZ	9	1	2	2	-	-	-	4	18
DE	2	1	-	-	-	-	-	-	3
FI	-	1	-	-	-	-	-	-	1
FR	10	-	-	-	-	-	-	2	12
DE	9	2	5	2	3	5	1	6	33
EL	3	-	-	-	-	-	-	-	3
HU	2	-	-	1	-	-	-	2	5
IT	4	-	1	-	-	-	-	23	28
NL	4	-	-	-	-	-	-	-	4
PL	8	1	2	-	-	-	-	-	11
PT	3	1	-	1	1	-	-	1	7
SK	2	-	-	-	-	-	-	-	2
ES	6	-	-	1	-	-	-	21	28
Total	98	8	13	9	4	6	2	59	199

NB: One plant reported two different sectors, i.e. Wall and floor tiles and bricks & roof tiles. The main sector is considered to be the first reported sector (i.e. wall and floor tiles).
Source: [35, TWG 2023]

3.1.3 Processes and emission sources

Table 3-4 presents emission sources of important process steps and the corresponding emission paths [23, TWG 2005], [26, UBA 2005], [27, VDI 2004], [30, TWG 2005], [35, TWG 2023].

Table 3-4: Overview of ~~possible~~ emission sources in the ceramic manufacturing industry

Process step	Emission from				Emission into			Emission of noise
	Raw material	Ceramic bodies	Deco-ration	Fuel	Air	Water	Land (process losses/waste)	
Preparation of raw material								
Primary/secondary crushing and grinding	x				x		x	x
Dry milling and dry mixing	x			x [1]	x		x	x
Wet milling and wet mixing	x					x	x	x
Screening/classification	x				x		x	x
Conveying	x				x		x	
Storage in silos	x				x			x
Body preparation								
Casting slip		x				x		
Extrusion paste for soft-plastic shaping		x			x	x	x	
Bodies for hard-plastic shaping by chip removing processes		x				x	x	
Dust pressing powder, dry process		x			x	x	x	x
Dust pressing powder, spray drying process		x		x	x	x	x	x
Granulation		x			x			x
Shaping/Forming of ware								
Slip casting		x				x		
Soft-plastic shaping (‘extrusion’)		x				x	x	
Shaping by cutting		x					x	
Pressing		x			x	x [2]	x	x
Treatment of green bodies		x			x	x	x	
Drying								
Intermittent and continuous dryers		x		x	x			x
Surface treatment/Decorating								
Glazing			x		x	x	x	
Engobing			x		x [3]	x	x	
Printing			x		x	x	x	
Firing								
Intermittent and continuous kilns	x	x	x	x	x			x
Subsequent treatment/Product finishing		x	x		x	x	x	x
Material storage	x	x		x	x [4]			x

[1] Possible for special applications, e.g. hot dry grinding of expanded clay aggregates
[2] Only cooling water
[3] For some sectors, e.g. ceramic tiles
[4] Material storage also covers storage of fuels
Source: [23, TWG 2005], [26, UBA 2005], [27, VDI 2004], [30, TWG 2005], [35, TWG 2023]

3.1.4 Number of emission points to air and water

Table 3-5 shows the number of emission points to air (EPs Air) and emission points to water (EPs Water). Additionally, emission points that only monitor dust emissions (EPs Dust) are presented separately.

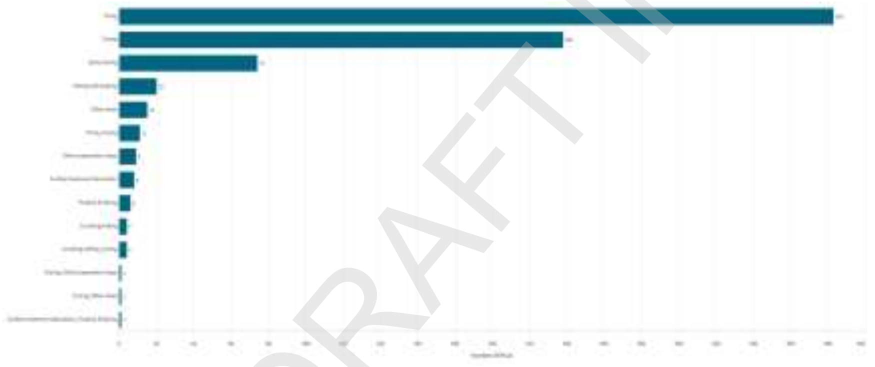
Table 3-5: Number of reported emission points

	Emission points data
Emission points to air (EPs Air)	782
Emission points that only monitor dust (EPs Dust)	716
Emission points to water (EPs Water)	106
Source: [35, TWG 2023]	

The number of emission points to air, emission points that only monitor dust and emission points to water data by plant can be found in the Annex, Section 4.2.

3.1.5 Processes associated with emission points

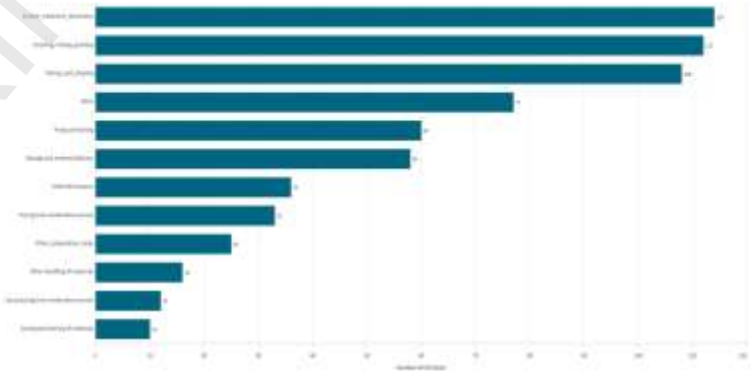
Figure 3-3 shows the distribution of associated process(es) for EPs Air that reported emission data.



Source: [35, TWG 2023]

Figure 3-3: Associated process(es) by EPs Air

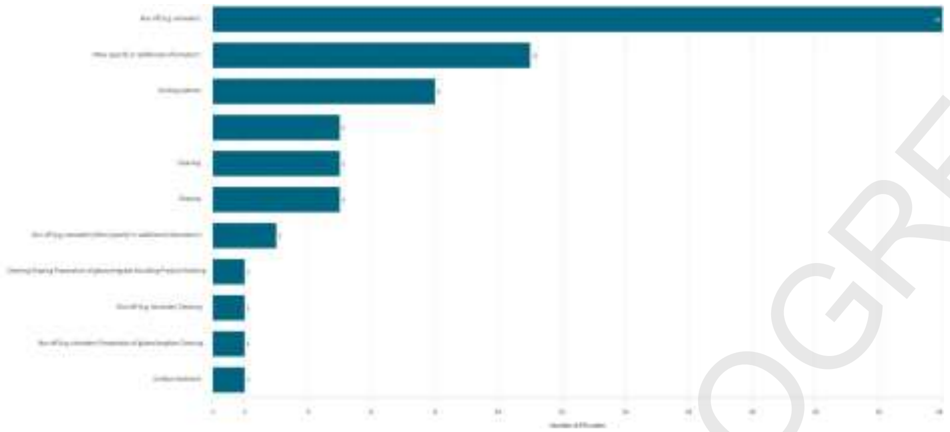
Figure 3-4 shows the distribution of main associated processes for EPs Dust that reported emission data.



Source: [35, TWG 2023]

Figure 3-4: Associated process(es) by EPs Dust

Figure 3-5 shows the distribution of the main associated process(es) to EPs Water that reported data on concentration.



Source: [35, TWG 2023]

Figure 3-5: Associated process(es) by EPs Water

3.2 Emissions to air

3.2.1 General overview

The following section presents an overview of the collected data on emissions to air. For emissions to air, the questionnaire distinguished the following types of emission points:

- Emission points that monitor other parameters besides dust, generally associated with combustion processes, e.g. firing of ware, drying-firing of expanded clay, drying of ware (EPs Air);
- Emission points that only monitor dust, generally associated with mechanical processes, surface treatment/decoration, transfer and handling of materials/products (EPs Dust).

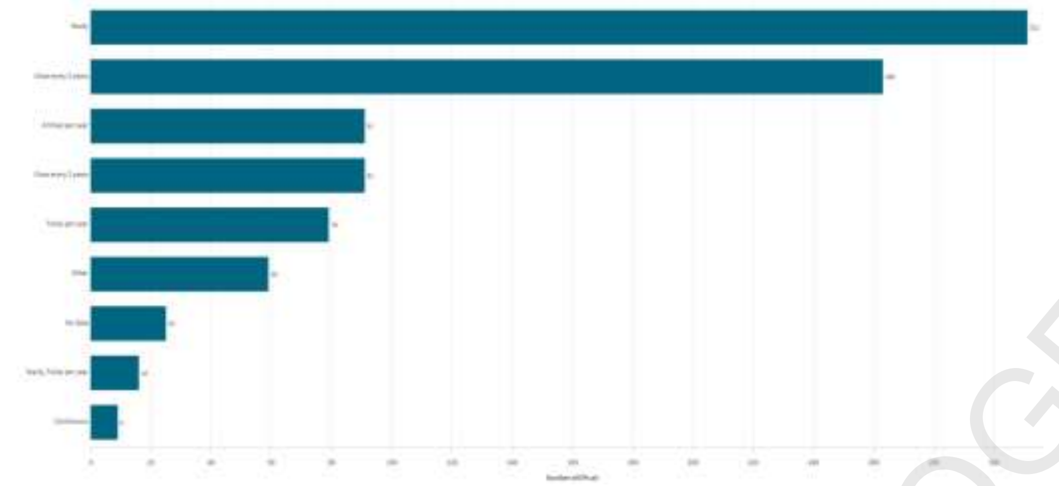
The 199 questionnaires represent a total of 782 EPs Air and 716 EPs Dust.

For emissions to air data, multiple pollutants can be monitored and measured at the same emission point (i.e. stack where emission of any air pollutant occurs). Therefore, the collected and reported data on emission points correspond to a combination of measurements made separately for a specific substance/parameter.

3.2.2 Monitoring frequency

Concerning the monitoring frequency, the questionnaire allowed various monitoring frequencies to be reported for emissions to air by a drop-down menu in the questionnaires. The monitoring frequency varies from daily to once every 3 years. The figures below show the most commonly reported monitoring frequencies for EPs Air.

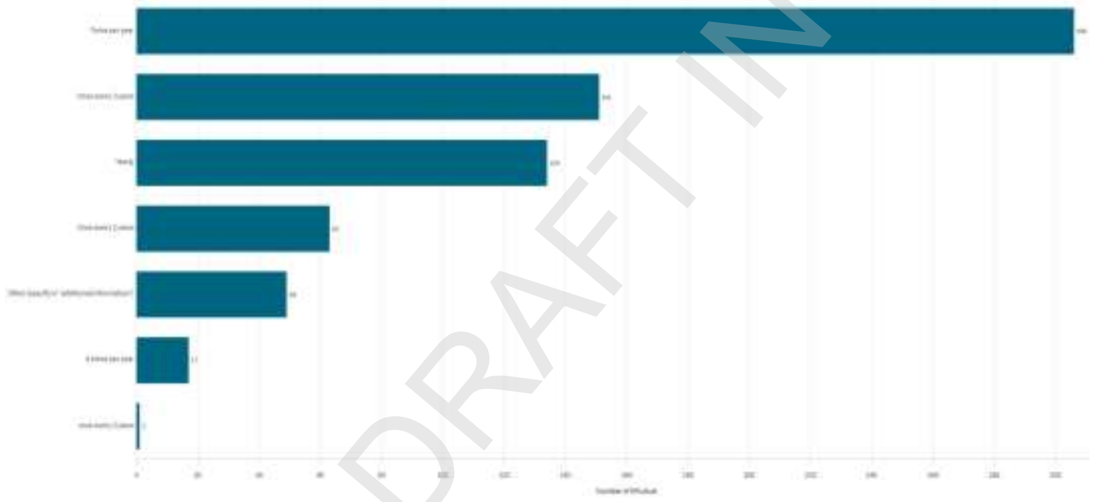
Figure 3-6 shows the monitoring frequency reported for EPs Air.



Source: [35, TWG 2023]

Figure 3-6: Monitoring frequency by EPs Air

Figure 3-7 shows the monitoring frequency for EPs Dust.



Source: [35, TWG 2023]

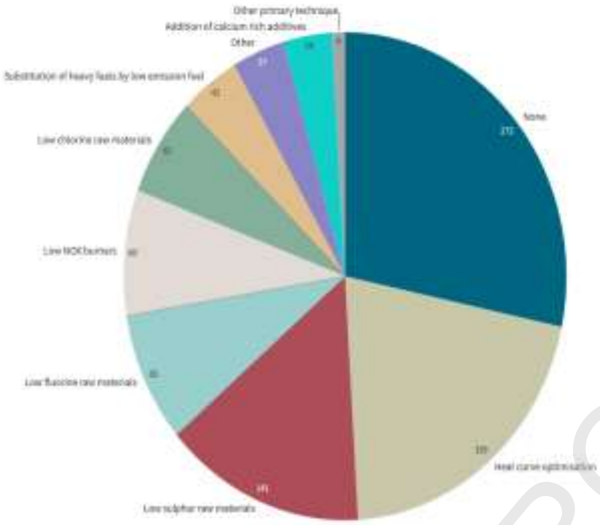
Figure 3-7: Monitoring frequency by EPs Dust

3.2.3 Techniques to prevent emissions (primary techniques)

The reported data for techniques to prevent emissions are summarised as follows:

- 512 EPs Air reported applying a primary technique.
- 37 EPs Air selected ‘Other’ as the type of primary technique and reported additional information on employed techniques (e.g. use of flue-gas for drying, steam boiler - economiser to preheat feed water, low-consumption burners, brushing of tiles, dry flue-gas filter cascade, drying curve optimisation, use of waste heat from the gas turbine and reducing the alpha-value by using a different material for the kiln cars).
- The total number does not sum up to the total emission points as some reported more than one primary technique (i.e. techniques most commonly applied alone or in combination).

Figure 3-8 shows the primary techniques reported by EPs Air.



Source: [35, TWG 2023]

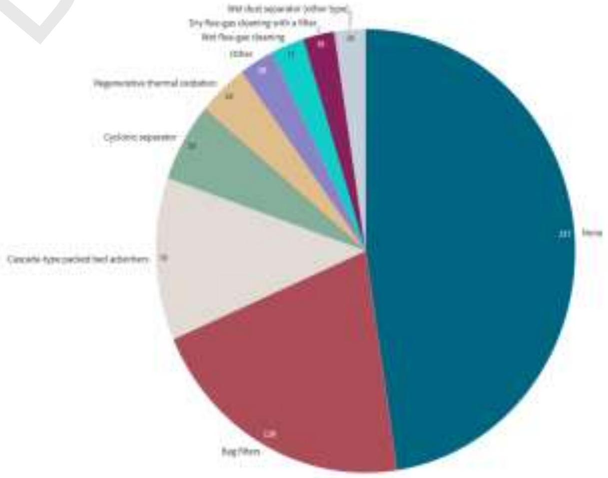
Figure 3-8: Primary techniques by EPs Air

3.2.4 Abatement techniques

The emission points that reported data for abatement techniques can be summarised as follows:

- 330 EPs Air reported abatement techniques.
- 18 EPs Air reported abatement techniques different to commonly applied techniques, such as internal thermal oxidation, fluorine cascade absorber, odour neutraliser.
- 595 EPs Dust reported information on abatement techniques.

Figure 3-9 presents the abatement techniques reported for EPs Air.



Source: [35, TWG 2023]

Figure 3-9: Abatement techniques by EPs Air

3.2.5 Content of oxygen in the off-gases

Emissions to air in ceramic manufacturing may arise from different sources such as thermal processes (e.g. drying, firing), mechanical processes (e.g. crushing, mixing, grinding), surface treatment/decoration and transfer/handling of materials.

Combustion processes involve the reaction of oxygen in the air with carbon and hydrogen in the fuel to form carbon dioxide (CO_2), water vapour (H_2O) and other compounds and produce heat. In practice, excess air is needed to ensure that almost complete combustion can be achieved. The combustion efficiency increases with increased excess air but decreases when the heat loss due to the excess air is greater than the heat generated by the more efficient combustion. The optimum amount of excess air depends on the fuels used and on the process characteristics. Excess air results in unreacted oxygen in the flue-gas [84, VITO 2018].

In order to assess emission levels to air, it is generally necessary to convert them to standard conditions and to the same O_2 reference value in order to account for the dilution of the off-gas that is caused by the excess air. The oxygen levels in the kiln atmosphere differ from one process/sector to another.

On the other hand, emission levels in waste gases from non-combustion processes (e.g. mechanical processes, surface treatment/decoration) are generally not corrected to a reference oxygen level.

The equation for calculating the emission concentration at the reference oxygen level is:

$$E_R = \frac{21 - O_R}{21 - O_M} \times E_M$$

Where:
E_R = emission concentration at the reference oxygen level O_R;
O_R = reference oxygen level (vol-%);
E_M = measured emission concentration;
O_M = measured oxygen level in (vol-%).

The equation above does not apply when additional air intake for safety reasons brings the oxygen level in the waste gas very close to 21 vol-%. In this case, the emission concentration at the reference oxygen level of 17 dry vol-% is calculated differently.

[Note to the TWG: please provide information on the reasons for certain kilns to operate close to 21% and how the emission level values are assessed when the oxygen level in the waste gas is very close to 21 vol-%]

The selected O_2 content for the reference level should be close to the real measured O_2 in the flue-gas to minimise unnecessary corrections. Out of 816 EPs Air in the data collection, 734 reported a measured O_2 content. Figure 3-10, Figure 3-11 and Figure 3-12 show the distribution of the average measured O_2 content by process (i.e. firing, drying, spray drying in the wall and floor tile sector and drying-firing of expanded clay (plotted together with firing in Figure 3-10)).

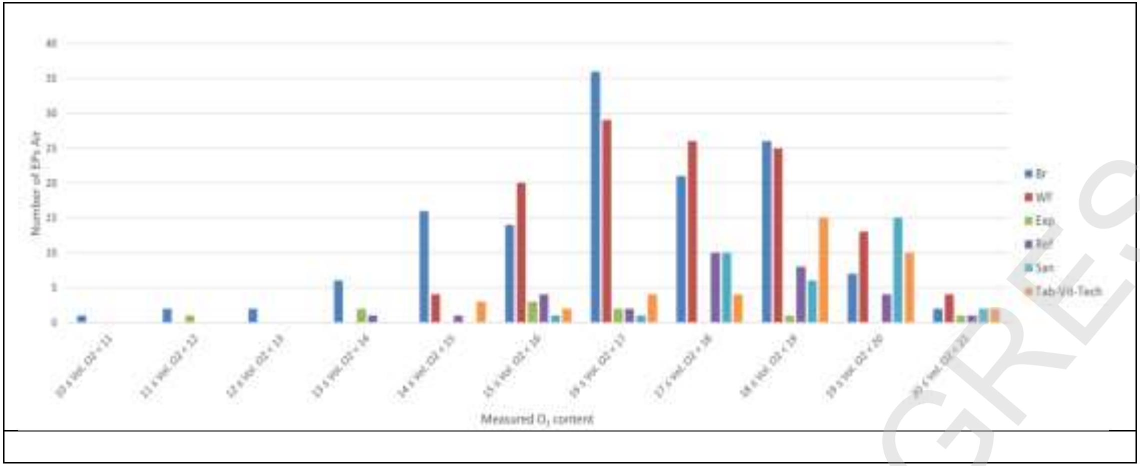


Figure 3-10: Average measured O_2 content in the off-gas from firing of ware and drying-firing of expanded clay

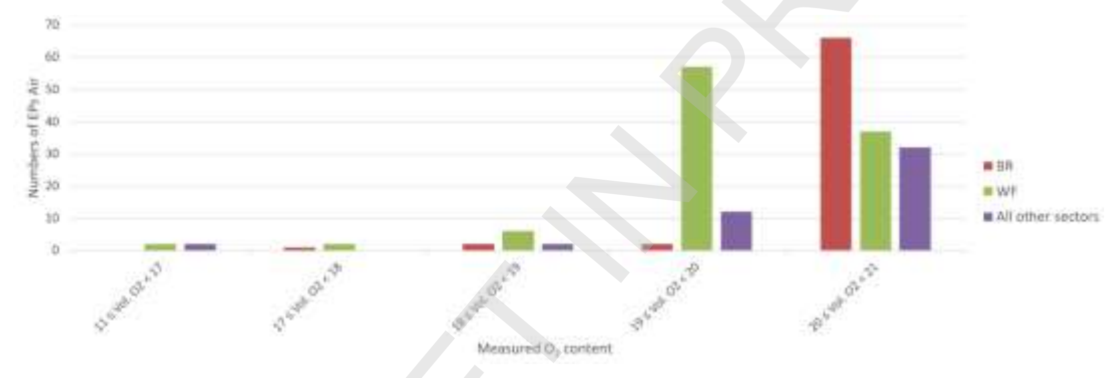


Figure 3-11: Average measured O_2 content in the off-gas from drying of ware

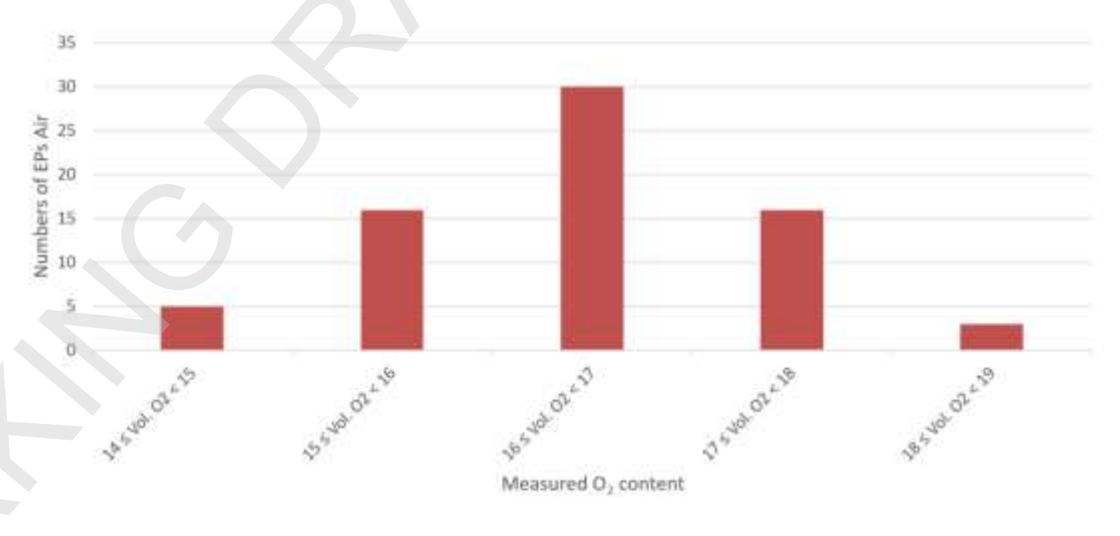


Figure 3-12: Average measured O_2 content in the off-gas from spray drying in the wall and floor tiles sector

Following the recommendations in the concluding remarks of the 2007 CER BREF, emissions from firing of ware, drying-firing of expanded clay and spray drying have been corrected to 17 vol-% in the figures in this section. For drying processes and mechanical processes (e.g. raw material preparation, surface treatment), no O_2 correction is applied.

[Note to the TWG: The concluding remarks of the 2007 CER BREF recommended to use 17 vol-% O_2 reference for the review of the CER BREF. Several TWG members have expressed their preference to use 18 vol- %. In order to increase energy efficiency, the amount of air in combustion processes may be further optimised in the future. Considering this, please provide your views on the O_2 reference for firing of ware, drying-firing of expanded clay and spray drying.]

3.2.6 Analysis of key parameters

For the substances/parameters identified as key environmental issues (KEIs) in the Kick-off meeting of the CER BREF review, the next sections include the reported information for each substance/parameter as follows:
- Number of plants;
- Number of EPs Air;
- Number of EPs Air by monitoring frequency;
- Number of EPs Air by main sector;
- Number of EPs Air by associated process(es);
- Distribution of maximum concentrations reported,

The tables and figures in this section present the summary of data based on commonly reported input information. For better visualisation, data reported at emission point level for released substances/parameters including reported concentration values are presented in Section 3.2.7. The techniques to prevent emissions and abatement techniques reported are presented in additional graphs and figures to improve the quality of the visualisation.

3.2.6.1 Dust

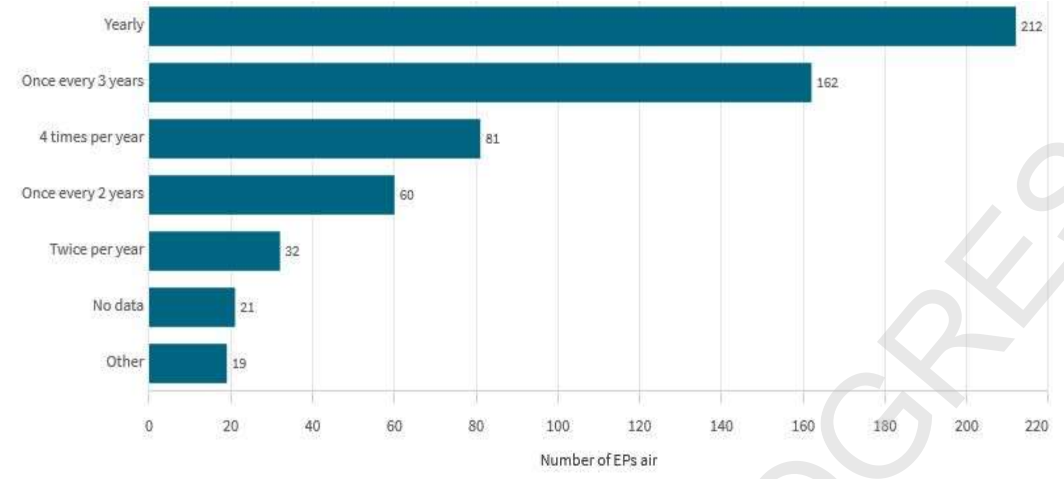
The processing of clays and other ceramic raw materials inevitably leads to dust formation – especially in the case of dry materials. Drying~~,~~ (including spray drying), comminution (grinding, milling) screening, mixing~~,~~ and conveying can all result in a release of fine dust, necessitating dust extraction equipment. Some dust also forms during decorating and firing of the ware, and during machining or finishing operations on fired ware. Dust is one of the main pollutants, in quantitative terms, from the ceramic processes.

Table 3-6 presents a summary of reported data for dust emissions. The reported levels of dust emissions are presented in Sections 3.2.7.1, 3.2.7.2, 3.2.7.3, 3.2.7.4, 3.2.7.6 and 3.2.7.4.

Table 3-6: Summary of data for dust emissions

Dust emissions	
Number of plants	193
Number of EPs Air	618
Source: [35, TWG 2023]	

Figure 3-13, Figure 3-14, Figure 3-15 and Figure 3-16 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.

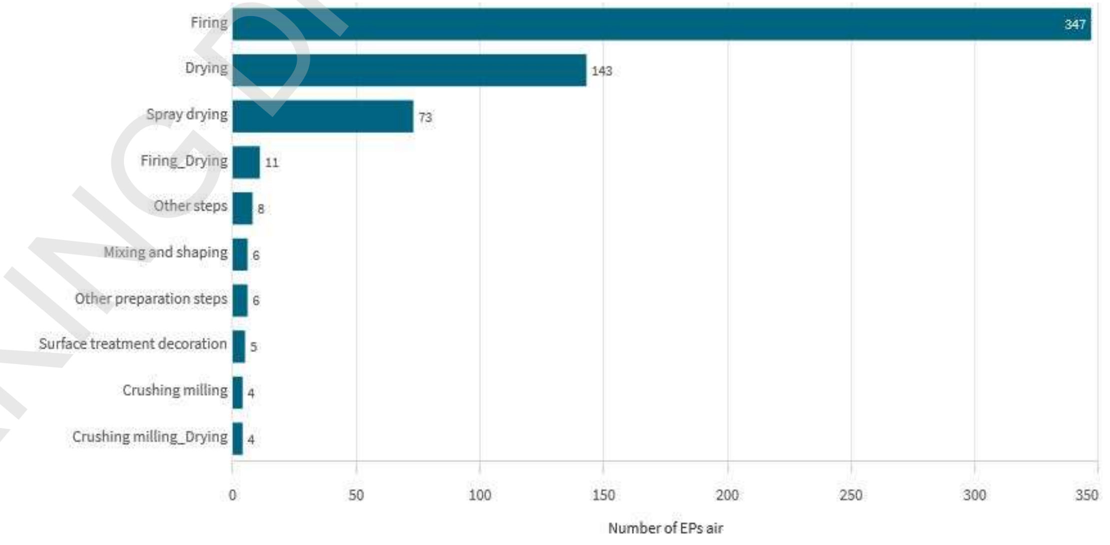


Source: [35, TWG 2023]

Figure 3-13: Monitoring frequency for dust emissions

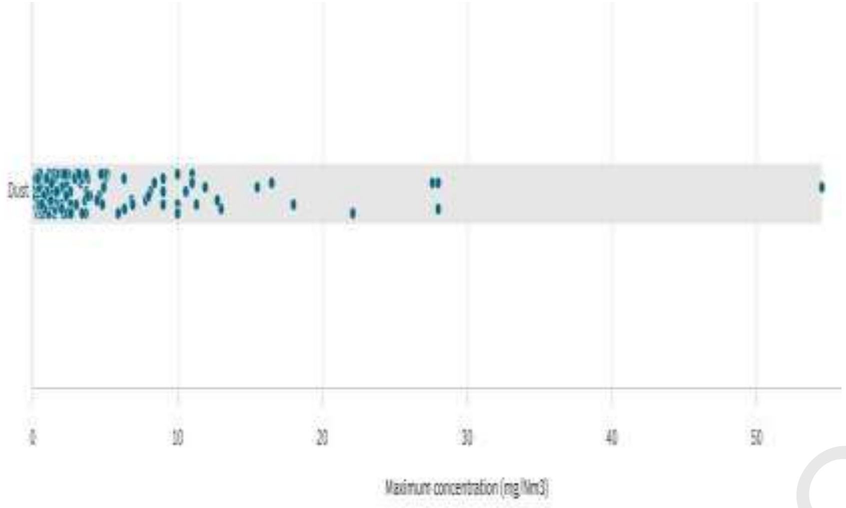
Source: [35, TWG 2023]

Figure 3-14: Number of emission points for dust by main sector



Source: [35, TWG 2023]

Figure 3-15: Number of emission points for dust by associated process(es)



Source: [35, TWG 2023]

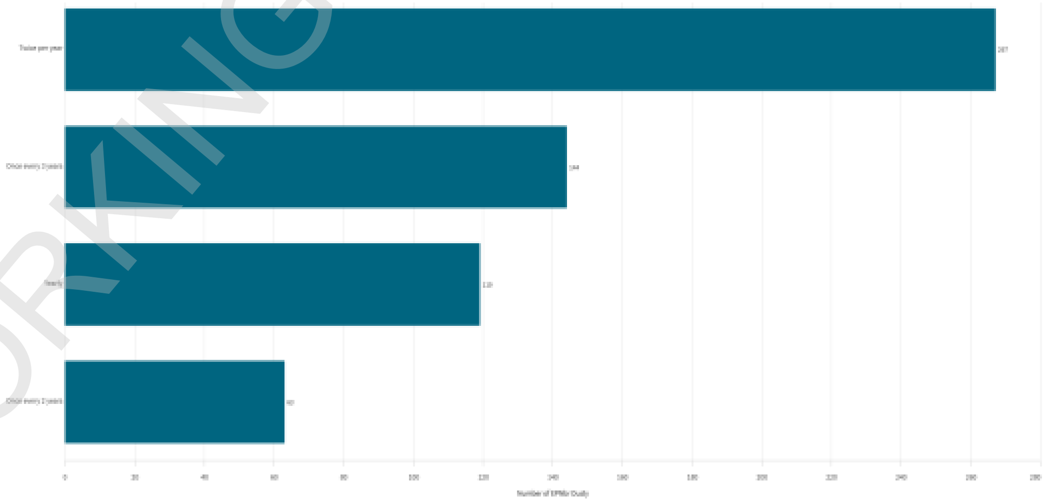
Figure 3-16: Distribution of maximum concentrations for dust emissions

Table 3-7 presents a summary of reported data for dust emissions from emission points that only monitor dust. These dust emissions are released during crushing and surface treatment processes and mainly occur in the wall and floor tiles production sector.

Table 3-7: Summary of data for emission points that only monitor dust emissions

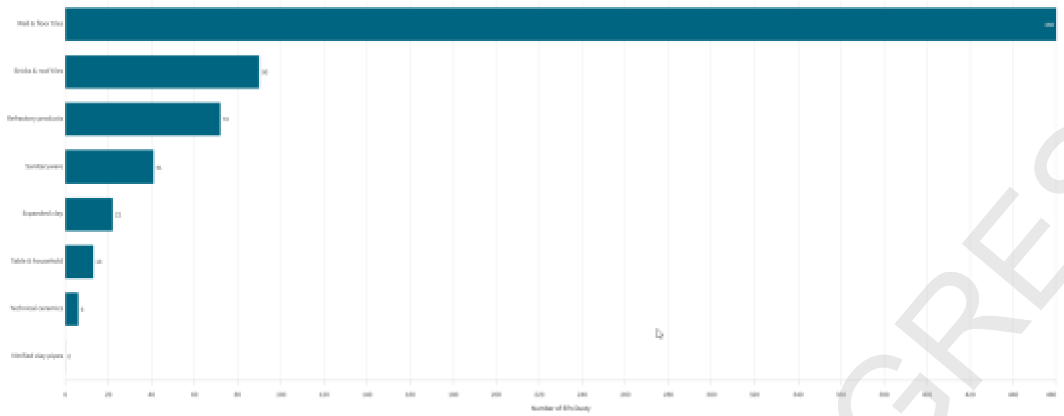
Dust emissions from dusty operations	
Number of plants	193
Number of EPs Dust	704
Source: [35, TWG 2023]	

Figure 3-17, Figure 3-18, Figure 3-19 and Figure 3-20 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



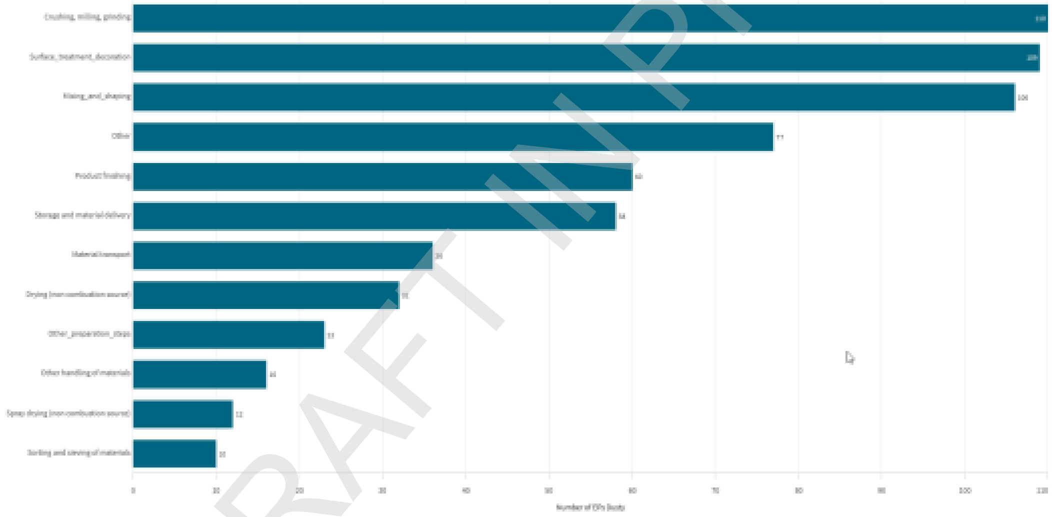
Source: [35, TWG 2023]

Figure 3-17: Monitoring frequency for dust emissions from emission points that monitor only dust



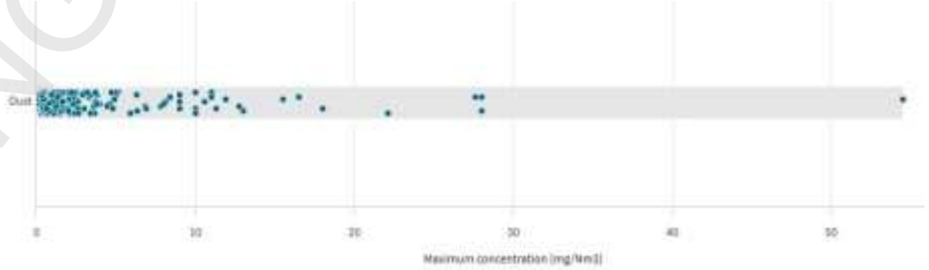
Source: [35, TWG 2023]

Figure 3-18: Number of emission points that monitor only dust by main sector



Source: [35, TWG 2023]

Figure 3-19: Number of emission points that monitor only dust by associated process(es)



Source: [35, TWG 2023]

Figure 3-20: Distribution of maximum concentrations for dust emissions from emission points that monitor only dust

3.2.6.2 Sulphur dioxide and sulphur compounds (SO_2)

The concentration of SO_2 in flue-gases is closely related to the sulphur content of the raw material, and of the fuel. Ceramic materials may contain sulphur in the form of pyrite (FeS_2), gypsum and other sulphates, and organic sulphur compounds.

One of the causes of SO_X emissions during firing is oxidative decomposition of the pyrite present in the raw material (reactions 1 and 2 below). Oxygen can diffuse inside the core of the raw material before the material sintering, around 480 °C, causing the oxidation of pyrite. A portion of the SO_X released by the decomposition of pyrite is readsorbed, mainly as calcium sulphate, at a low temperature in the preheating zone of the kiln. These sulphates, along with other sulphates present in the clay, decompose between 850 °C and 1 250 °C (reactions 3 and 4 below) [75, Huybrechts et al. 2007].

$$FeS_2 + O_2 \longrightarrow FeS + SO_2 \quad (1)$$
$$4\,FeS + 7O_2 \longrightarrow 2Fe_2O_3 + 4SO_2 \quad (2)$$
$$CaSO_4 \longrightarrow CaO + SO_3 \quad (3)$$
$$Fe2(SO_4)_3 \longrightarrow Fe_2O_3 + 3SO_3 \quad (4)$$

Gaseous fuels are virtually sulphur-free, but solid fuels and fuel oils contribute sulphur oxides on combustion. Basic compounds from raw materials (e.g. CaO formed by dissociation of $CaCO_3$ during firing) can reduce sulphur emissions by reacting with sulphur oxides. The reaction products are retained within the body of the ware.

In the production of refractory products, the use of sulphur-containing binders (e.g. lignosulphonates) can also generate SO_2 emissions.

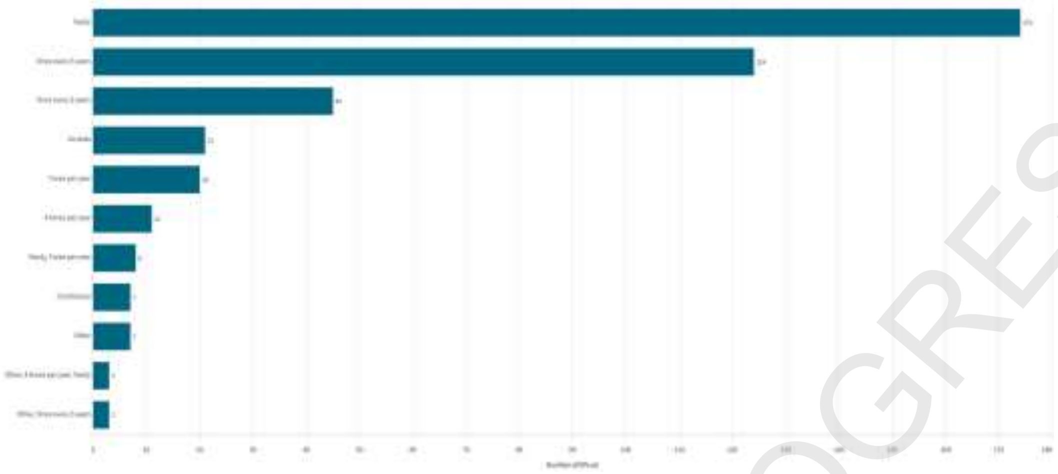
Table 3-8 presents a summary of reported data for SO_2 emissions. The reported levels for SO_X emissions are presented in Sections 3.2.7.7, 3.2.7.9 and 3.2.7.7.

Table 3-8: Summary of data for SO_X and SO_2 emissions

	SO_X emissions	**SO_2 emissions**
Number of plants	145	17
Number of EPs Air	395	42

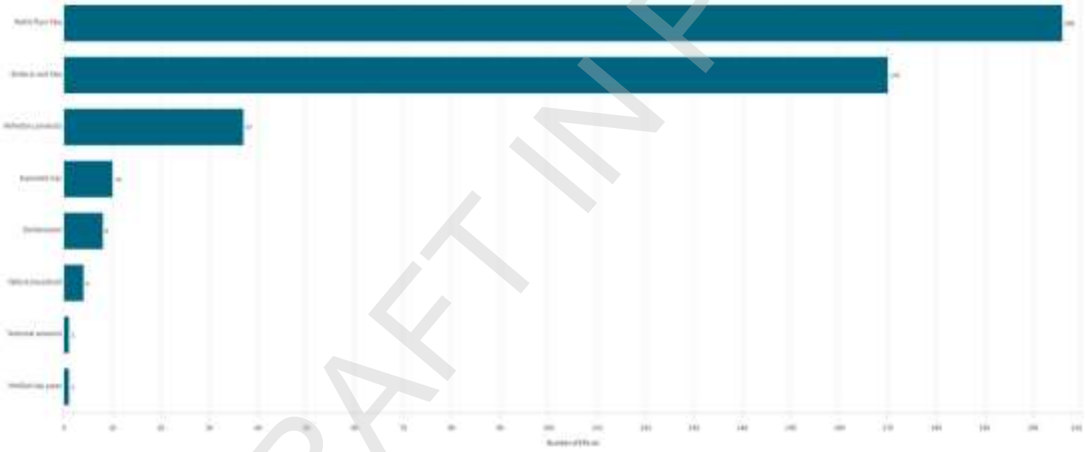
Source: [35, TWG 2023]

Figure 3-21, Figure 3-22, Figure 3-23 and Figure 3-24 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



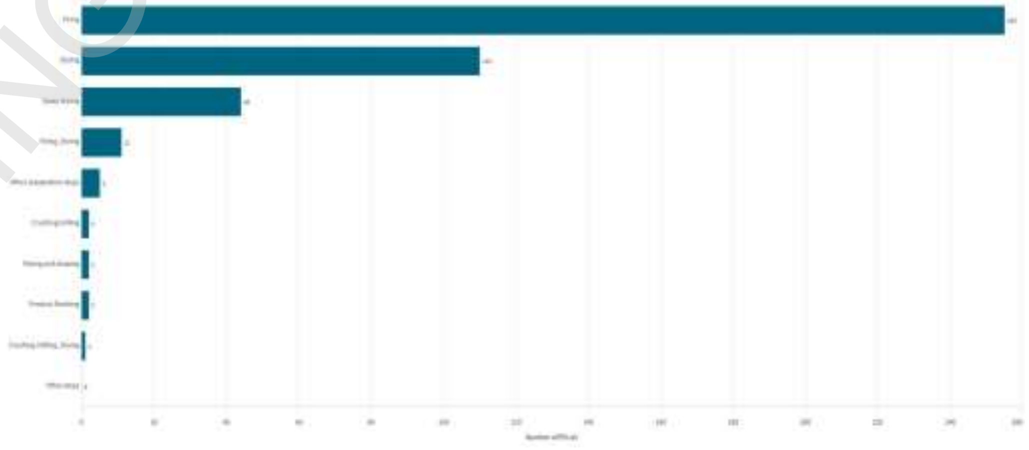
Source: [35, TWG 2023]

Figure 3-21: Monitoring frequency for SO_X and SO_2 emissions



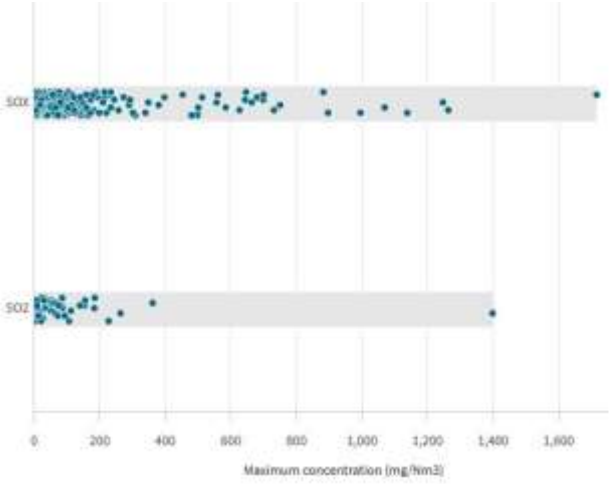
Source: [35, TWG 2023]

Figure 3-22: Number of SO_X and SO_2 emission points by main sector



Source: [35, TWG 2023]

Figure 3-23: Number of SO_X and SO_2 emission points by associated process(es)



Source: [35, TWG 2023]

Figure 3-24: Distribution of maximum concentrations for SO_X and SO_2 emissions

3.2.6.3 Oxides of nitrogen and other nitrogen compounds (NO_X)

NO_X is mainly produced by thermal ‘fixation’ of nitrogen and oxygen from the combustion air during firing, drying and spray drying. This reaction is favoured by high temperatures (especially >1 200 ºC) and by excess oxygen. Fixation can occur within hot flames, even when the actual kiln temperature is below 1 200 ºC.

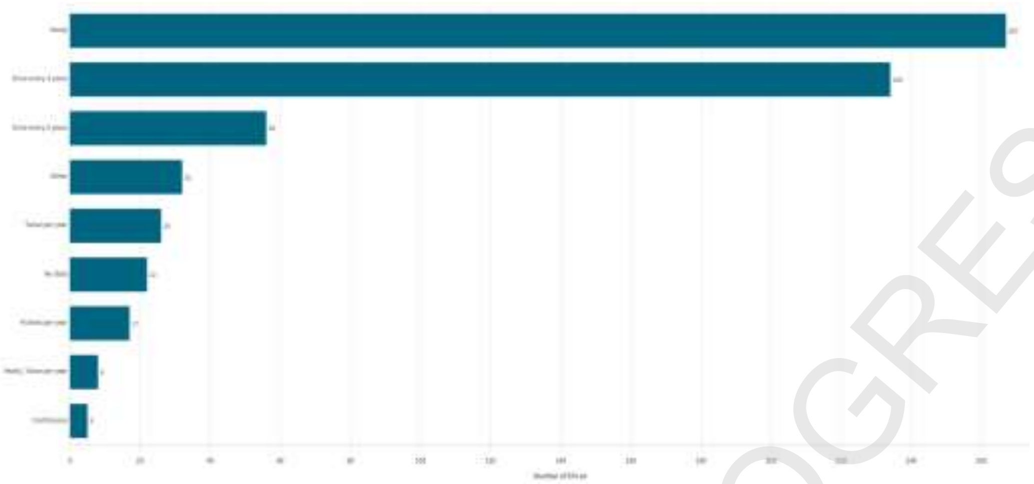
Nitrogen compounds present in fuels (mainly solid or liquid types), or in organic additives, form NO_X during combustion at much lower temperatures.

Table 3-9 presents the summary of reported data for NO_X emissions. The reported levels for NO_X emissions are presented in Sections 3.2.7.10, 3.2.7.12 and 3.2.7.10.

Table 3-9: Summary of data for NO_X emissions

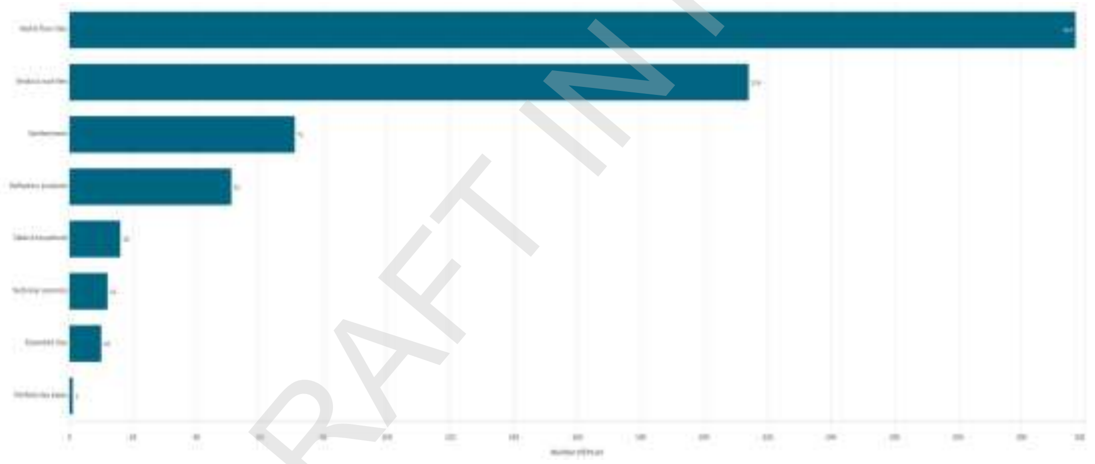
NO_X emissions	
Number of plants	194
Number of EPs Air	692
Source: [35, TWG 2023]	

Figure 3-25, Figure 3-26, Figure 3-27 and Figure 3-28 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



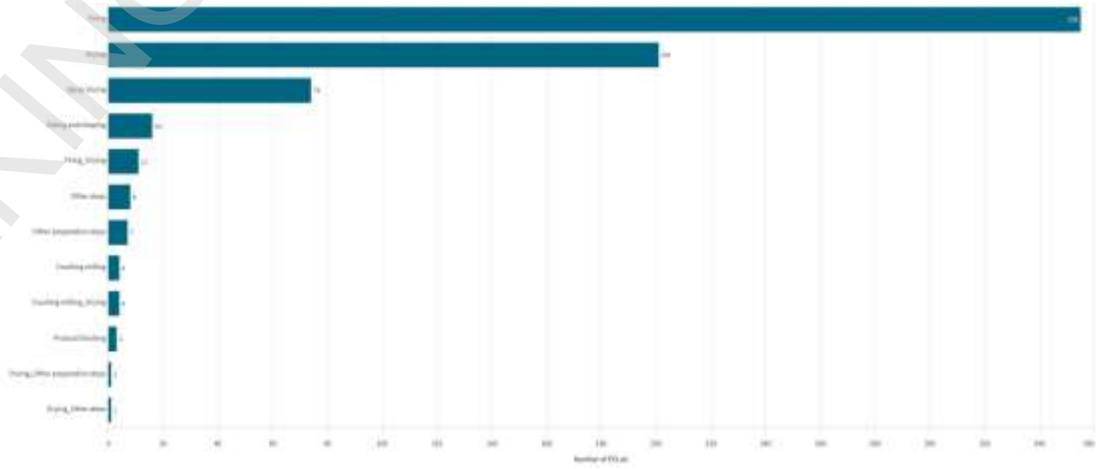
Source: [35, TWG 2023]

Figure 3-25: Monitoring frequency for NO$_X$ emissions



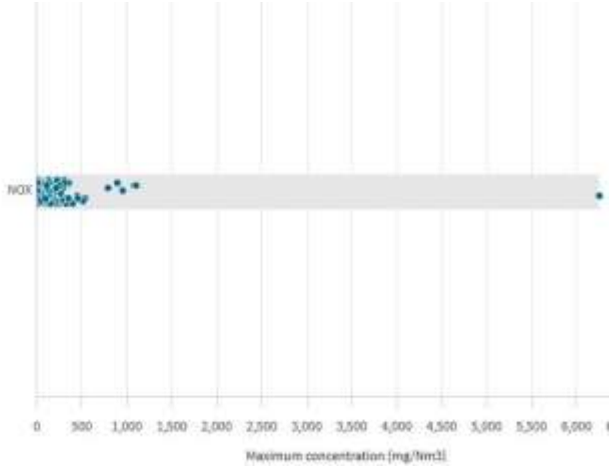
Source: [35, TWG 2023]

Figure 3-26: Number of NO$_X$ emission points by main sector



Source: [35, TWG 2023]

Figure 3-27: Number of NO$_X$ emission points by associated process(es)



Source: [35, TWG 2023]

Figure 3-28: Distribution of maximum concentrations for NO_X emissions

3.2.6.4 Carbon monoxide (CO)

Carbon monoxide, CO, arises from the combustion of organic matter in the ceramic body – especially under low oxygen conditions. It may also be formed by the reaction of ‘fixed carbon’ in the body with carbon dioxide (CO_2) released by the thermal dissociation of alkali and earth alkali carbonates, for instance calcium or magnesium carbonate during firing:

- $CaCO_3 \longrightarrow CaO + CO_2$
- $C + CO_2 \longrightarrow 2\ CO$

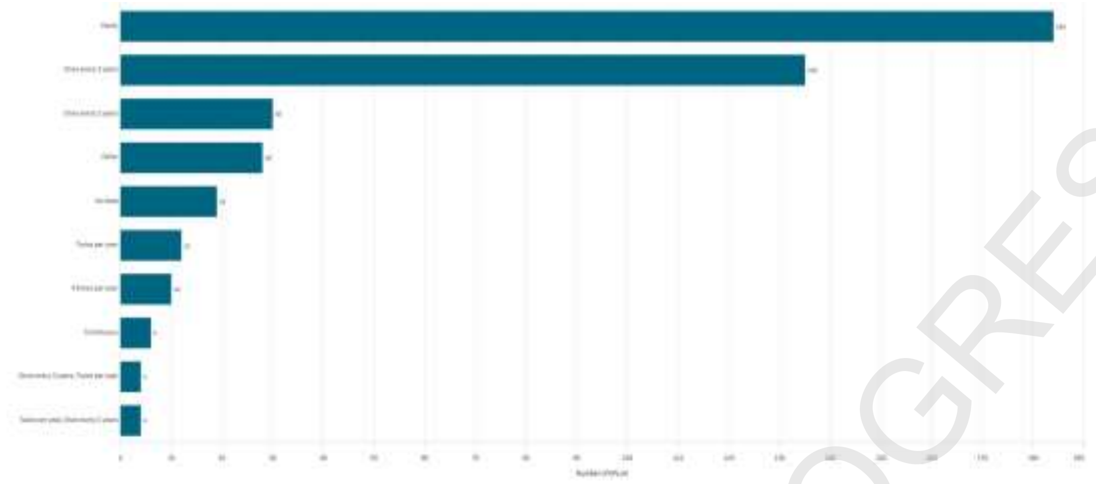
(Carbon dioxide forms as above, and is the main oxide of carbon formed during the combustion of fossil fuels).

Table 3-10 presents a summary of reported data for CO emissions. The reported levels for CO emissions are presented in Sections 3.2.7.13, 3.2.7.15 and 3.2.7.13.

Table 3-10: Summary of data for CO emissions

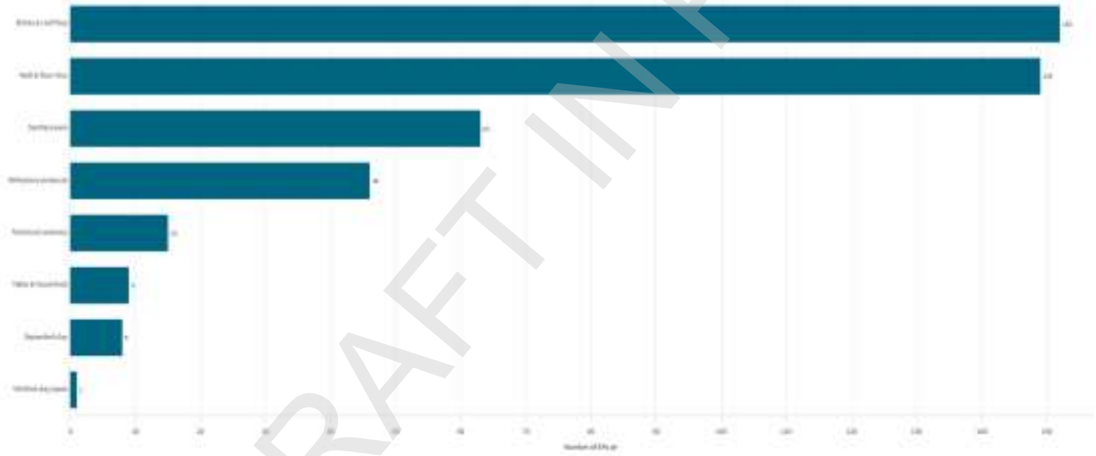
CO emissions	
Number of plants	131
Number of EPs Air	443
Source: [35, TWG 2023]	

Figure 3-29, Figure 3-30, Figure 3-31 and Figure 3-32 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



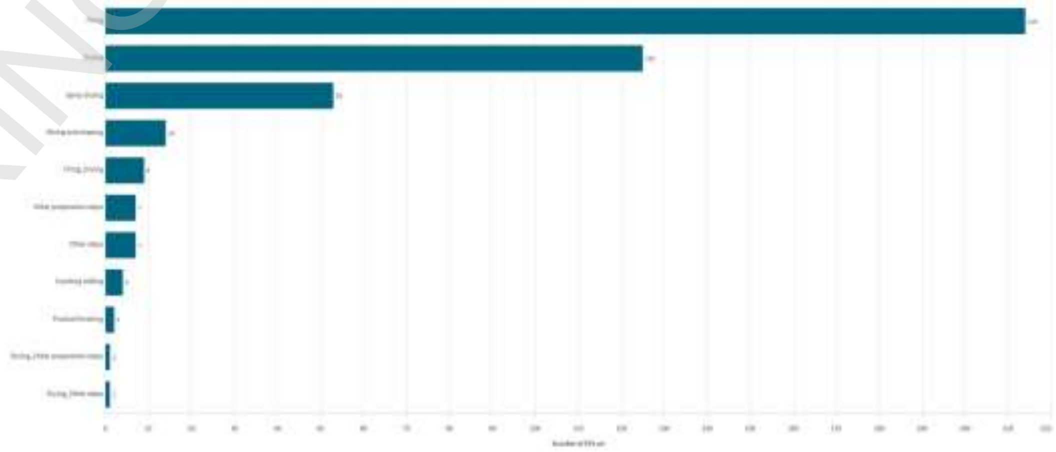
Source: [35, TWG 2023]

Figure 3-29: Monitoring frequency for CO emissions



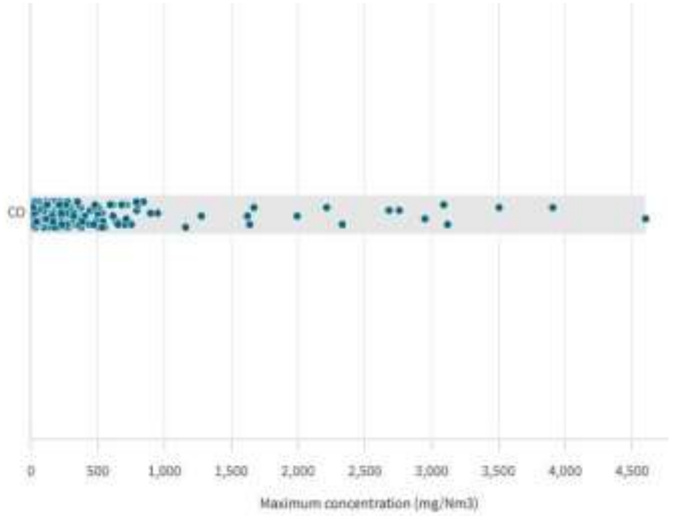
Source: [35, TWG 2023]

Figure 3-30: Number of CO emission points by main sector



Source: [35, TWG 2023]

Figure 3-31: Number of CO emission points by associated process(es)



Source: [35, TWG 2023]

Figure 3-32: Distribution of maximum concentrations for CO emissions

3.2.6.5 Gaseous chlorides (as HCl)

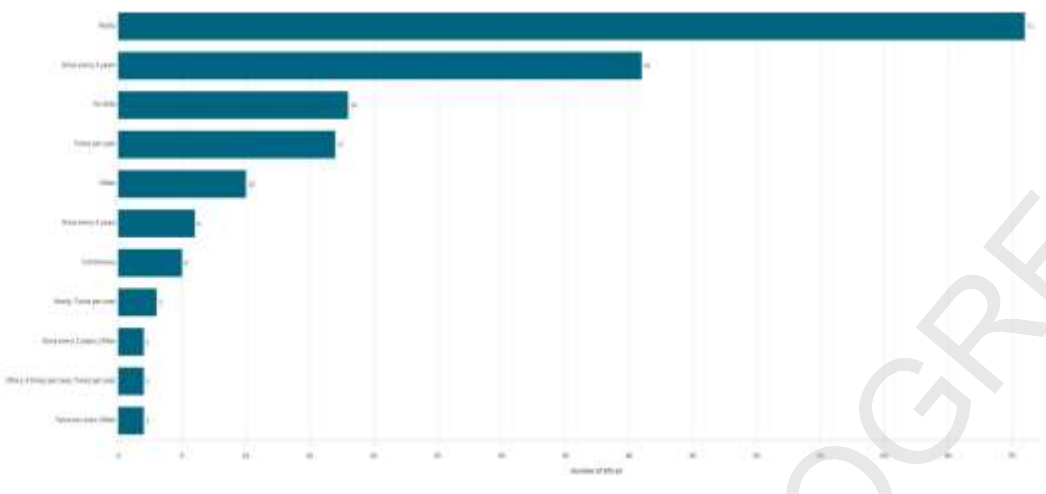
Most clays contain trace levels of chloride, often derived from an original marine formation, but also additives or water containing chloride are possible sources of hydrochloric acid (HCl) emissions (e.g. the Cl content of water added during the preparation of the raw materials may be in the range of 50-100 mg/l or even higher) [23, TWG 2005], [30, TWG 2005]. Due to the decomposition of mineral salts containing chloride at temperatures in excess of 850 ºC and of organic compounds containing chloride at temperatures of between 450 °C and 550 °C, HCl occurs during the firing process in the flue-gases of a kiln [25, Voland, T., Leuenberger, C., Roque, R. 2004].

Table 3-11 presents a summary of reported data for HCl emissions. The reported levels for HCl are presented in Sections 3.2.7.16 and 3.2.7.16.

Table 3-11: Summary of data for HCl emissions

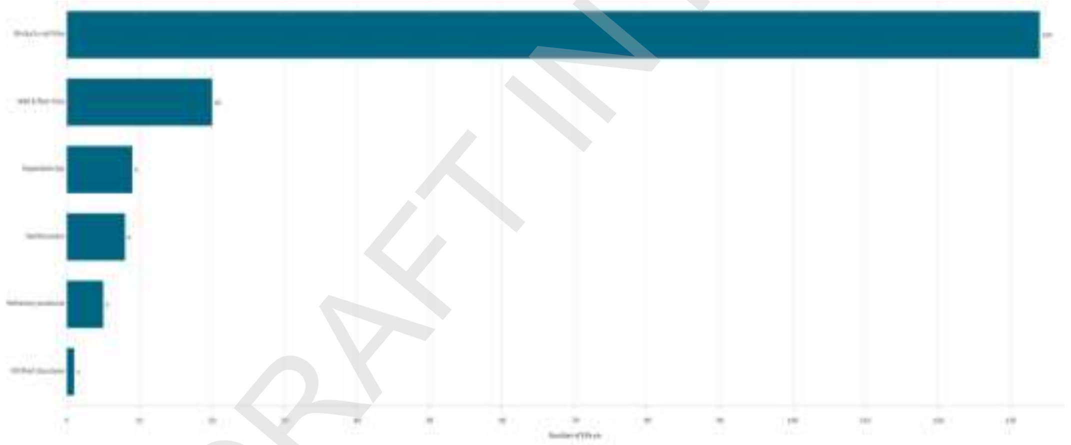
HCl emissions	
Number of plants	97
Number of EPs Air	185
Source: [35, TWG 2023]	

Figure 3-33, Figure 3-34, Figure 3-35 and Figure 3-36 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



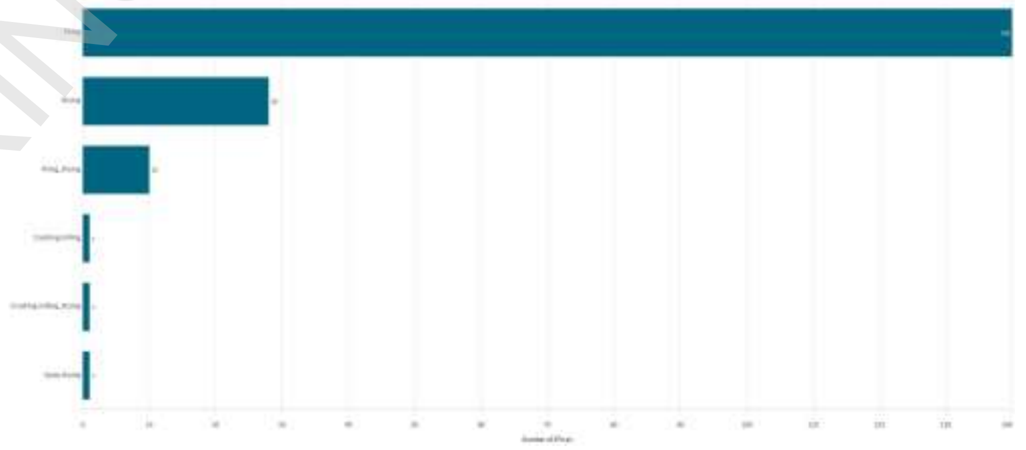
Source: [35, TWG 2023]

Figure 3-33: Monitoring frequency for HCl emissions



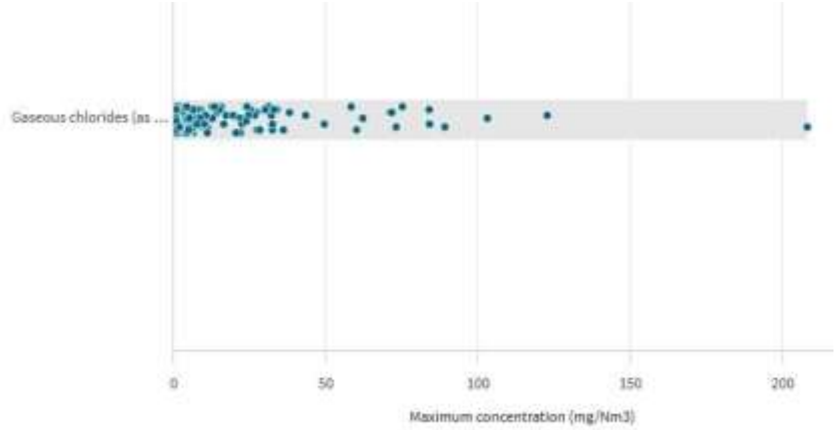
Source: [35, TWG 2023]

Figure 3-34: Number of HCl emission points by main sector



Source: [35, TWG 2023]

Figure 3-35: Number of HCl emission points by associated process(es)



Source: [35, TWG 2023]

Figure 3-36: Distribution of maximum concentrations for HCl emissions

3.2.6.6 Gaseous fluorides (as HF)

Nearly all natural raw materials contain fractional amounts of fluoride (which readily substitutes for OH groups in clays and hydrous minerals). Hydrofluoric acid (HF) comes mainly from the decomposition of these fluorosilicates present in clay material. The emission of HF takes place in accordance with two different mechanisms:

- by direct decomposition of the fluoride minerals which depends heavily on the type of clay (e.g. smectite at temperatures from 550 ºC, illite at temperatures from 750 ºC, apatite at temperatures from 600 ºC to 700 ºC);
- by decomposition of CaF2 at temperatures in excess of 900 ºC, the reaction is favoured by the presence of water vapour, [25, Voland, T., Leuenberger, C., Roque, R. 2004], [23, TWG 2005].

In this context, the water, present in the kiln atmosphere (e.g. formed by combustion of fuels), plays an important role in the mechanism of HF formation. The following reactions are involved:

- mineral-F + H2O —› mineral-OH + HF (1) (release of HF by hydrolysis of mineral-F)
- 2HF + CaO —› CaF2 + H2O (2) (resorption of HF)
- CaF2 + H2O —› 2HF + CaO (3).

Reaction (2) occurs at relatively low temperatures, in the preheating section of the kiln. It explains why the presence of $CaCO_3$/CaO (limestone/lime) can result in a significant reduction of HF emissions. Slow preheating increases the reaction time for resorption and may result in lower HF emissions. Reaction (3) occurs at higher temperatures (> 900 ºC) if the water concentration in the kiln is very high [2, VITO 2003] [23, TWG 2005].

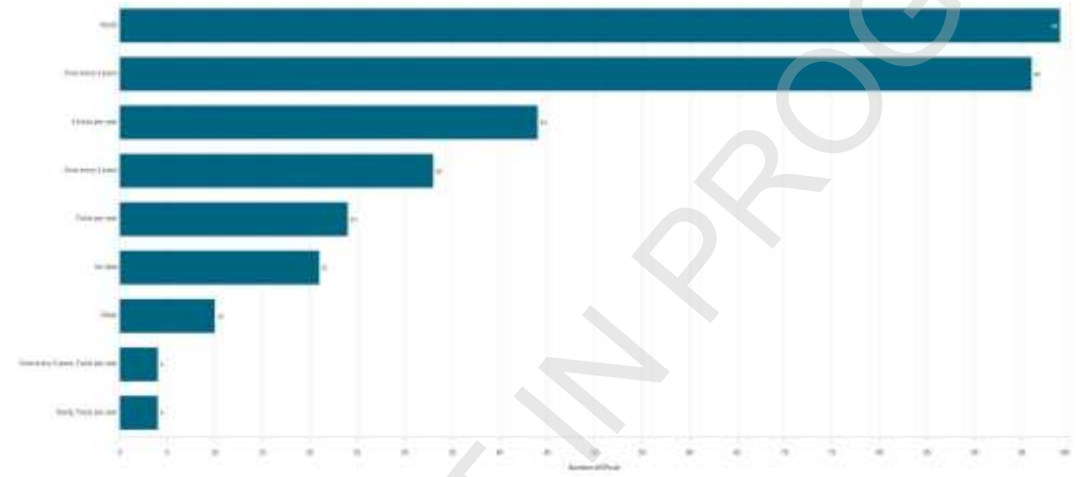
The concentration of fluoride in flue-gases is not only related to the level in the raw materials, the presence of water vapour, the body composition and the temperature curve, but also the setting and the specific surface of the ware to be fired effect the diffusion of H_2O and HF into and out of the ware [23, TWG 2005], [30, TWG 2005].

Table 3-12 presents a summary of reported data for HF emissions. The reported levels for HF emissions are presented in Sections 3.2.7.18 and 3.2.7.18.

Table 3-12: Summary of data for HF emissions

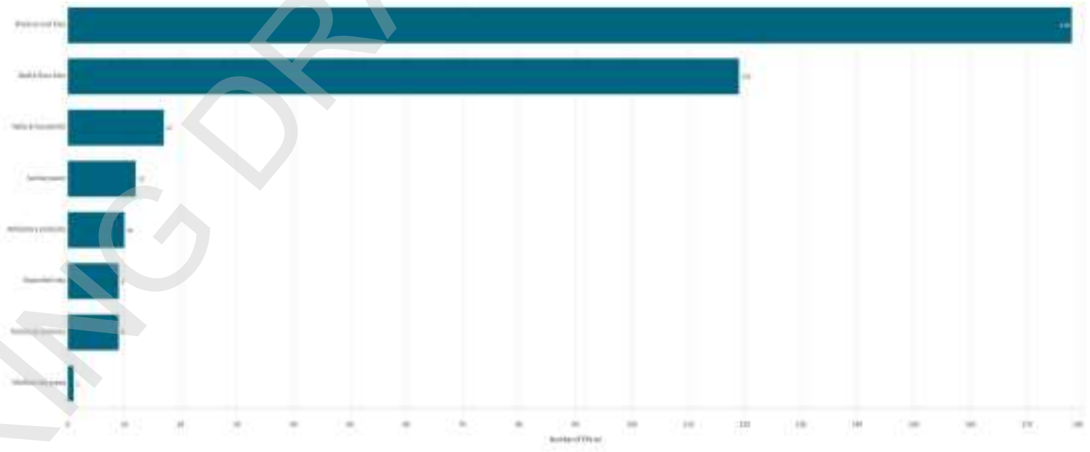
HF emissions	
Number of plants	168
Number of EPs Air	355
Source: [35, TWG 2023]	

Figure 3-37, Figure 3-38, Figure 3-39 and Figure 3-40 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



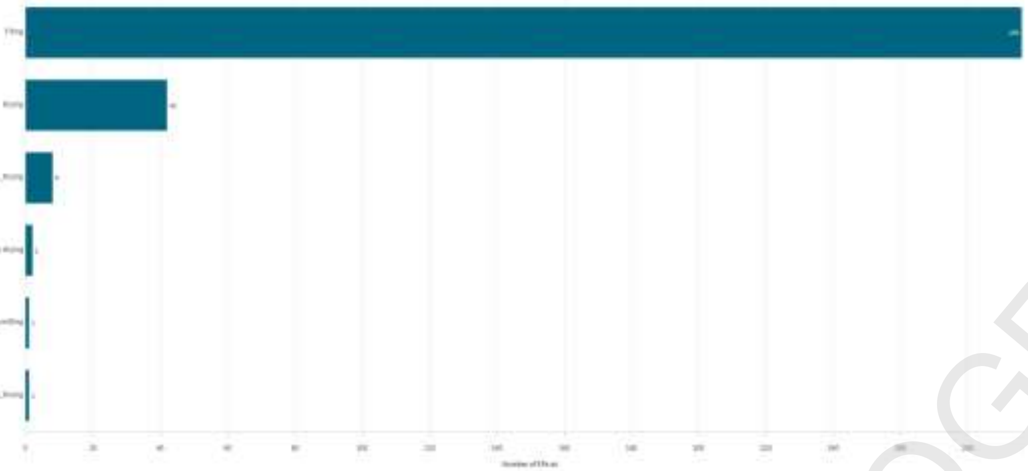
Source: [35, TWG 2023]

Figure 3-37: Monitoring frequency for HF emissions



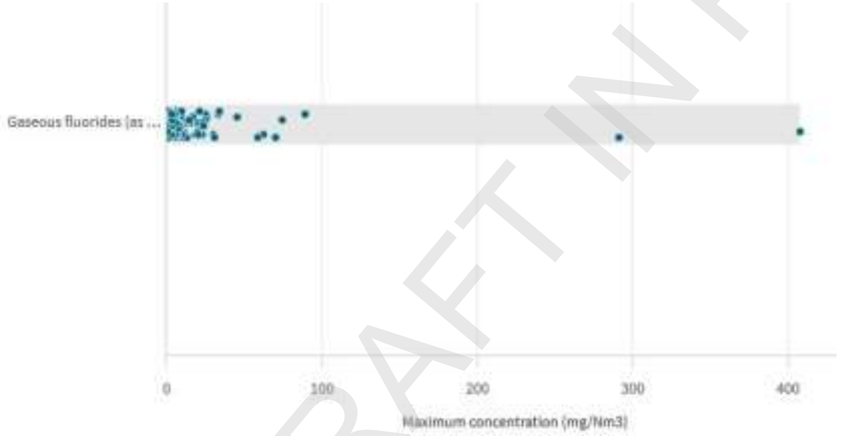
Source: [35, TWG 2023]

Figure 3-38: Number of HF emission points by main sector



Source: [35, TWG 2023]

Figure 3-39: Number of HF emission points by associated process(es)



Source: [35, TWG 2023]

Figure 3-40: Distribution of maximum concentrations for HF emissions

3.2.6.7 Total volatile organic compounds (TVOC)

Ceramic raw materials may themselves contain organic matter, and a wide range of organic materials are added in the form of, for example, binding agents, pore-forming agents, drying aids, adhesives, body fuels, burnout additives, inks~~, etc~~.

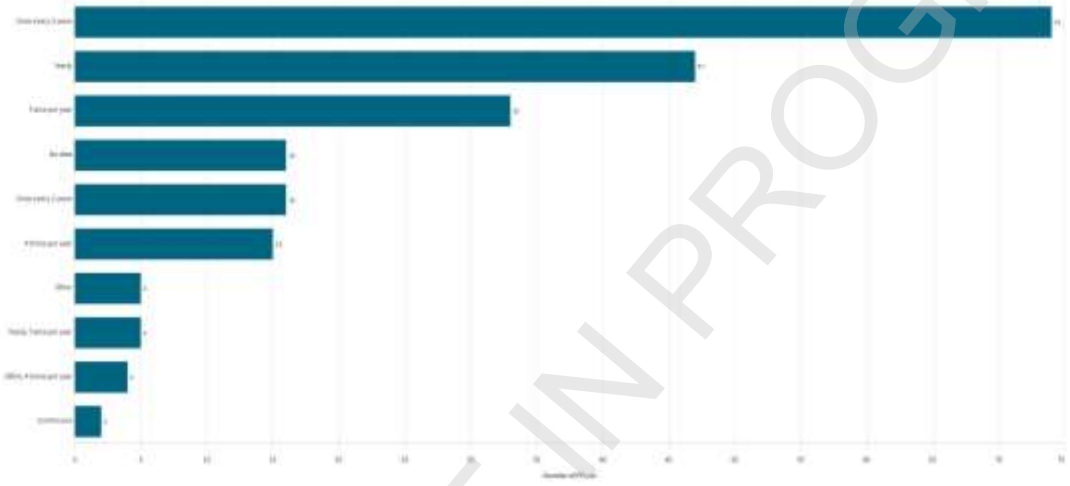
During the early heating process, carbonisation of organic compounds may occur with the release of a complex range of VOCs.

Table 3-13 presents a summary of reported data for TVOC emissions. The reported levels for TVOC emissions are presented in Sections 3.2.7.20 and 3.2.7.20.

Table 3-13: Summary of data for TVOC emissions

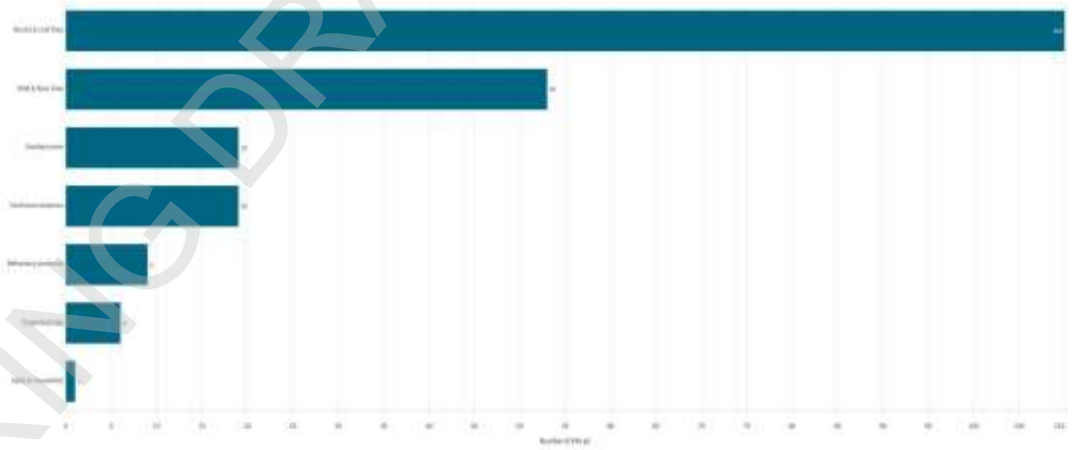
TVOC emissions	
Number of plants	102
Number of EPs Air	217
Source: [35, TWG 2023]	

Figure 3-41, Figure 3-42, Figure 3-43 and Figure 3-44 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



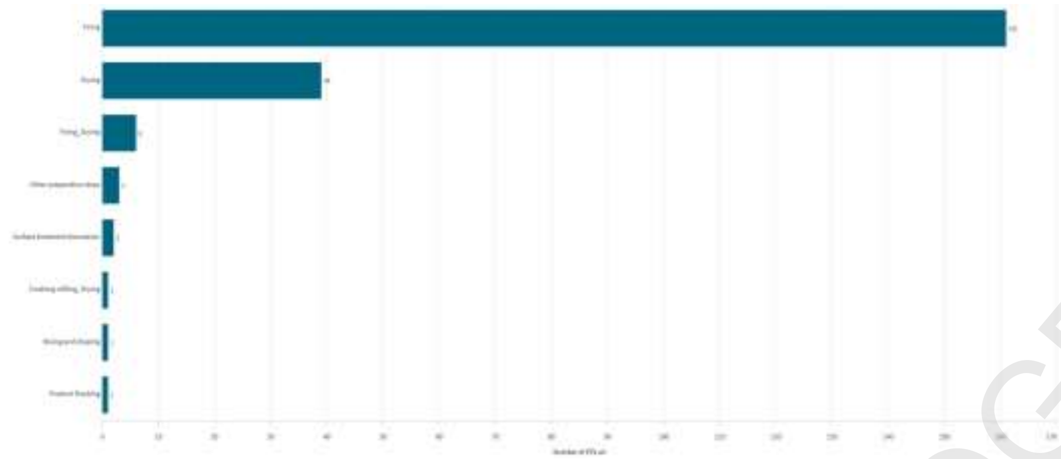
Source: [35, TWG 2023]

Figure 3-41: Monitoring frequency for TVOC emissions



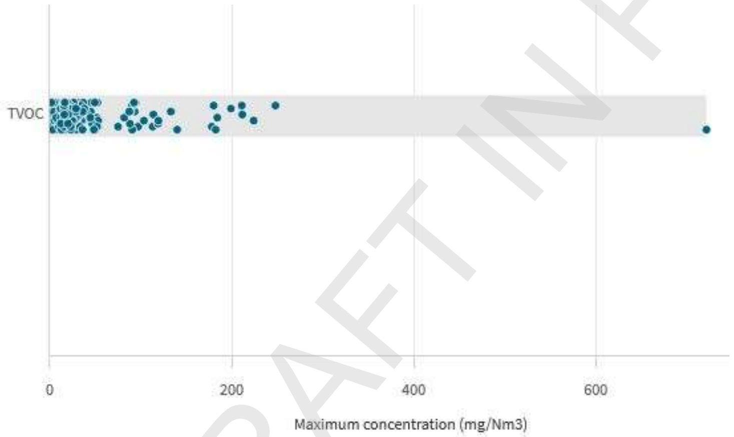
Source: [35, TWG 2023]

Figure 3-42: Number of TVOC emission points by main sector



Source: [35, TWG 2023]

Figure 3-43: Number of TVOC emission points by associated process(es)



Source: [35, TWG 2023]

Figure 3-44: Distribution of maximum concentrations for TVOC emissions

3.2.6.8 Acetaldehyde

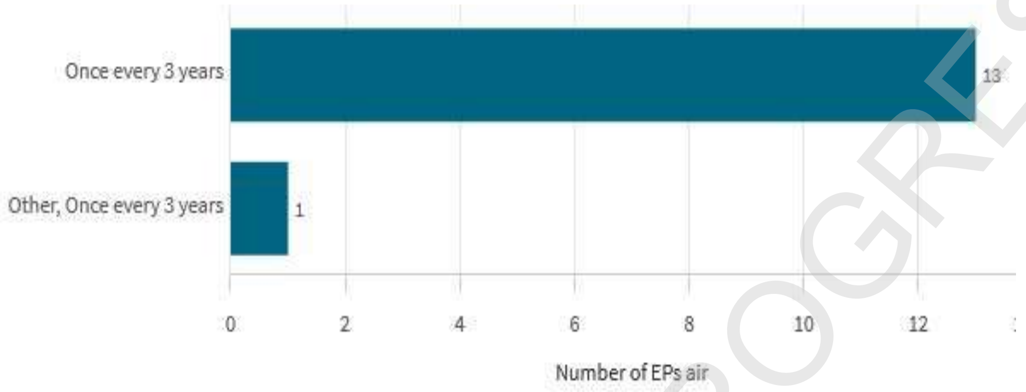
Acetaldehyde emissions are released during the manufacturing of bricks, clay blocks, wall and floor tiles and refractory products. It is mainly released during the firing process [35, TWG 2023], [44, COM 2020].

Table 3-14 presents a summary of reported data for acetaldehyde emissions. The reported levels for acetaldehyde emissions are presented in Sections 3.2.7.22.

Table 3-14: Summary of data for acetaldehyde emissions

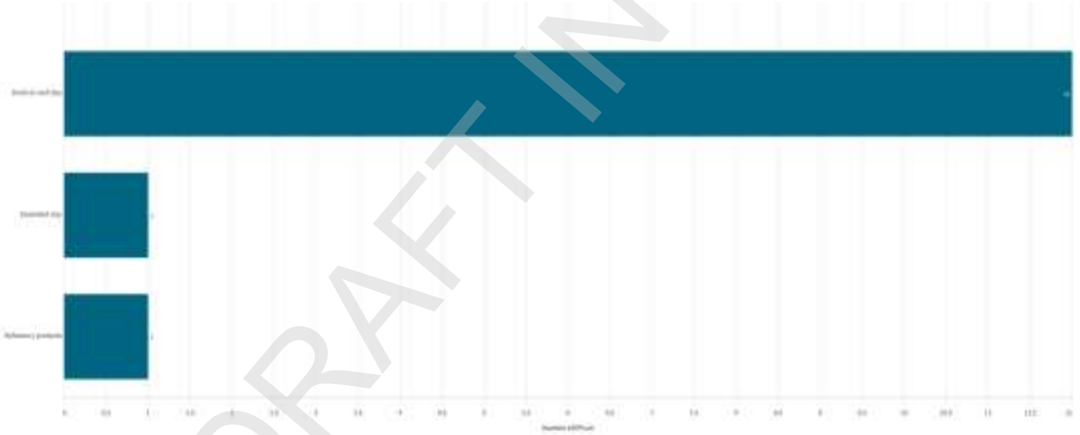
Acetaldehyde emissions	
Number of plants	14
Number of EPs Air	14
Source: [35, TWG 2023]	

Figure 3-45, Figure 3-46, Figure 3-47 and Figure 3-48 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



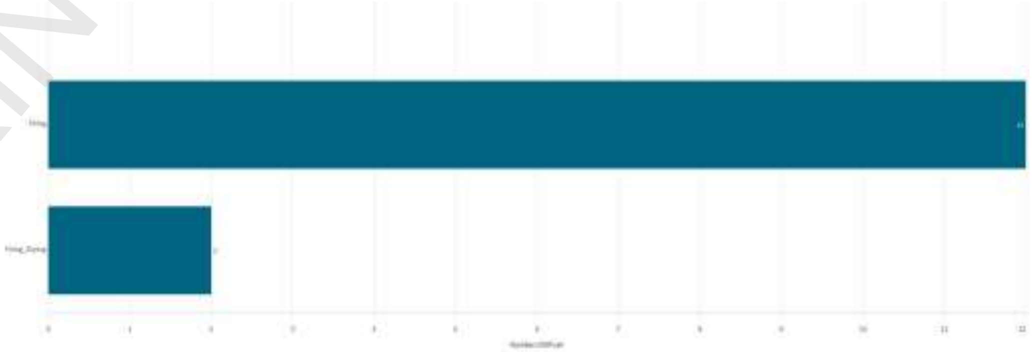
Source: [35, TWG 2023]

Figure 3-45: Monitoring frequency for acetaldehyde emissions



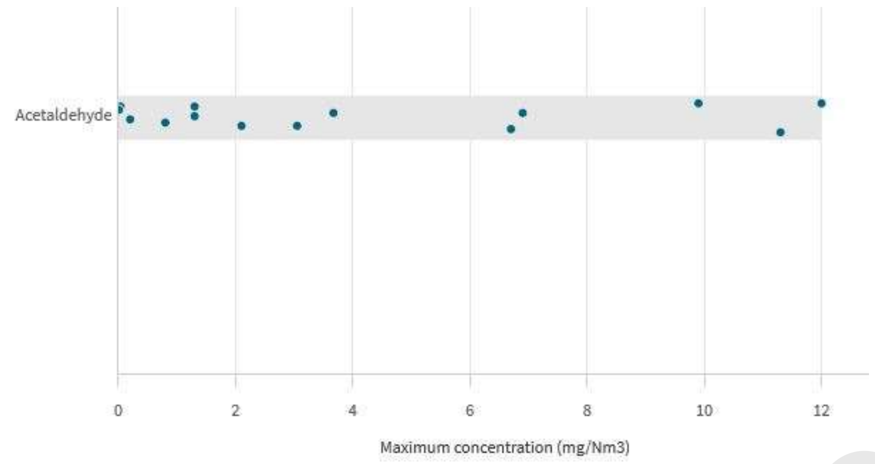
Source: [35, TWG 2023]

Figure 3-46: Number of acetaldehyde emission points by main sector



Source: [35, TWG 2023]

Figure 3-47: Number of acetaldehyde emission points by associated process(es)



Source: [35, TWG 2023]

Figure 3-48: Distribution of the maximum concentrations for acetaldehyde emissions

3.2.6.9 Benzene

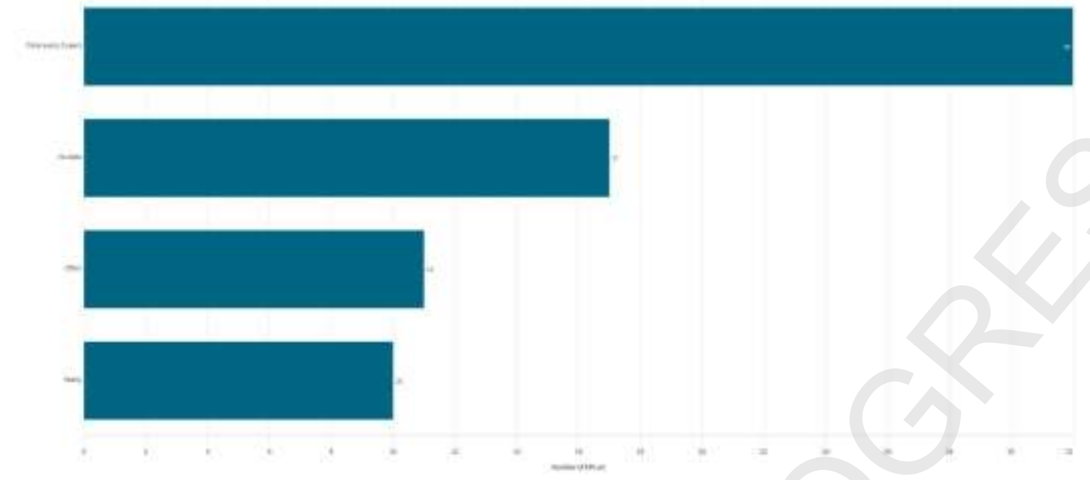
Benzene emissions to air may occur mainly during the firing processes (e.g. firing of ware) and other thermal processes. All production sectors where organic additives are used (additives/auxiliary agents, e.g. organic pore-forming agents) release benzene emissions. [35, TWG 2023], [44, COM 2020].

Table 3-15 presents a summary of reported data for benzene emissions. The reported levels for benzene emissions are presented in Section 3.2.7.23.

Table 3-15: Summary of data for benzene emissions

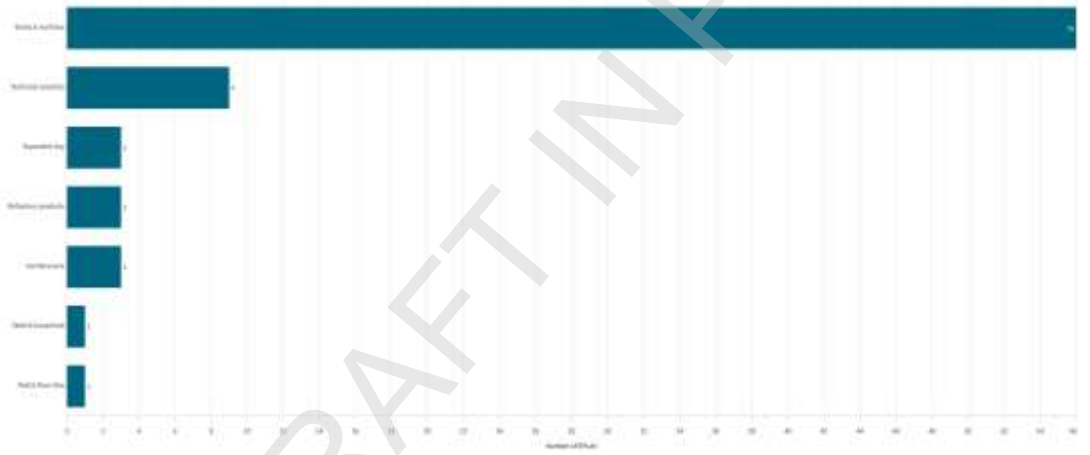
Benzene emissions	
Number of plants	57
Number of EPs Air	76
Source: [35, TWG 2023]	

Figure 3-49, Figure 3-50, Figure 3-51 and Figure 3-52 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



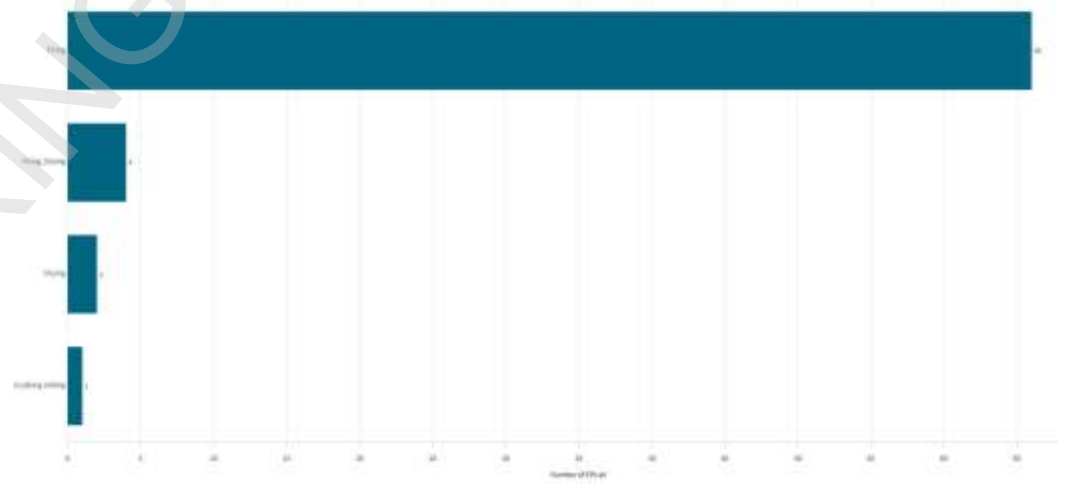
Source: [35, TWG 2023]

Figure 3-49: Monitoring frequency for benzene emissions



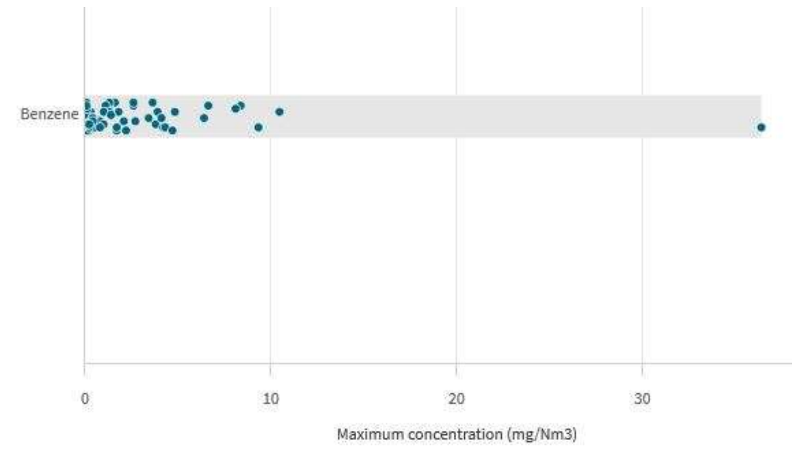
Source: [35, TWG 2023]

Figure 3-50: Number of benzene emission points by main sector



Source: [35, TWG 2023]

Figure 3-51: Number of benzene emission points by associated process(es)



Source: [35, TWG 2023]

Figure 3-52: Distribution of maximum concentrations for benzene emissions

3.2.6.10 Formaldehyde

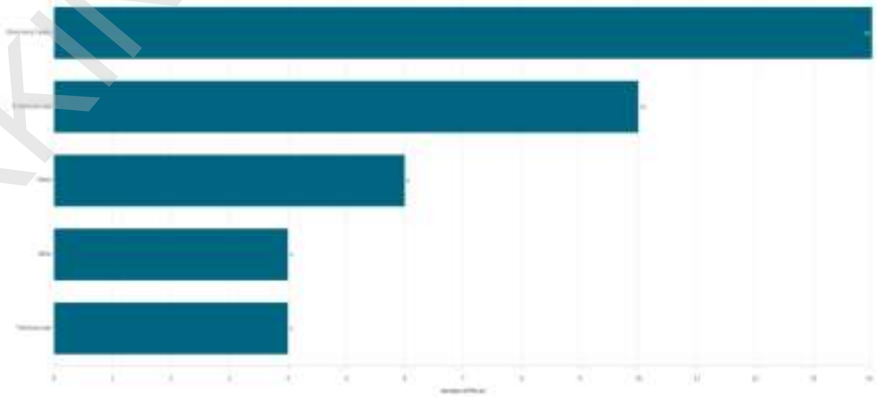
Formaldehyde can be released mainly from firing and drying process and special process steps (e.g. formation of carbon bonding, pitch impregnation) during the production of refractory products [35, TWG 2023], [44, COM 2020].

Table 3-16 presents a summary of reported data for formaldehyde emissions. The reported levels for formaldehyde emissions are presented in Sections 3.2.7.24.

Table 3-16: Summary of data for formaldehyde emissions

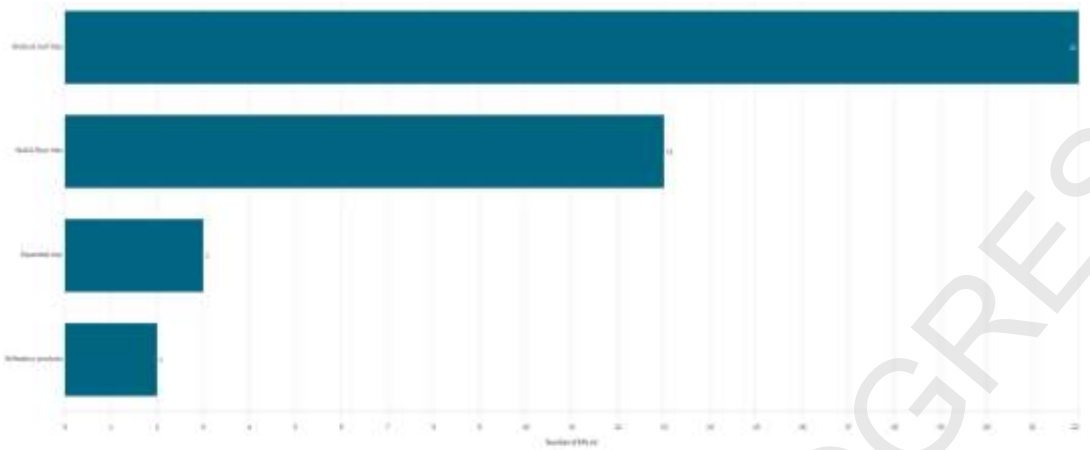
Formaldehyde emissions	
Number of plants	29
Number of EPs Air	40
Source: [35, TWG 2023]	

Figure 3-53, Figure 3-54, Figure 3-55 and Figure 3-56 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



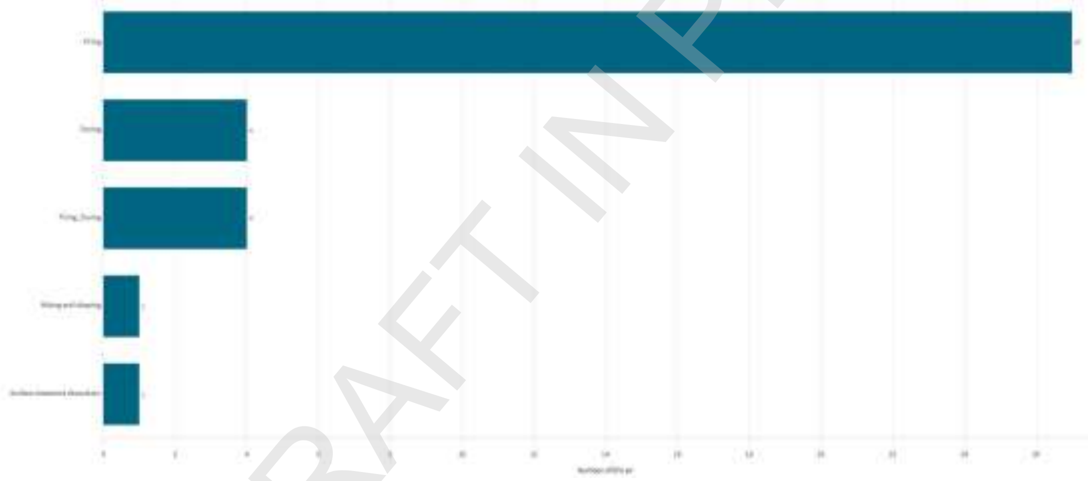
Source: [35, TWG 2023]

Figure 3-53: Monitoring frequency for formaldehyde emissions



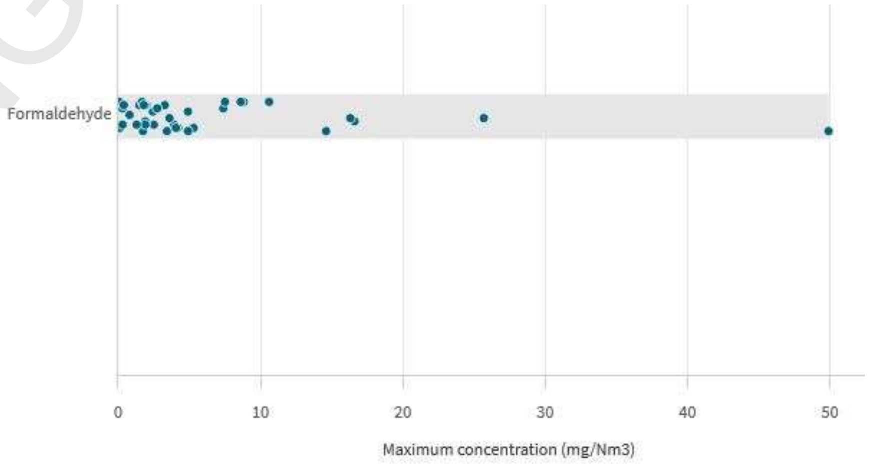
Source: [35, TWG 2023]

Figure 3-54: Number of formaldehyde emission points by main sector



Source: [35, TWG 2023]

Figure 3-55: Number of formaldehyde emission points by associated process(es)



Source: [35, TWG 2023]

Figure 3-56: Distribution of maximum concentrations reported for formaldehyde emissions

3.2.6.11 Phenol

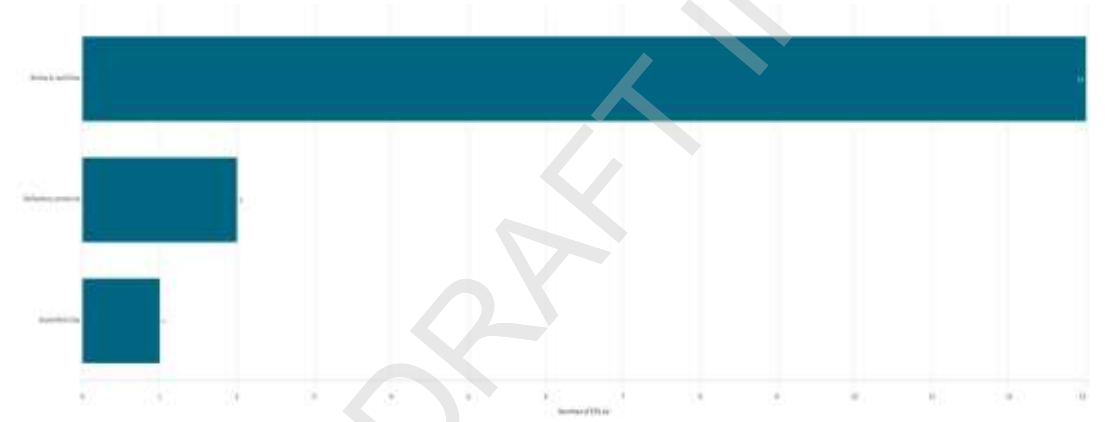
Phenol emissions are mainly released during firing process, i.e. firing of ware (e.g. mainly when additives/auxiliary agents (e.g. organic pore-forming agents, such as sawdust) are used) [35, TWG 2023], [44, COM 2020].

Table 3-17 presents a summary of reported data for phenols emissions. The reported levels for phenol emissions are presented in Section 3.2.7.25.

Table 3-17: Summary of data for phenol emissions

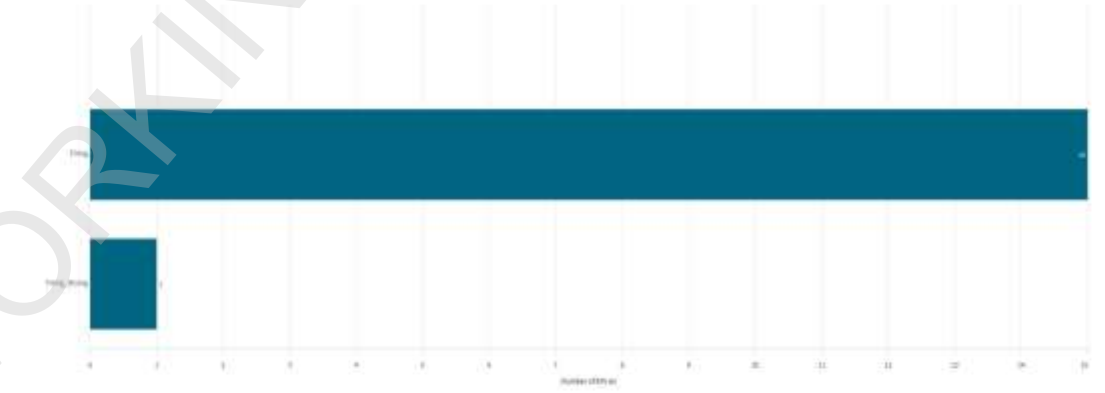
Phenol emissions	
Number of plants	16
Number of EPs Air	16
Source: [35, TWG 2023]	

Figure 3-57, Figure 3-58 and Figure 3-59 present the reported data on distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations. The most commonly reported monitoring frequency for phenol emissions was reported as measurement once every 3 years.



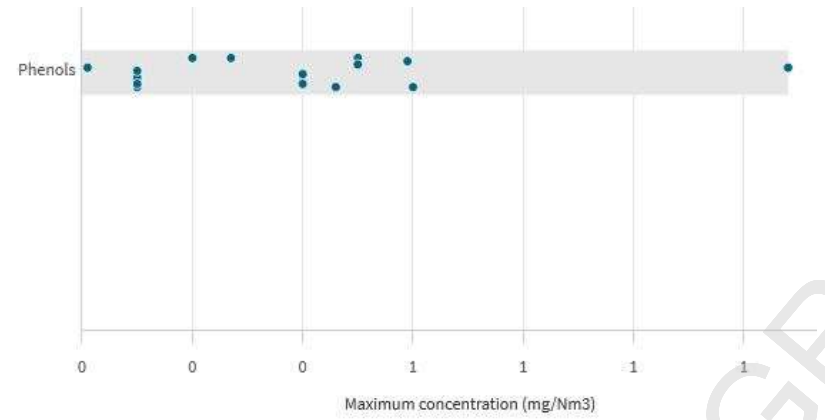
Source: [35, TWG 2023]

Figure 3-57: Number of phenol emission points by main sector



Source: [35, TWG 2023]

Figure 3-58: Number of phenol emission points by associated process(es)



Source: [35, TWG 2023]

Figure 3-59: Distribution of maximum concentrations for phenol emissions

3.2.6.12 Styrene

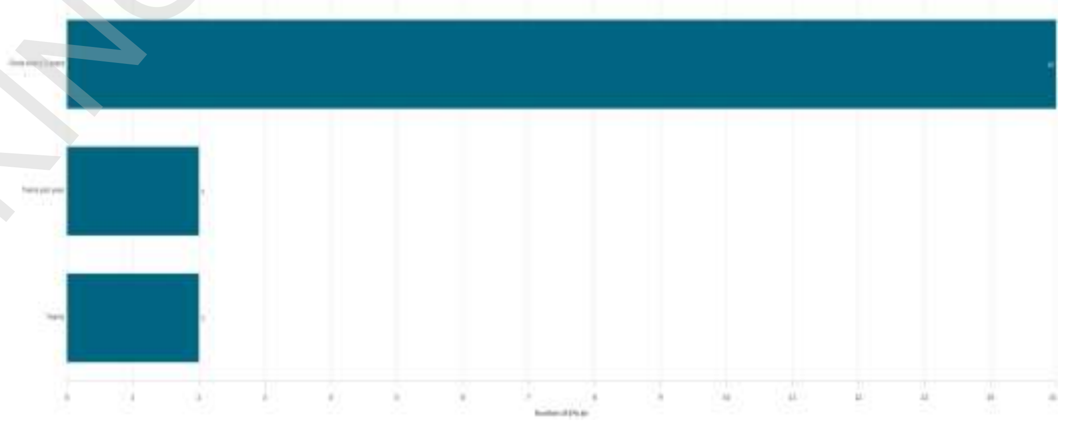
Styrene may be released during the firing step due to the use of polystyrene as a pore-forming agent in the production of clay blocks or as protection in other sectors. [35, TWG 2023], [44, COM 2020].

Table 3-18 presents a summary of reported data for styrene emissions. The reported levels for styrene emissions are presented in Section 3.2.7.26.

Table 3-18: Summary of data for styrene emissions

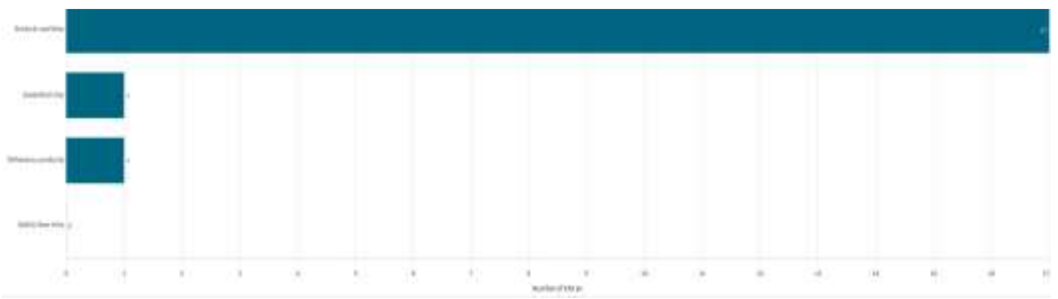
Styrene emissions	
Number of plants	17
Number of EPs Air	19
Source: [35, TWG 2023]	

Figure 3-61, Figure 3-62 and Figure 3-63 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



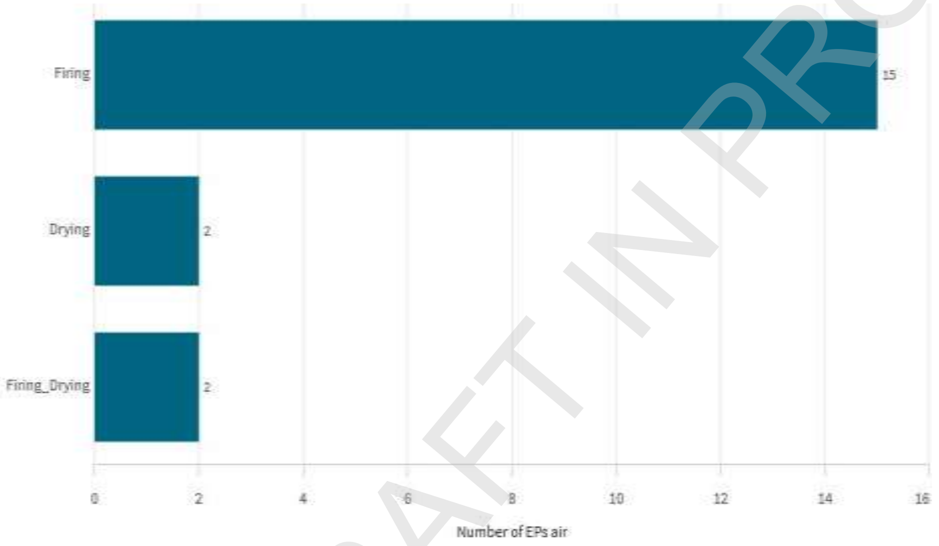
Source: [35, TWG 2023]

Figure 3-60: Monitoring frequency for styrene emissions



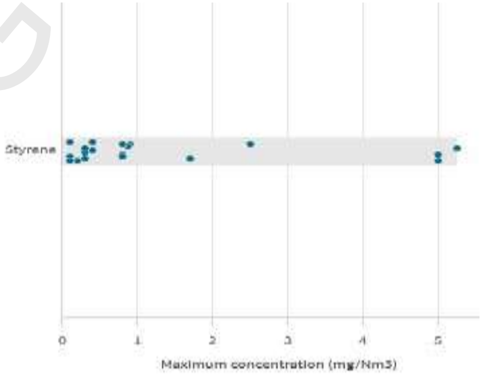
Source: [35, TWG 2023]

Figure 3-61: Number of styrene emission points by main sector



Source: [35, TWG 2023]

Figure 3-62: Number of styrene emission points by associated process(es)



Source: [35, TWG 2023]

Figure 3-63: Distribution of maximum concentrations for styrene emissions

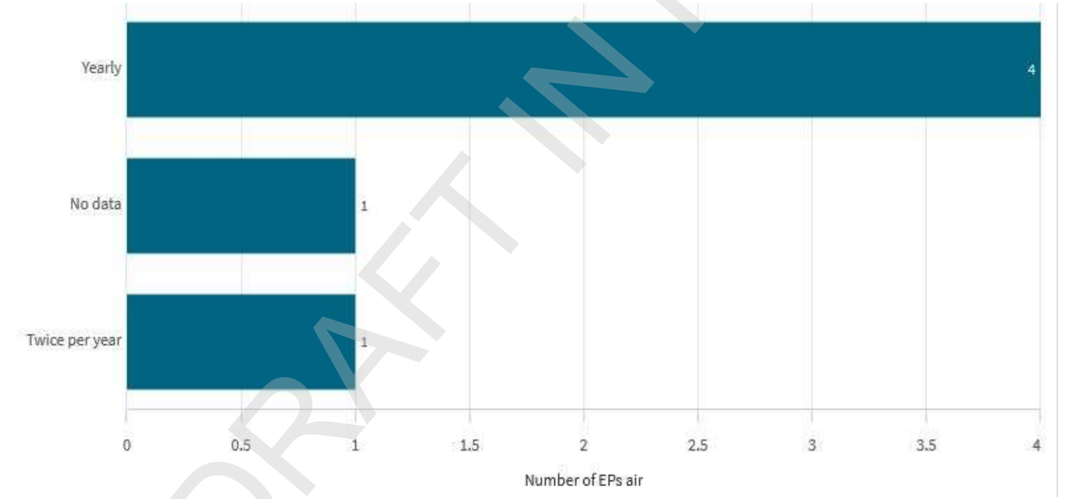
3.2.6.13 Polycyclic aromatic hydrocarbons (PAHs)

PAHs may be released during firing, drying of ware and finishing of processes for the production of wall and floor tiles, refractory products, bricks and expanded clay aggregates, ceramic tiles and inorganic bonded abrasives. PAHs can bind to or form small particles in the air. [35, TWG 2023], [44, COM 2020]. Table 3-19 presents a summary of reported data for PAH emissions.

Table 3-19: Summary of data for PAH emissions

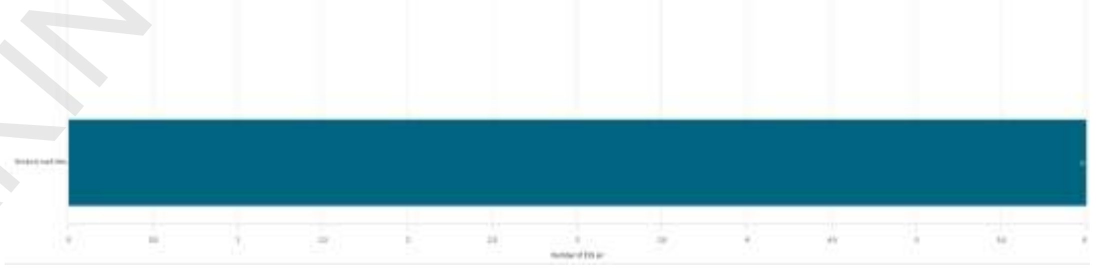
PAH emissions	
Number of plants	6
Number of EPs Air	6
Source: [35, TWG 2023]	

Figure 3-64, Figure 3-65 and Figure 3-66 present the reported data on monitoring frequency, distribution of the number of emission points by main sector, and distribution of maximum reported concentrations.



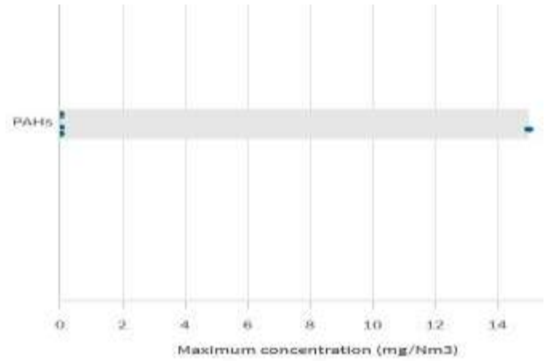
Source: [35, TWG 2023]

Figure 3-64: Monitoring frequency for PAH emissions



Source: [35, TWG 2023]

Figure 3-65: Number of PAH emission points by main sector



Source: [35, TWG 2023]

Figure 3-66: Distribution of maximum concentrations for PAH emissions

3.2.6.14 Dioxins and furans (PCDD/Fs)

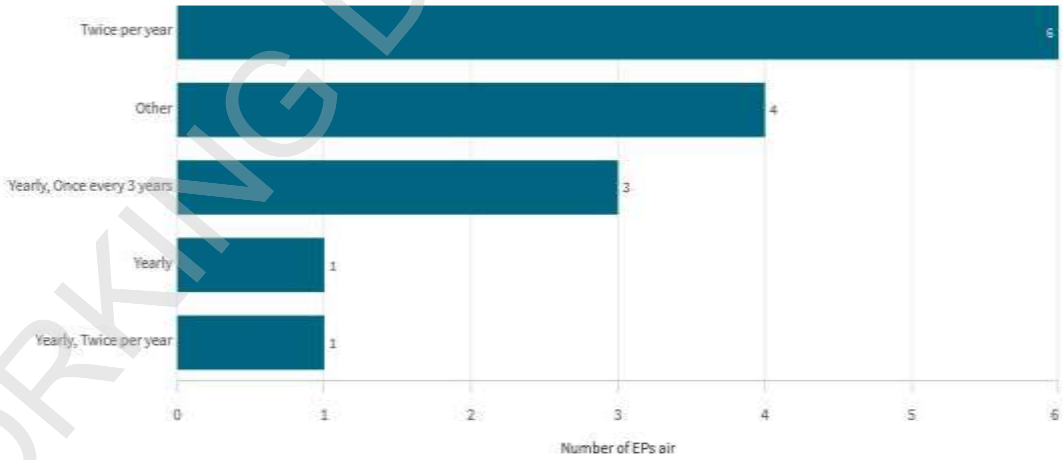
PCDD/F emissions are mainly released during firing and drying of ware processes [35, TWG 2023], [44, COM 2020].

Table 3-20 presents a summary of reported data for PCDD/F emissions. The reported levels for PCDD/F emissions are shown in Section 3.2.7.27.

Table 3-20: Summary of data for PCDD/F emissions

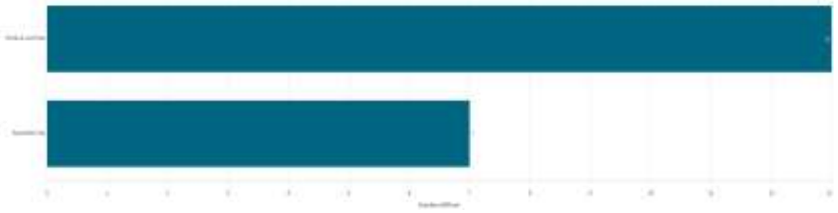
PCDD/F emissions	
Number of plants	16
Number of EPs Air	20
Source: [35, TWG 2023]	

Figure 3-67, Figure 3-68, Figure 3-69 and Figure 3-70 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



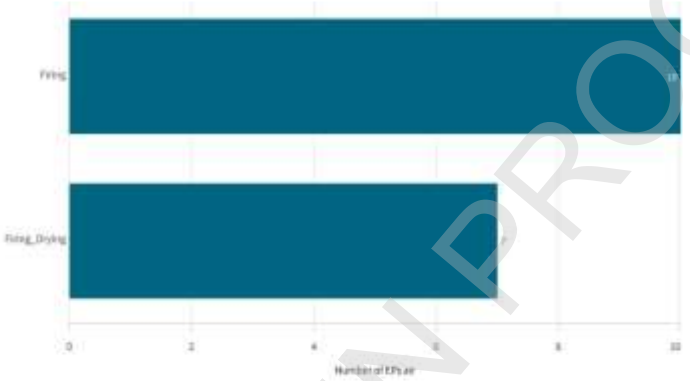
Source: [35, TWG 2023]

Figure 3-67: Monitoring frequency for PCDD/F emissions



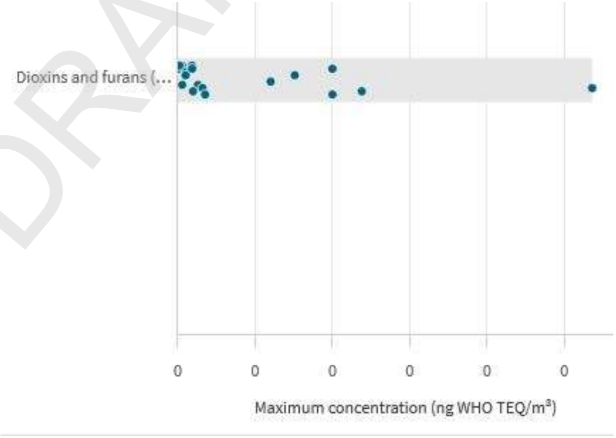
Source: [35, TWG 2023]

Figure 3-68: Number of PCDD/F emission points by main sector



Source: [35, TWG 2023]

Figure 3-69: Number of PCDD/F emission points by associated process(es)



Source: [35, TWG 2023]

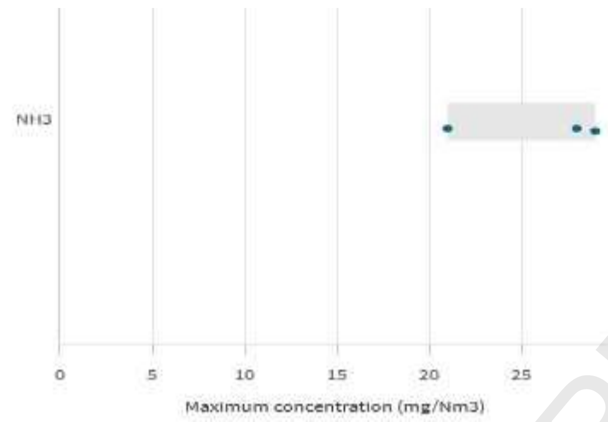
Figure 3-70: Distribution of the maximum concentrations reported for PCDD/s emissions

3.2.6.15 Ammonia (NH_3)

Table 3-21 presents a summary of reported data for NH_3 emissions. The monitoring frequency is reported as continuous measurement. Only one plant in the data collection reported emission data for NH_3, which may be due to the use of sewage sludge as an expansion additive for the production of expanded clay. Figure 3-71 presents the distribution of the maximum concentration values.

Table 3-21: Summary of data for NH_3 emissions

NH_3 emissions	
Number of plants	1
Number of EPs Air	3
Source: [35, TWG 2023]	



Source: [35, TWG 2023]

Figure 3-71: Distribution of the maximum concentrations reported for NH_3 emissions

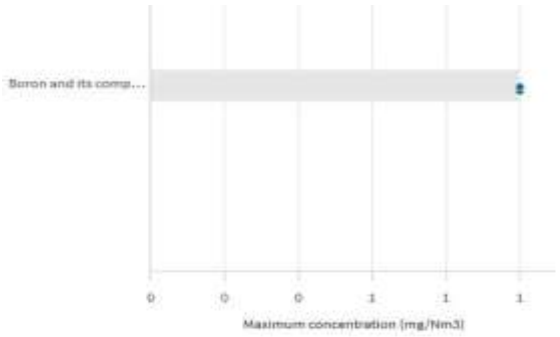
3.2.6.16 Boron and its compounds (B)

Boron and its compounds emissions may be released during surface treatment and firing of ware. Boron emissions to air may result from the use of boron compounds as fluxing agents and in the glazing step. [35, TWG 2023], [44, COM 2020]. Table 3-22 presents a summary of reported data for emissions of boron and its compounds.

Table 3-22: Summary of data for B emissions to air

B emissions	
Number of plants	1
Number of EPs Air	4
Source: [35, TWG 2023]	

Figure 3-72 below shows the distribution of maximum reported concentrations.



Source: [35, TWG 2023]

Figure 3-72: Distribution of the maximum concentrations reported for B emissions to air

3.2.6.17 Lead and its compounds (Pb)

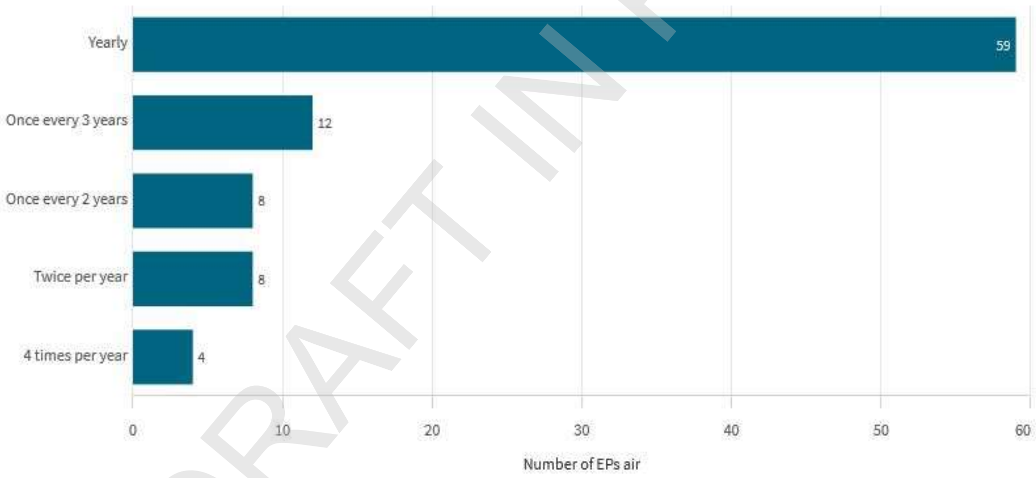
Lead and its compounds (Pb) are generally released during surface treatment, firing of ware, drying of ware with flue-gases. [35, TWG 2023], [44, COM 2020].

Table 3-23 presents the number of emission points that reported data for Pb. The reported levels for Pb are shown in Section 3.2.7.28 and 3.2.7.29.

Table 3-23: Summary of data for Pb emissions to air

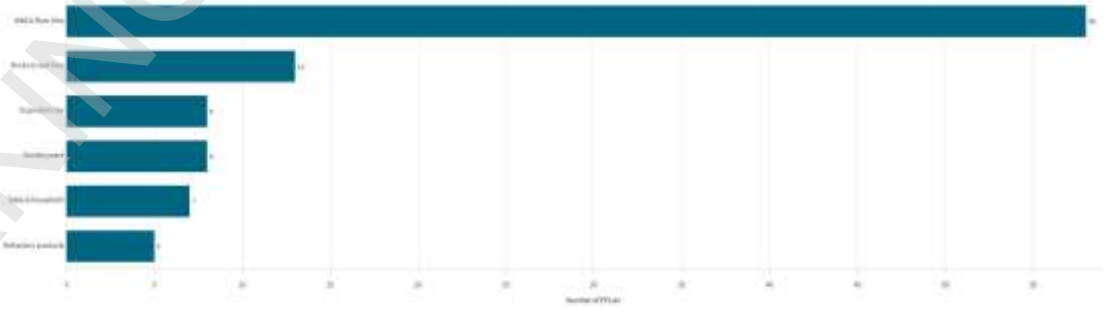
Pb emissions	
Number of plants	41
Number of EPs Air	99
Source: [35, TWG 2023]	

Figure 3-73, Figure 3-74, Figure 3-75 and Figure 3-76 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated processes, and distribution of maximum reported concentrations.



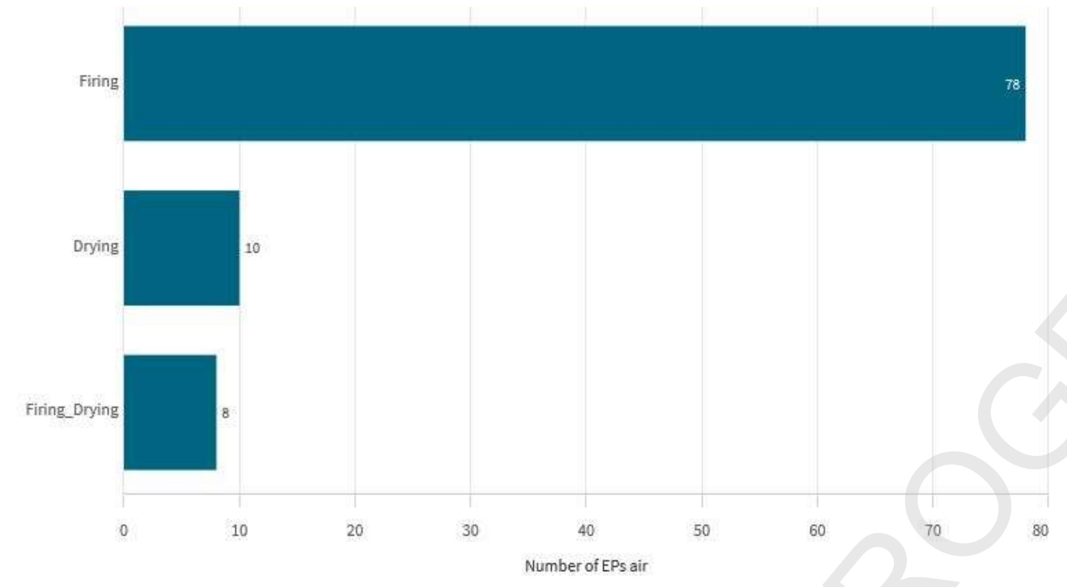
Source: [35, TWG 2023]

Figure 3-73: Monitoring frequency for Pb emissions to air



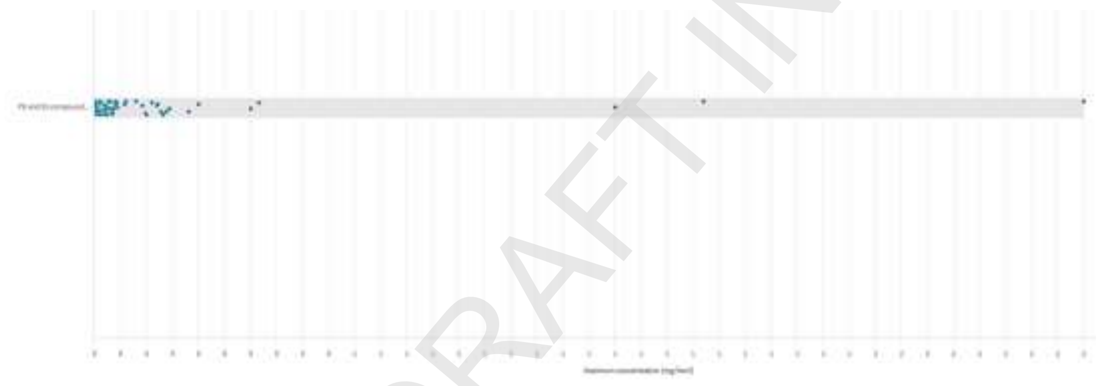
Source: [35, TWG 2023]

Figure 3-74: Number of emission points for Pb emissions to air by main sector



Source: [35, TWG 2023]

Figure 3-75: Number of emission points for Pb emissions to air by associated process(es)



Source: [35, TWG 2023]

Figure 3-76: Distribution of maximum concentrations for lead and its compounds emissions to air

3.2.6.18 Other metals and metalloids

Metals and other metalloids emissions to air may have a significant environmental impact. For instance, metals and metalloids emissions might occur mainly during firing and surface treatment processes. ~~The heavy metal content of most ceramic raw materials is very low, and causes no emission problems.~~ ~~Exceptions occur in the case of ceramic pigments and glaze materials, but present practice is to use coloured compounds (‘stain’ containing pigments), which are stable at high temperatures and inert in silicate systems, where the metallic oxides have a stable crystal structure like spinel or zircon [23, TWG 2005]. These types of glaze are also subject to extremely short firing cycles, minimising the risk of volatility.~~

Heavy fuel oils and solid fuels may contain low levels of nickel and vanadium, but tests have shown these elements to be largely absorbed by a reaction with the product during firing. More specifically, the following observations have been made:

- Sb, Cr (VI), Cr, Co, Mn, Ni, Sn, V and their compounds are emitted in sectors producing glazed, engobed, printed or decorated products. Emission of these metals and metalloids to air occurs in the form of particles from surface treatment, firing and finishing processes. In particular, chromium can be used as raw material in the production of refractory products [35, TWG 2023], [44, COM 2020].

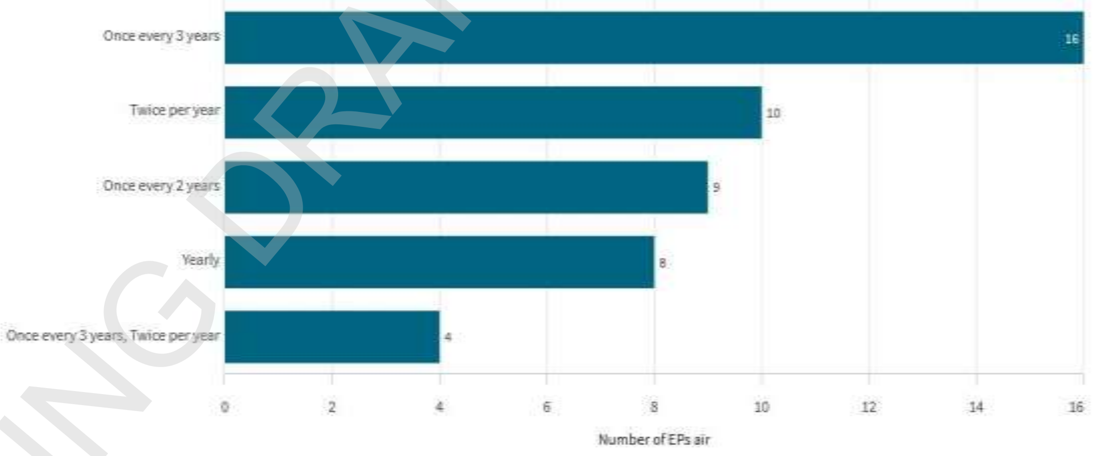
- Hg emissions may be generated during the firing step due to the raw materials and type of fuel used.
- Co, Cr, Cu, Mn, Ni, V and Zn are emitted from the ceramic manufacturing plants. In particular, Mn compounds are used as a colouring agent in the production of brick and roof tiles.
- As, Cd, Cr, Co, Cu, Hg, Mn, Ni, Pb, Sb, Se, Sn, Tl, Te, V and Zn are commonly reported pollutants when various types of fuel are used [35, TWG 2023].

Table 3-24 presents a summary of reported data for other metals and metalloids emissions. The reported levels for Cd, Cr, Ni and Zn emissions are presented in 3.2.7.30 to 3.2.7.33.

Table 3-24: Summary of data for other metals and metalloids emissions

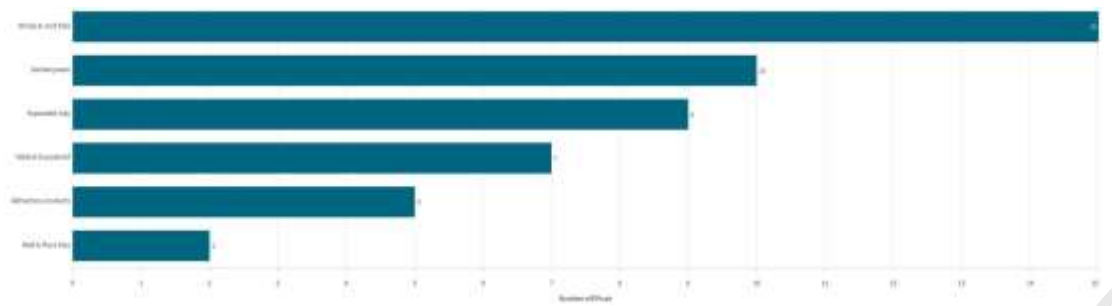
Other metals and metalloids emissions	
Number of plants	25
Number of EPs Air	48*
NB: Summary of data for other metals and metalloids includes reported data for As, Cd, Cr, Co, Cu, Hg, Mn, Ni, Sb, Se, Sn, Tl, Te, V and Zn emissions. *Source:* [35, TWG 2023]	

Figure 3-77, Figure 3-78, Figure 3-79 and Figure 3-80 present the reported data for As, Cd, Cr, Co, Cu, Hg, Mn, Ni, Sb, Se, Sn, Tl, Te, V and Zn emissions on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum concentrations reported. For emission data, levels with sufficient data points are presented separately.



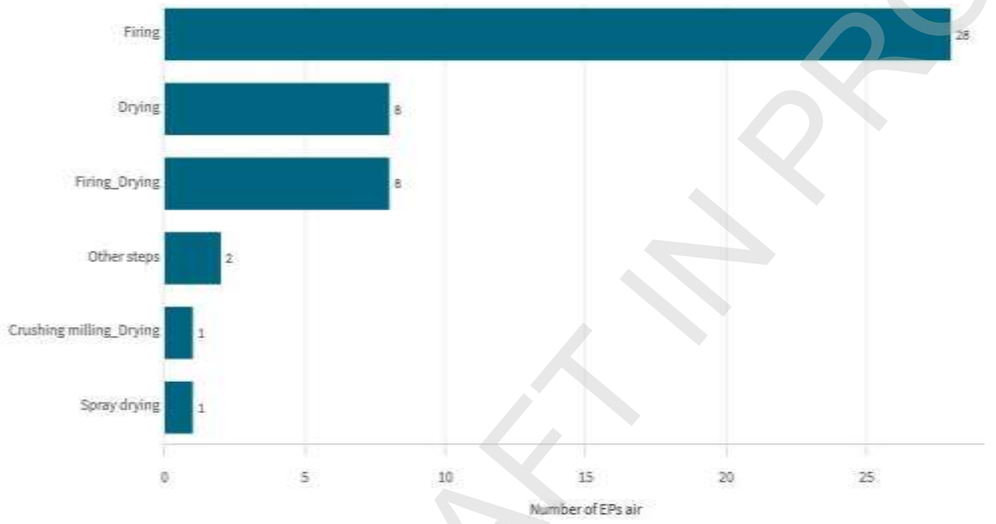
Source: [35, TWG 2023]

Figure 3-77: Monitoring frequency for other metals and metalloids emissions to air



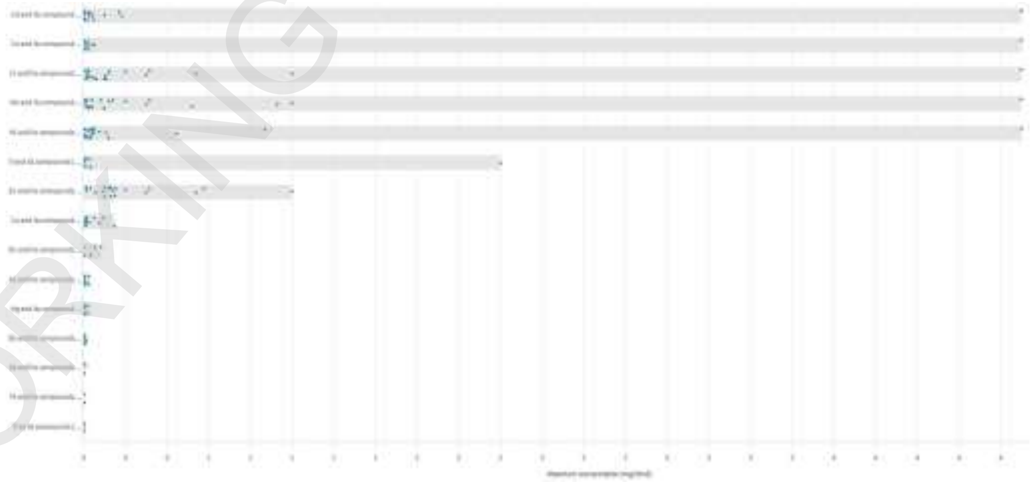
Source: [35, TWG 2023]

Figure 3-78: Number of other metals and metalloids emission points for emissions to air by main sector



Source: [35, TWG 2023]

Figure 3-79: Number of other metals and metalloids emission points for emissions to air by associated process(es)



Source: [35, TWG 2023]

Figure 3-80: Distribution of maximum concentrations for other metals and metalloids emissions to air

3.2.7 Figures for emissions to air

This section reports on the ranges of reported emissions to air in concentration values (in mg/Nm³; except dioxins and furans, which are shown in ng WHO TEQ/m³).
Each graph for emission data shows the minimum, average and maximum emission concentrations over the 3-year reference period and the emission limit value (ELV). In the box below the graph, the following contextual information is given: emission point, the monitoring frequency and, when relevant, other key contextual information (e.g. sector, temperature range). The average concentration is shown by a blue square and the minimum and maximum concentrations by error bars. Emission limit values (ELVs) are shown with a red line.

Emission data for firing processes is corrected to an O_2 content of 17 vol-%. Therefore only data with a corresponding reported O_2 content are shown for ‘firing of ware’ and ‘drying and firing of ware’ (in the expanded clay sector). For all other emission data (e.g. for mechanical processes, drying of ware), no O_2 correction is applied.

For better visualisation, the presentation of a wide range of concentration values is avoided. Graphs and figures show only emission points with concentration values in a certain range. When the emission limit value or maximum concentration value of a certain pollutant/parameter is above the given range, these emission points are not shown or not shown in the graphs and figures.

For each pollutant/parameter, figures present other key information reported as follows: primary and abatement techniques applied at the emission point level and other relevant key information (e.g. fuel composition, substance content in the raw material).

The meanings of the acronyms used in figures are as follows:

Table 3-25: Description of acronyms for monitoring frequency

Monitoring frequency	Abbreviation
Continuous	C
Weekly	W
Monthly	M
Yearly	Y
Twice per year	2Y
4 times per year	4Y
Once every 2 years	1/2y
Once every 3 years	1/3y
Other	Oth.
No information	-

Source: [35, TWG 2023]

Table 3-26: Description of acronyms for sector

Sectors	Abbreviation
Wall and floor tiles	WF.
Expanded clay	Exp
Bricks and floor tiles	Br
Refractory products	Ref
Sanitaryware	San
Tableware and household ceramics	Tab
Technical ceramics	Tech
Vitrified clay pipes	Vit
No information	-

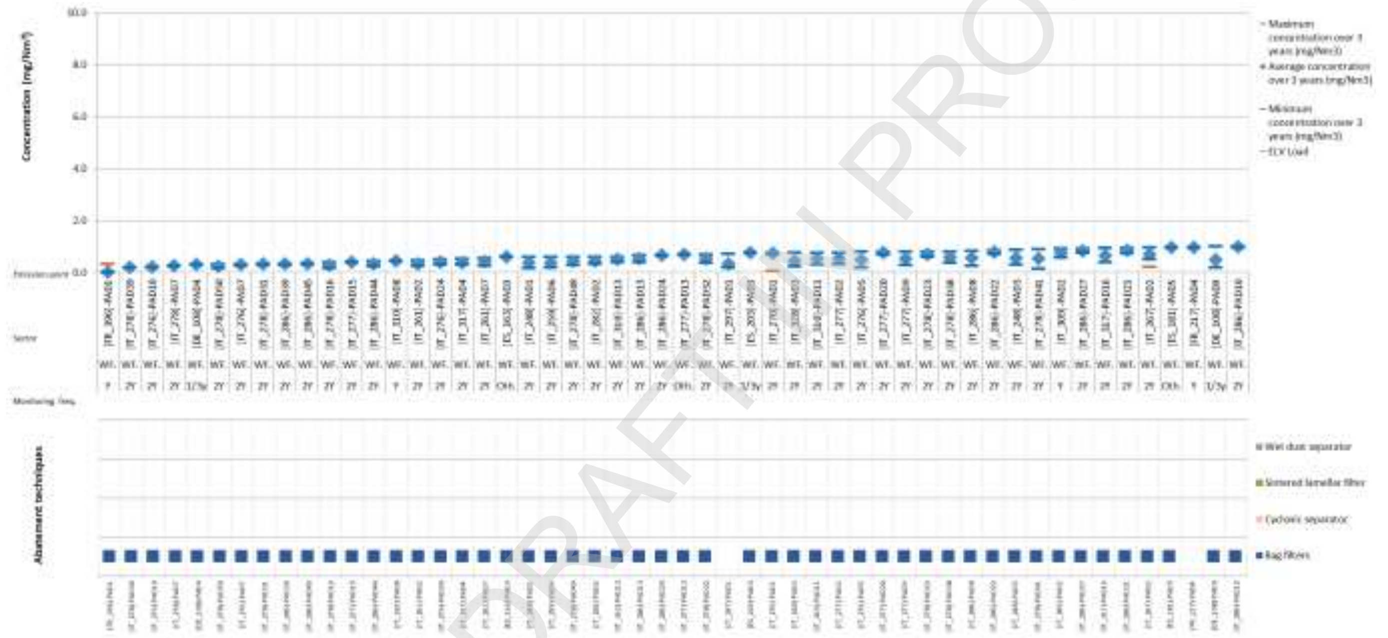
Source: [35, TWG 2023]

For each pollutant/parameter, figures present reported data at emission point level when there are a sufficient number of data points for the relevant key information field.

[Note to the TWG: figures for emissions to air by pollutants/parameters could be extended and updated when relevant information and data on emission levels is provided.]

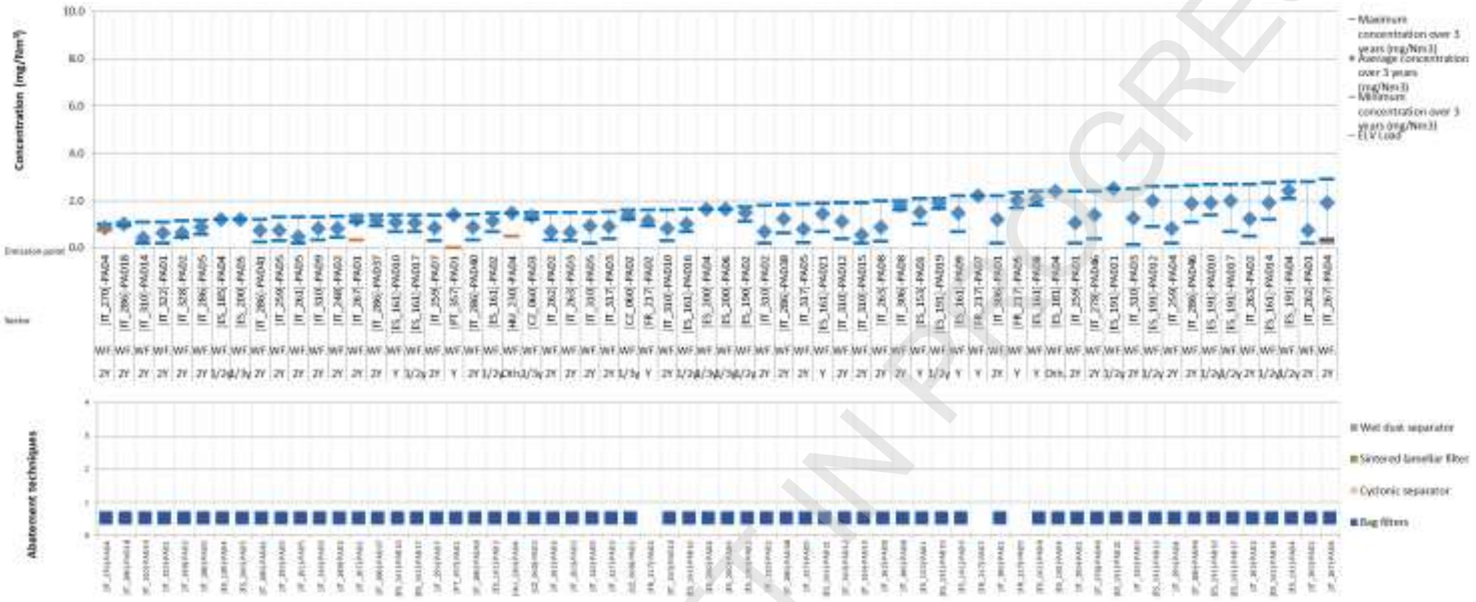
3.2.7.1 Dust emissions to air from mechanical processes

Figure 3-81, Figure 3-82, Figure 3-83, Figure 3-84 and Figure 3-85 show the reported levels for dust emissions from mechanical processes in which the size, shape or surface of the materials is transformed. This includes crushing, milling, grinding, mixing, shaping and product finishing.



NB: For better visualisation, and given the high number of reported data, emission points with maximum concentration values less than or equal to 1 mg/Nm^3 are shown and only reported relevant abatement techniques are shown.
Source: [35, TWG 2023]

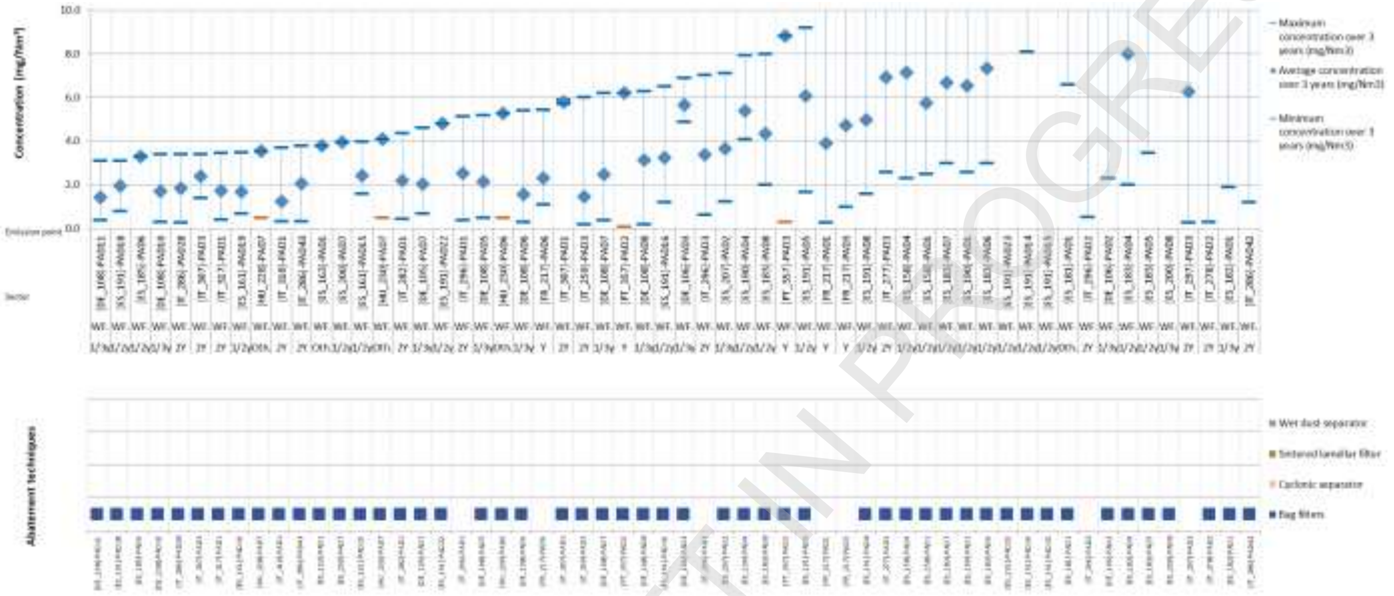
Figure 3-81: Dust emissions to air from mechanical processes in the wall and floor tiles sector (1/5)



NB: For better visualisation, and given the high number of reported data, only emission points with maximum concentration values in the range of 1-3 mg/Nm^3 are shown and only reported relevant abatement techniques are shown.

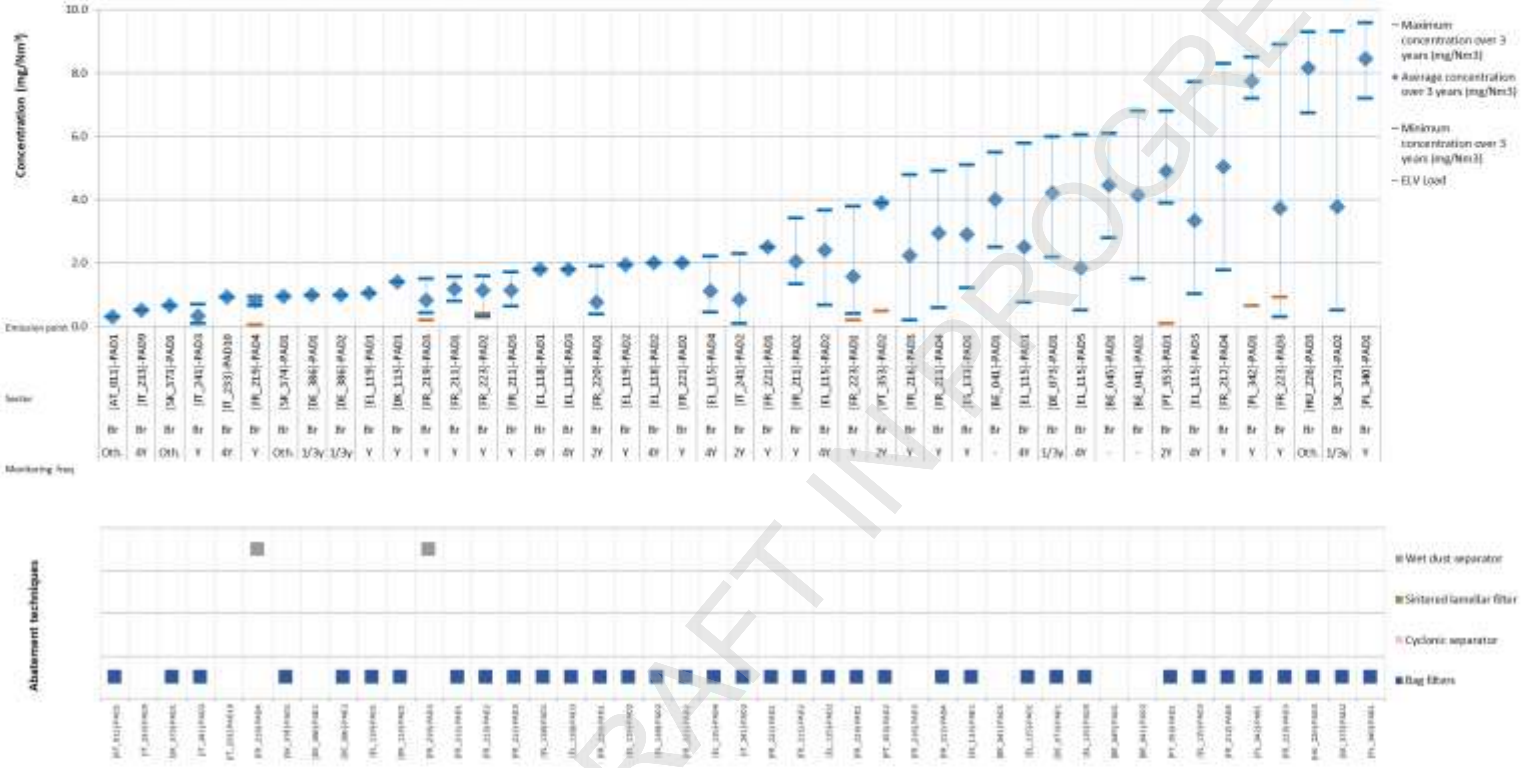
Source: [35, TWG 2023]

Figure 3-82: Dust emissions to air from mechanical processes in the wall and floor tiles sector (2/5)



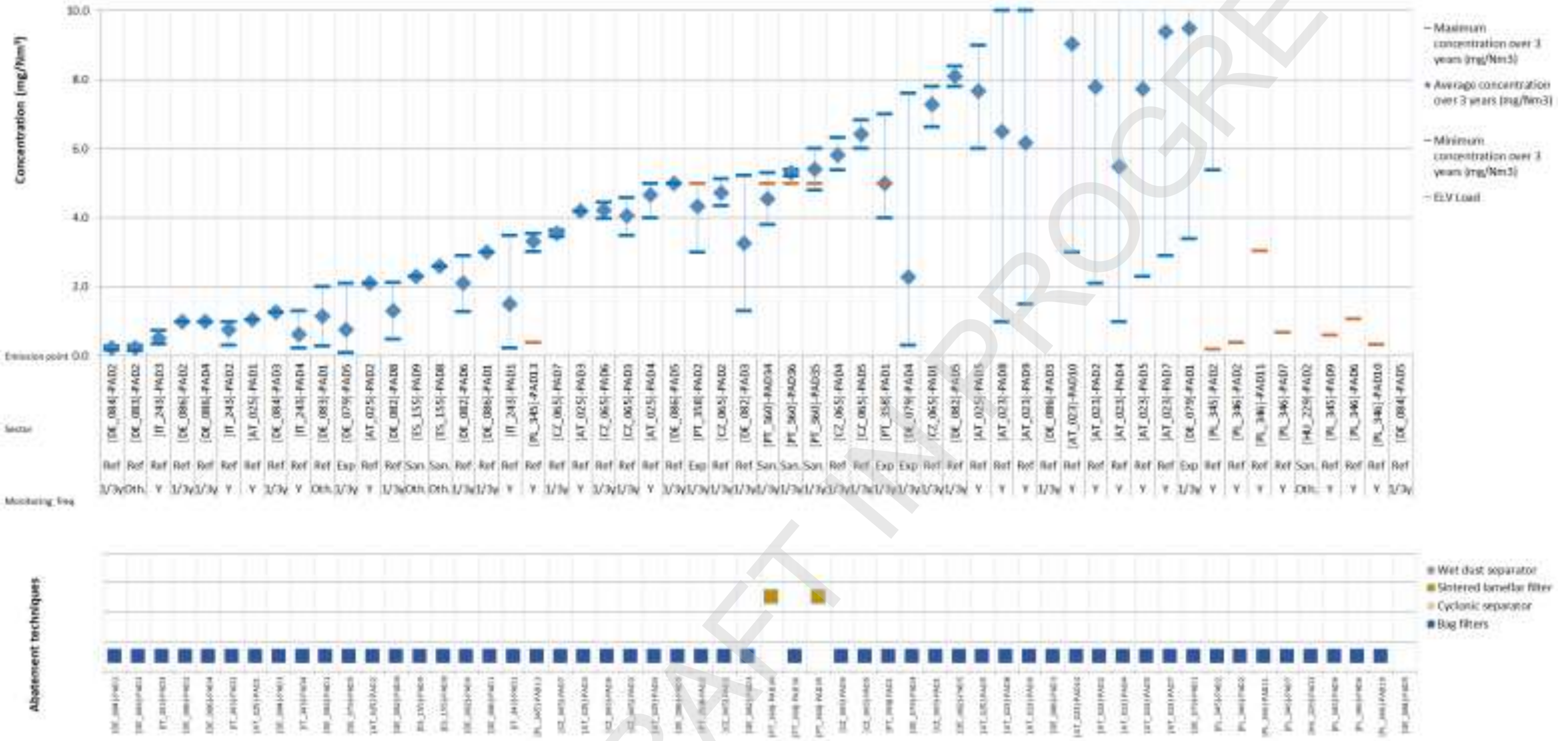
NB: For better visualisation, and given the high number of reported data, only emission points with maximum concentration values in the range of 3-10 mg/Nm^3 are shown and reported relevant abatement techniques are shown.
Source: [35, TWG 2023]

Figure 3-83: Dust emissions to air from mechanical processes in the wall and floor tiles sector (3/5)



NB: For better visualisation, and given the high number of reported data, emission points with maximum concentration values above 10 mg/Nm^3 are not shown and only reported relevant abatement techniques are shown.
Source: [35, TWG 2023]

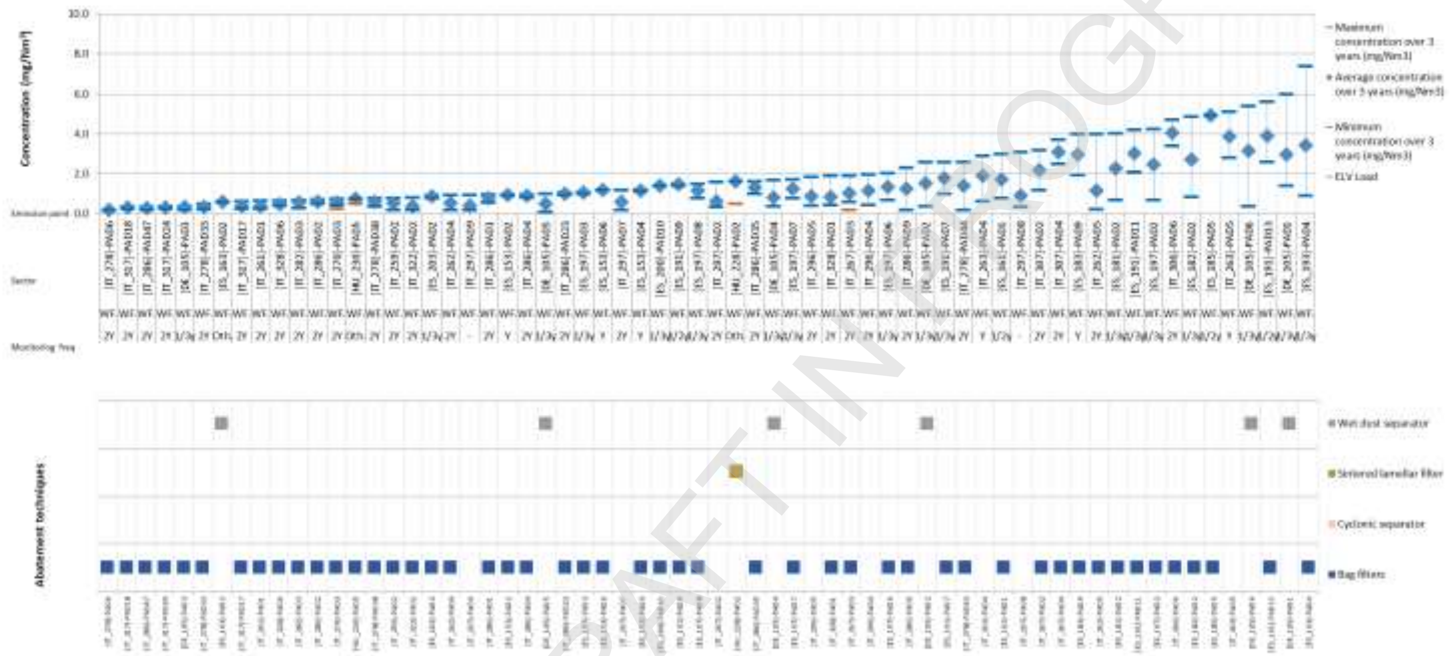
Figure 3-84: Dust emissions to air from mechanical processes in the brick and roof tiles sector (4/5)



NB: For better visualisation, and given the high number of reported data, maximum concentration values above 10 mg/Nm^3 are not shown and only reported relevant abatement techniques are shown.
Source: [35, TWG 2023]

Figure 3-85: Dust emissions to air from mechanical processes in other sectors (5/5)

3.2.7.2 Dust emissions to air from surface treatment and decoration processes



NB: For better visualisation, and given the high number of reported data, emission points with maximum concentration values above 10 mg/Nm^3 are not shown and only reported relevant abatement techniques are shown.
Source: [35, TWG 2023]

Figure 3-86: Dust emissions to air from surface treatment and decoration processes in the wall and floor tiles sector (1/2)

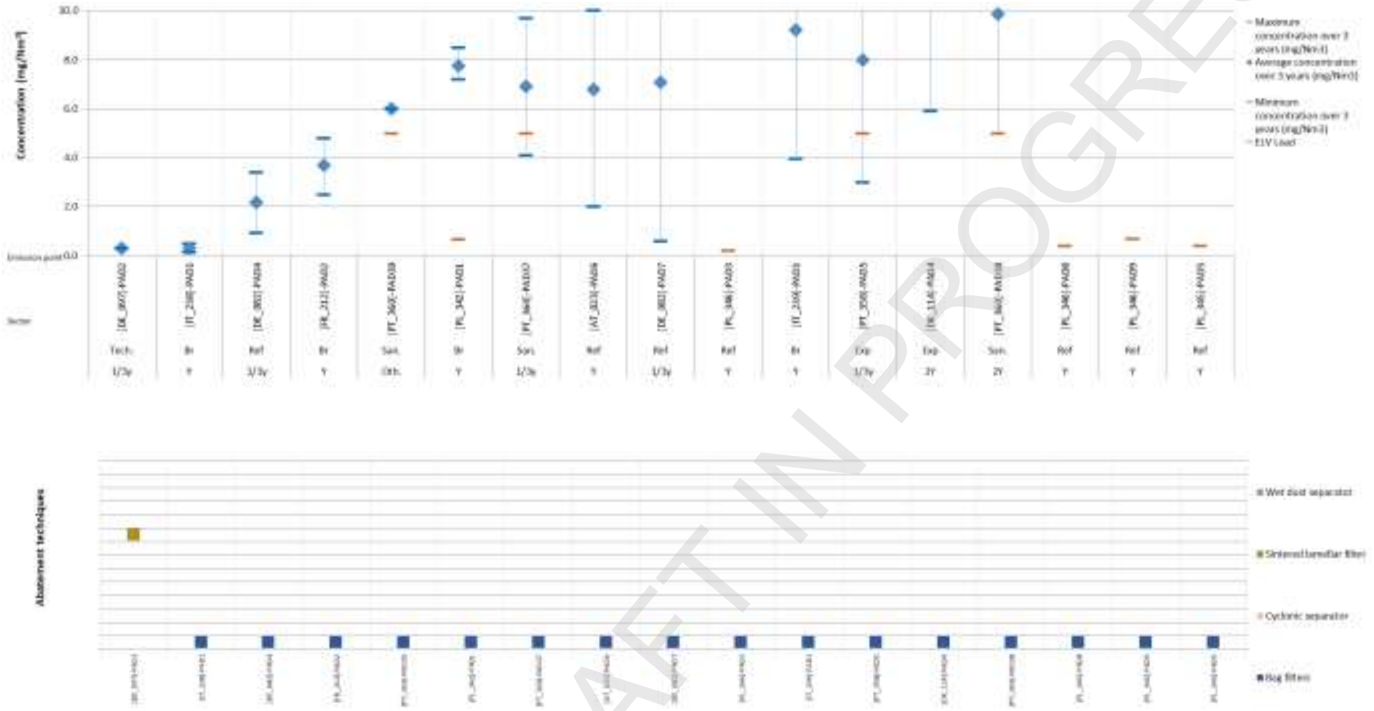
NB: For better visualisation, and given the high number of reported data, emission points with maximum concentration values above 10 mg/Nm^3 are not shown and only reported relevant abatement techniques are shown.
Source: [35, TWG 2023]

Figure 3-87: Dust emissions to air from surface treatment and decoration processes in other sectors (2/2)

3.2.7.3 Dust emissions to air from transfer/handling of materials

NB: For better visualisation, and given the high number of reported data, emission points with maximum concentration values above 10 mg/Nm^3 are not shown and only reported relevant abatement techniques are shown.
Source: [35, TWG 2023]

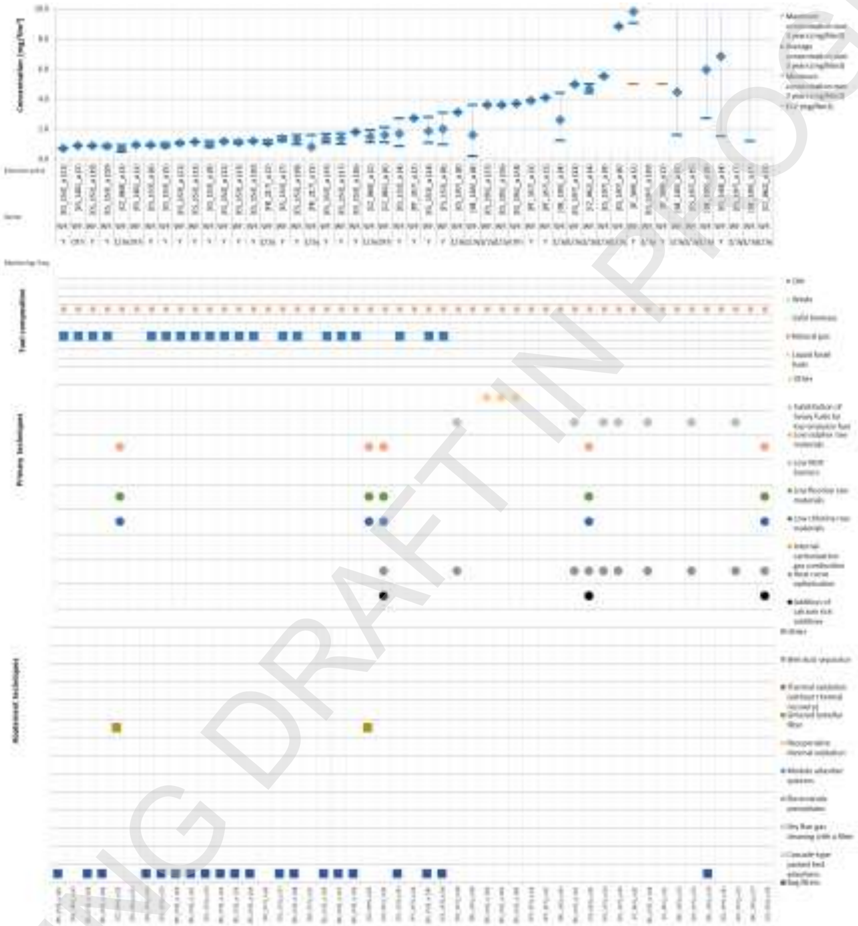
Figure 3-88: Dust emissions to air from transfer/handling of materials/products in the wall and floor tiles sectors (1/2)



NB: For better visualisation, and given the high number of reported data for dust emissions, emission points with maximum concentration values above 10 mg/Nm^3 are not shown and only reported relevant abatement techniques are shown.
Source: [35, TWG 2023]

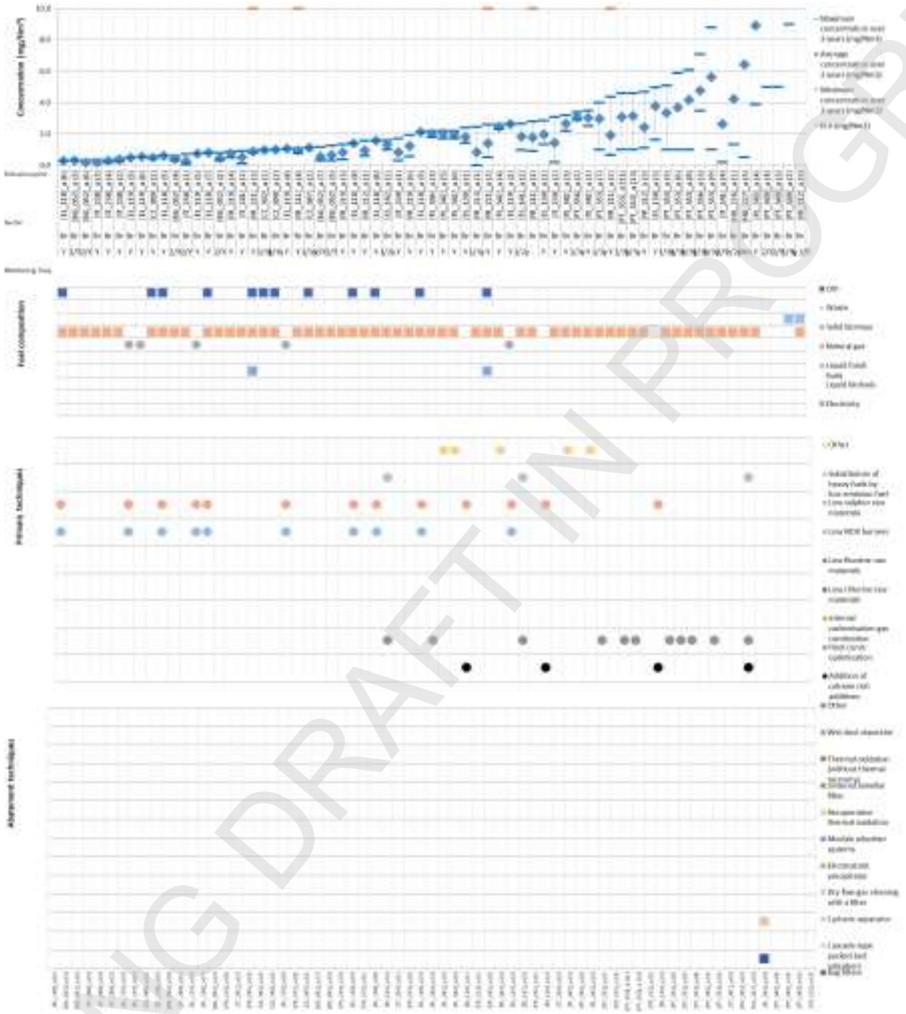
Figure 3-89: Dust emissions to air from transfer/handling of materials/products in other sectors (2/2)

3.2.7.4 Dust emissions to air from drying process



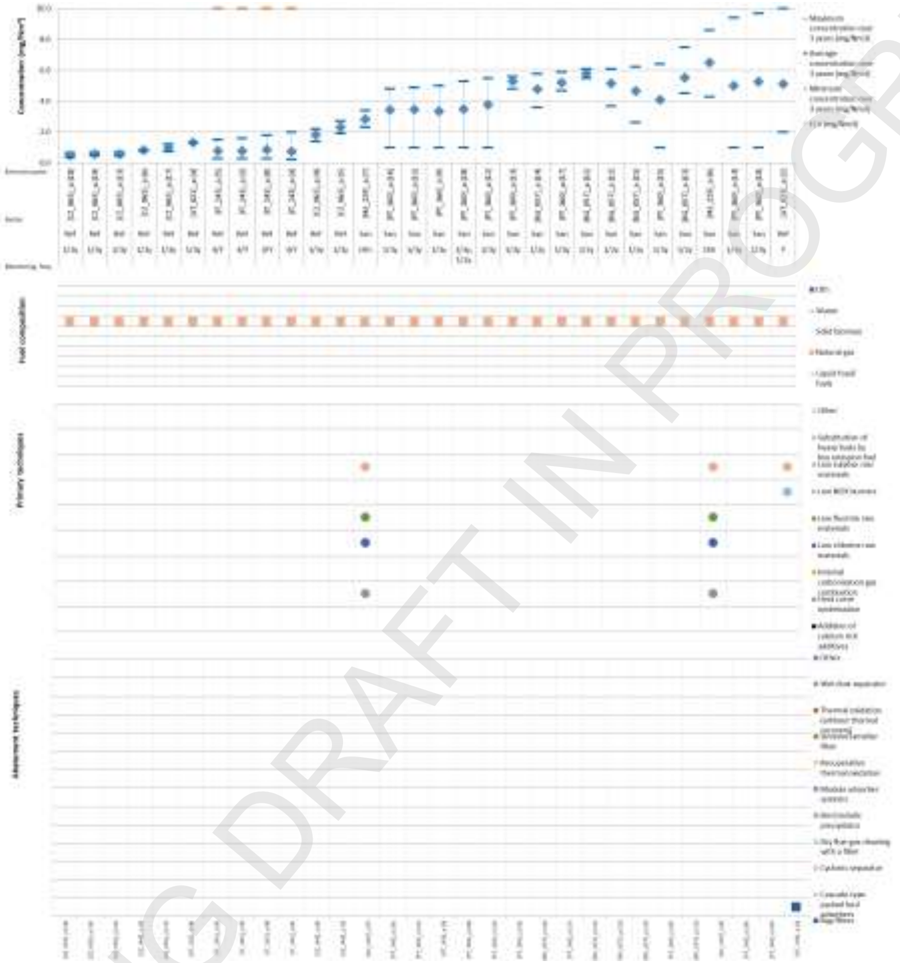
NB: For better visualisation, emission points with maximum concentration values above 10 mg/Nm^3 are not shown and only relevant reported abatement techniques are shown.
Source: [35, TWG 2023]

Figure 3-90: Dust emissions to air from drying process in the wall and floor tiles sector (1/3)



NB: For better visualisation, maximum concentration values above 10 mg/Nm^3 are not shown and only relevant reported abatement techniques are shown.
Source: [35, TWG 2023]

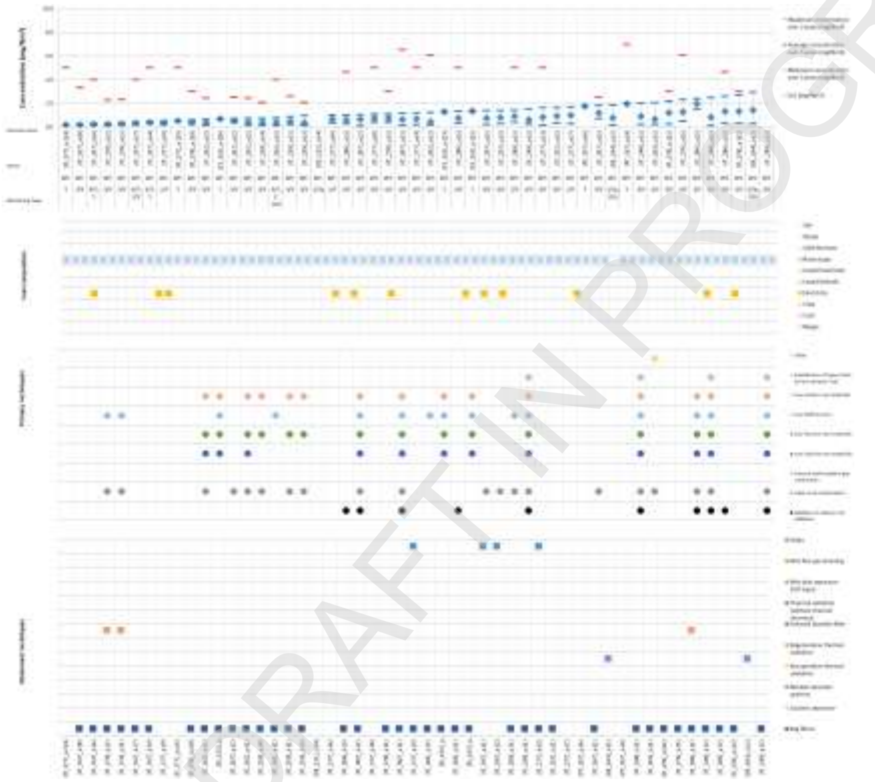
Figure 3-91: Dust emissions to air from drying process in the brick and roof tiles sector (2/3)



NB: For better visualisation, emission points with maximum concentration values above 10 mg/Nm^3 are not shown and only relevant reported abatement techniques are shown.
Source: [35, TWG 2023]

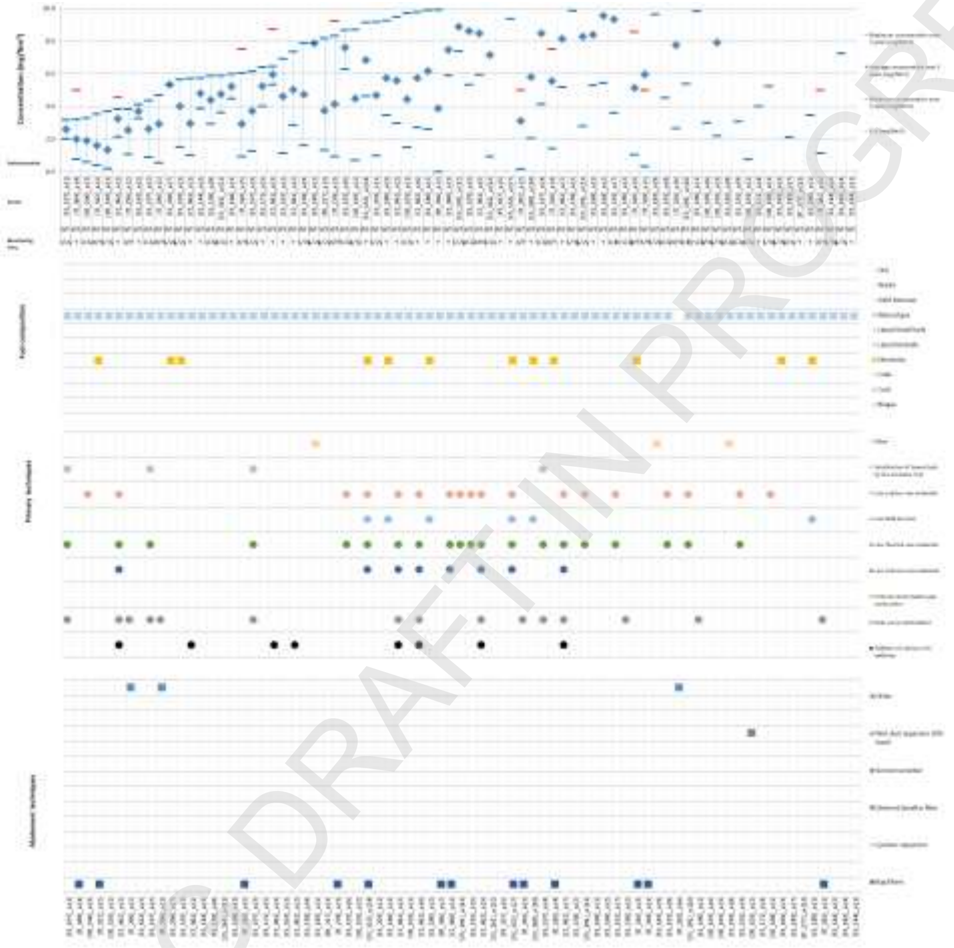
Figure 3-92: Dust emissions to air from drying process in other sectors (3/3)

3.2.7.5 Dust emissions to air from firing process



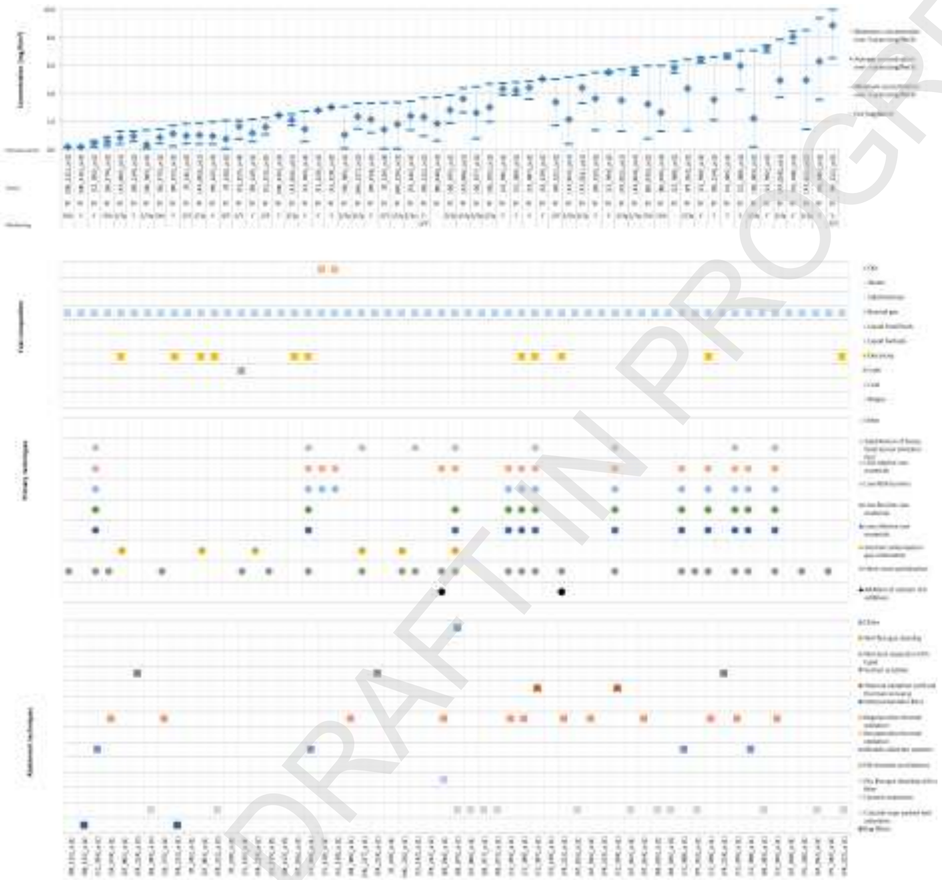
NB: For better visualisation, and given the high number of reported data, emission points with maximum concentration values above 3 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

Figure 3-93: Dust emissions to air from firing process in the wall and floor tiles sector (1/4)



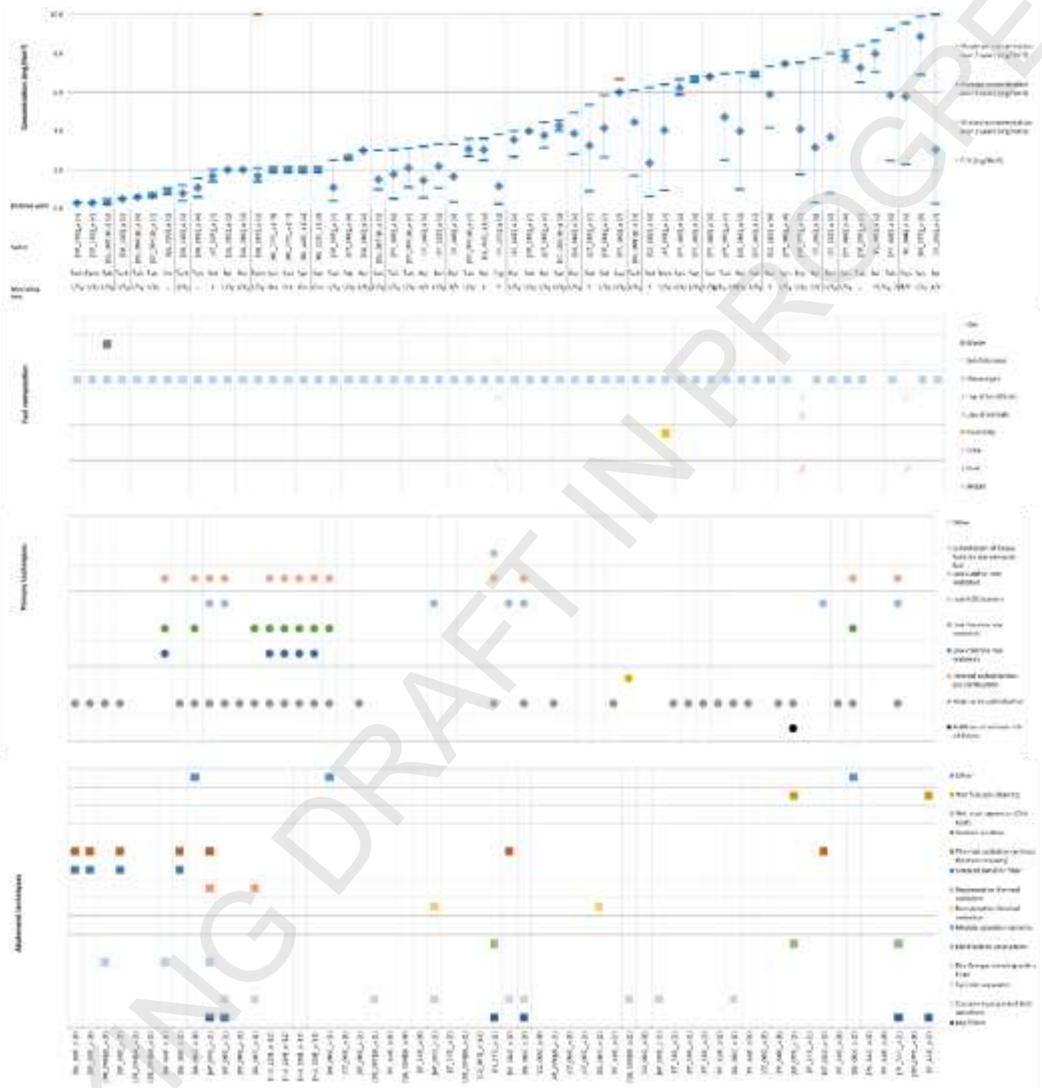
NB: For better visualisation, and given the high number of reported data for dust emissions, emission points with maximum concentration values above 3 mg/Nm^3 are shown.
Source: [35, TWG 2023]

Figure 3-94: Dust emissions to air from firing process in the wall and floor tiles sector (2/4)



NB: For better visualisation, and given the high number of reported data, emission points with maximum concentration values above 10 mg/Nm^3 are shown.
Source: [35, TWG 2023]

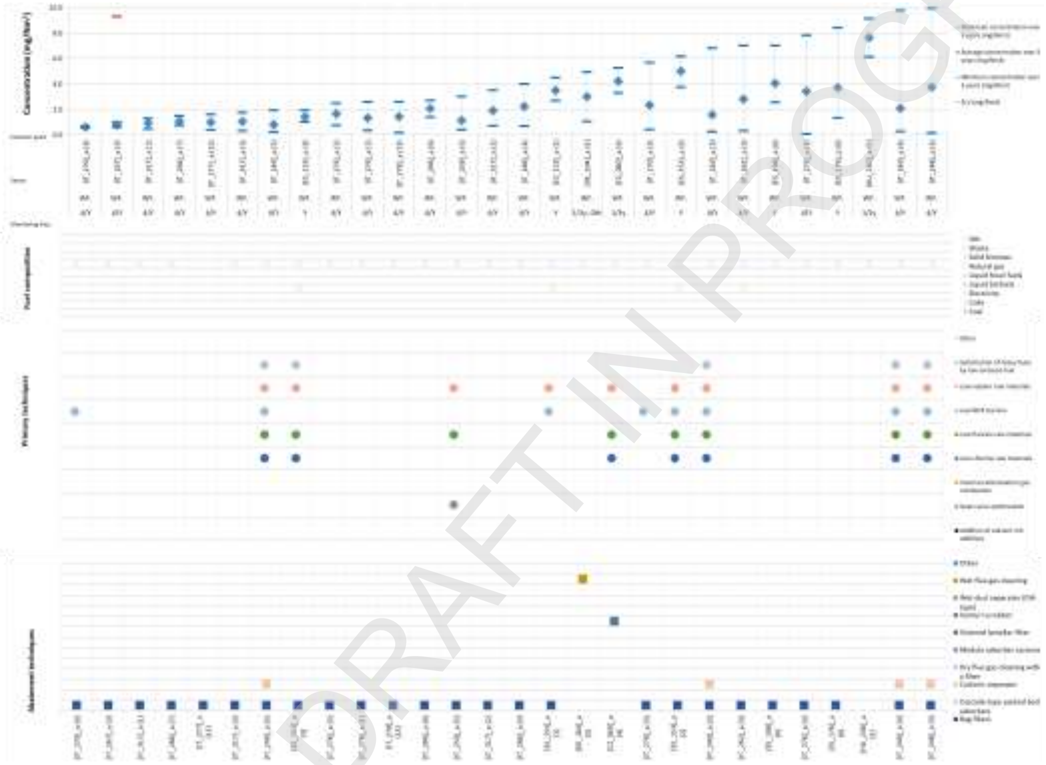
Figure 3-95: Dust emissions to air from firing process in the brick and roof tiles sector (3/4)



NB: For better visualisation, and given the high number of reported data, only emission points with maximum concentration values equal and below 10 mg/Nm^3 are shown.
Source: [35, TWG 2023]

Figure 3-96: Dust emissions to air from firing and drying-firing process in other sectors (4/4)

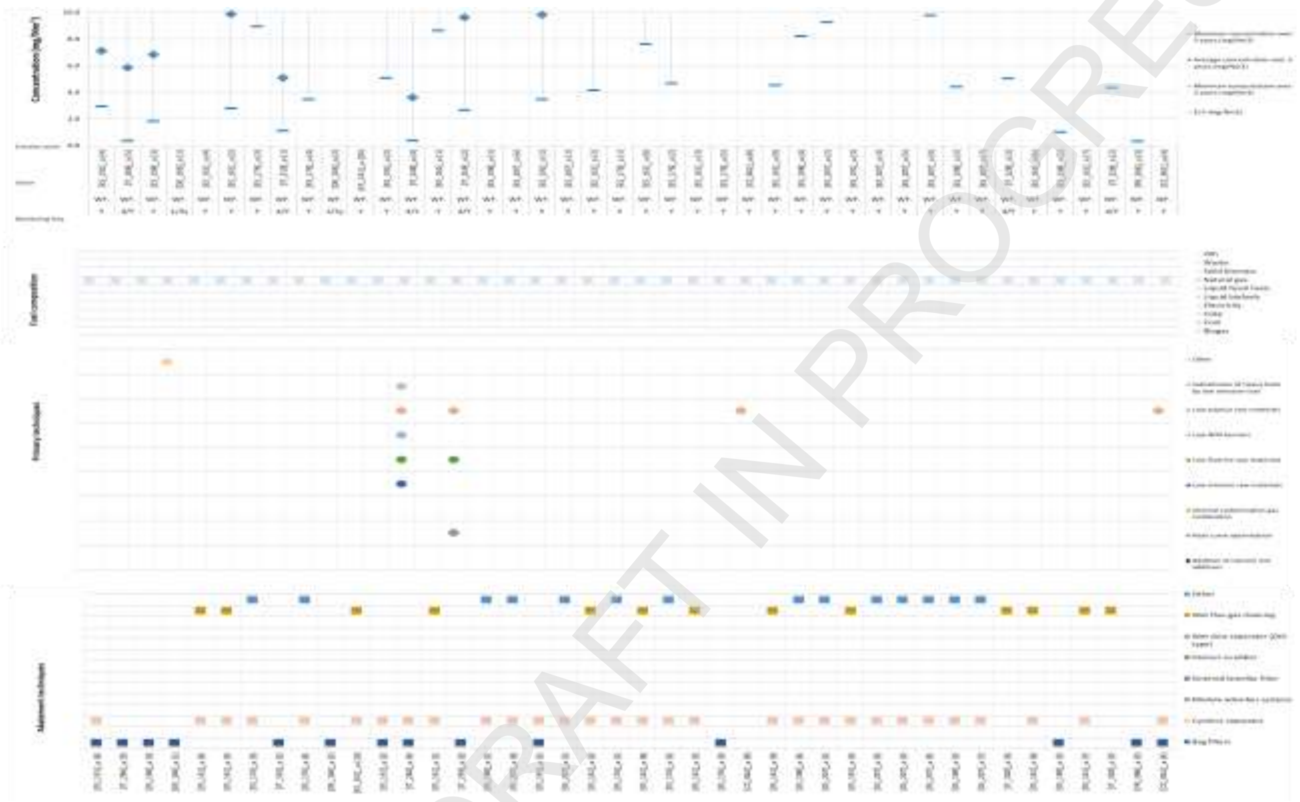
3.2.7.6 Dust emissions to air from spray-drying process



Source: [35, TWG 2023]

Figure 3-97: Dust emissions to air from spray-drying process in the wall and floor tiles sector (1/2)

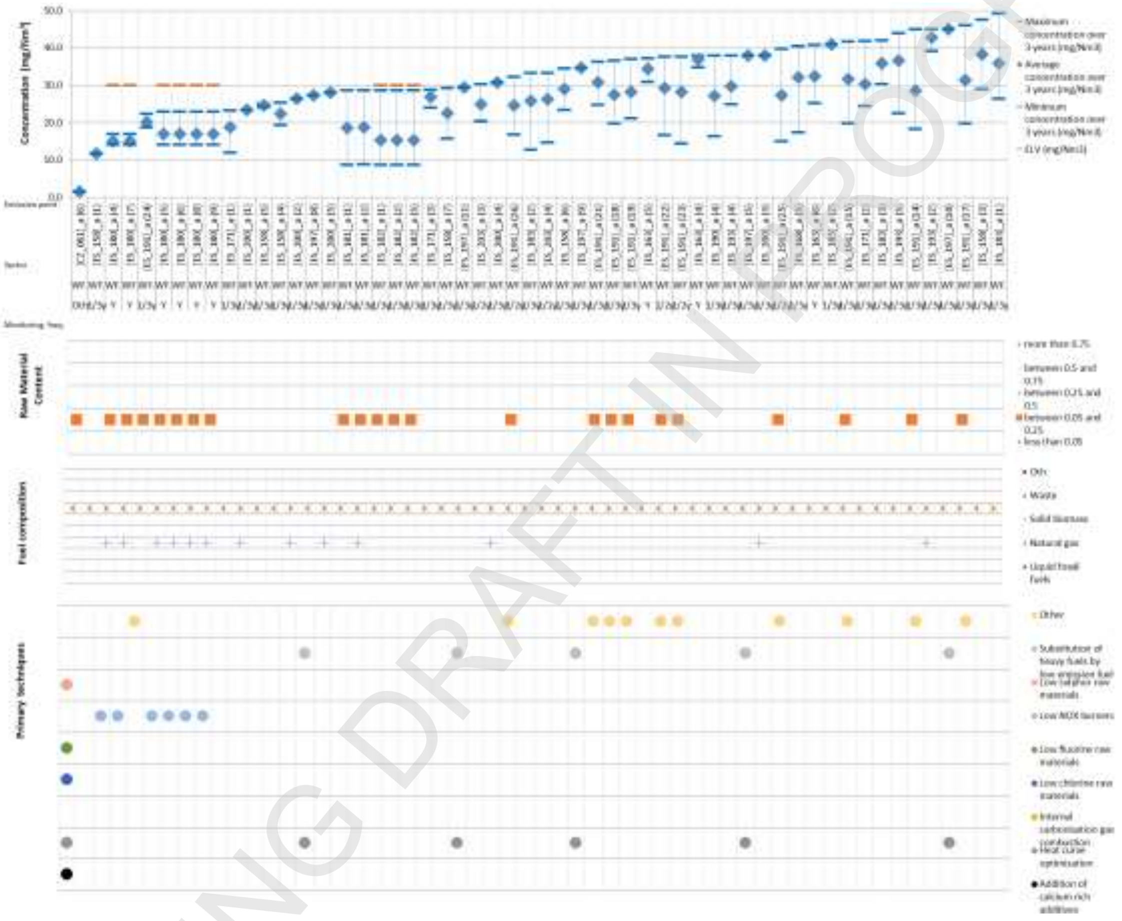
NB: For better visualisation, emission points with maximum concentration values above 10 mg/Nm^3 are not shown.



NB: For better visualisation, emission points with maximum concentration values above 10 mg/Nm^3 are not shown and only relevant reported abatement techniques are shown.
Source: [35, TWG 2023]

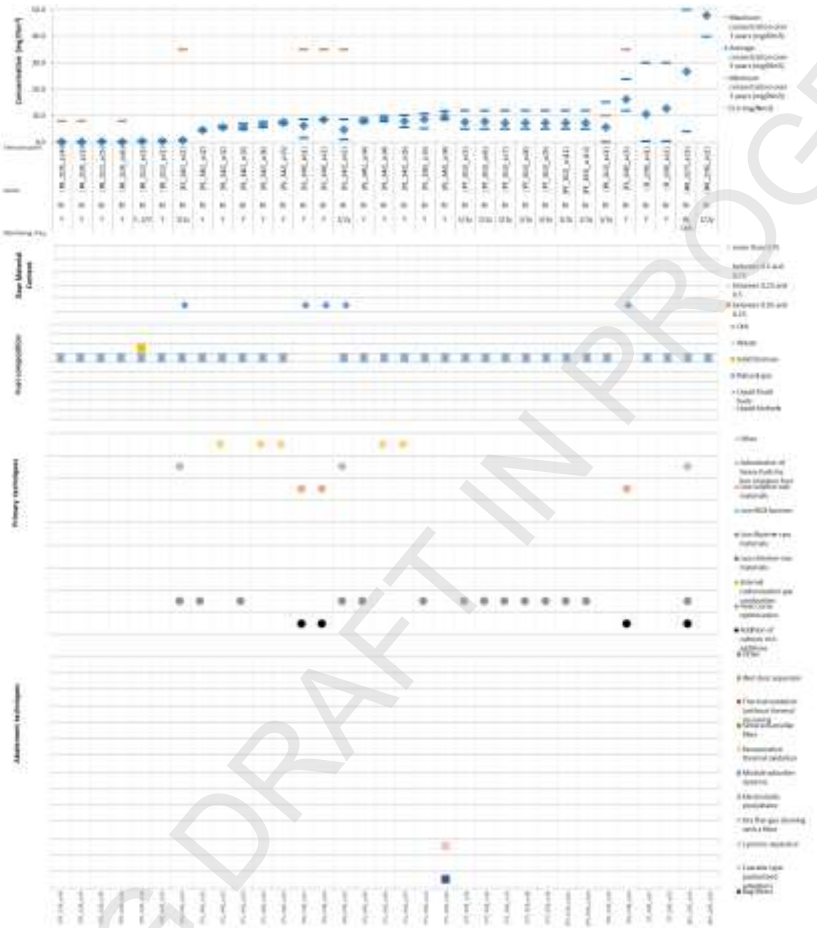
Figure 3-98: Dust emissions to air from spray-drying process in the wall and floor tiles sector (2/2)

3.2.7.7 SO_X and SO_2 emissions to air from drying process



NB: For SOX and SO_2 emissions to air, most of the emission points did not report information on applied abatement techniques. Therefore, the graph is not shown in this figure. For better visualisation, and given the high number of reported data, emission points with maximum concentration values above 50 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

Figure 3-99: SO_X and SO_2 emissions to air from drying process in the wall and floor tiles sector (1/3)



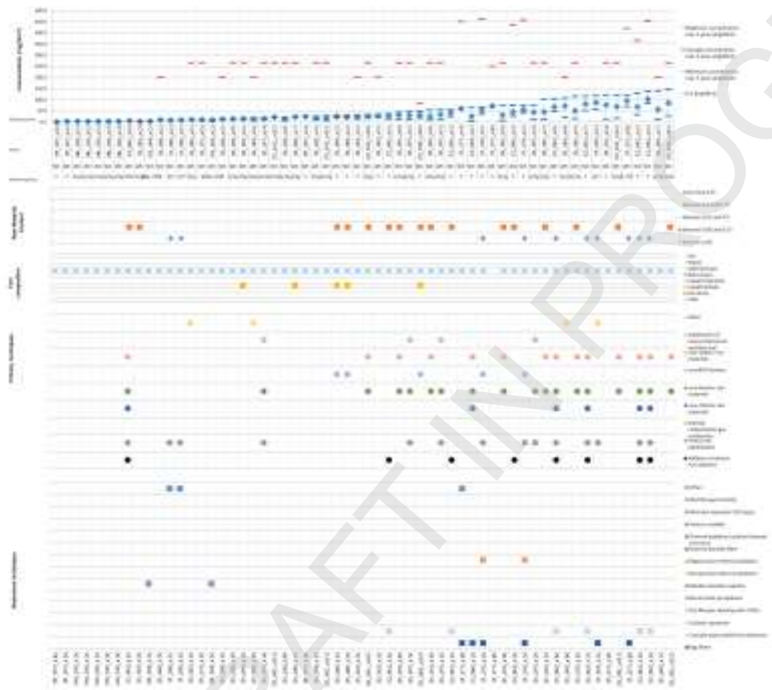
NB: For better visualisation, maximum concentration values above 50 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

Figure 3-100: SO_X and SO_2 emissions to air from drying process in the brick and roof tiles sector (2/3)

NB: For SOx and SO_2 emissions to air from drying process, most of the emission points did not report information on applied primary and abatement techniques. Therefore, graphs are not shown in this figure.
Source: [35, TWG 2023]

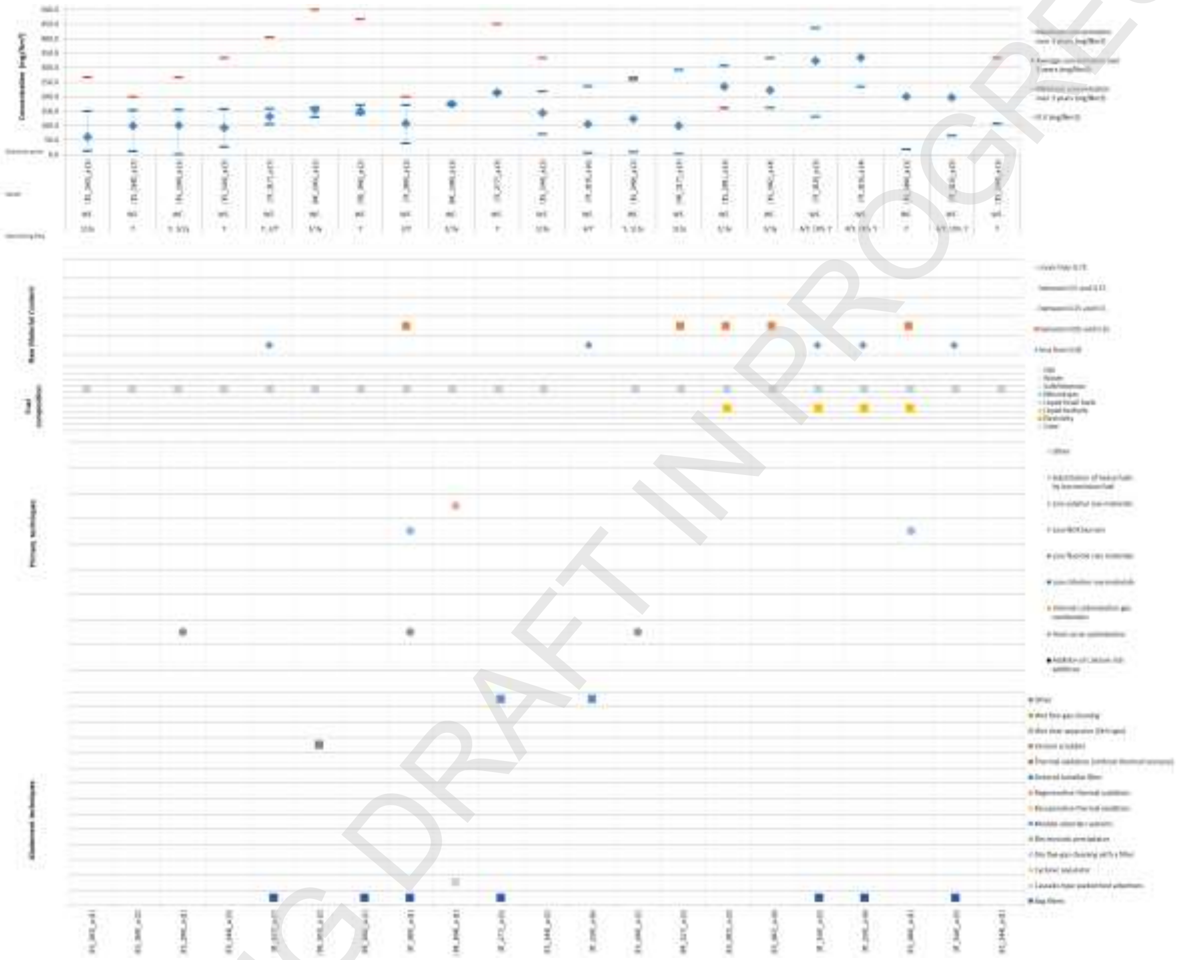
Figure 3-101: SOx and SO_2 emissions to air from drying process in other sectors (3/3)

3.2.7.8 SO_X and SO_2 emissions to air from firing process



NB: For better visualisation, and given the high number of reported data, emission points with maximum concentration values less than or equal to 150 mg/Nm^3 are shown and abatement techniques are shown.
Source: [35, TWG 2023]

Figure 3-102: SO_X and SO_2 emissions to air from firing process in the wall and floor tiles sector (1/5)



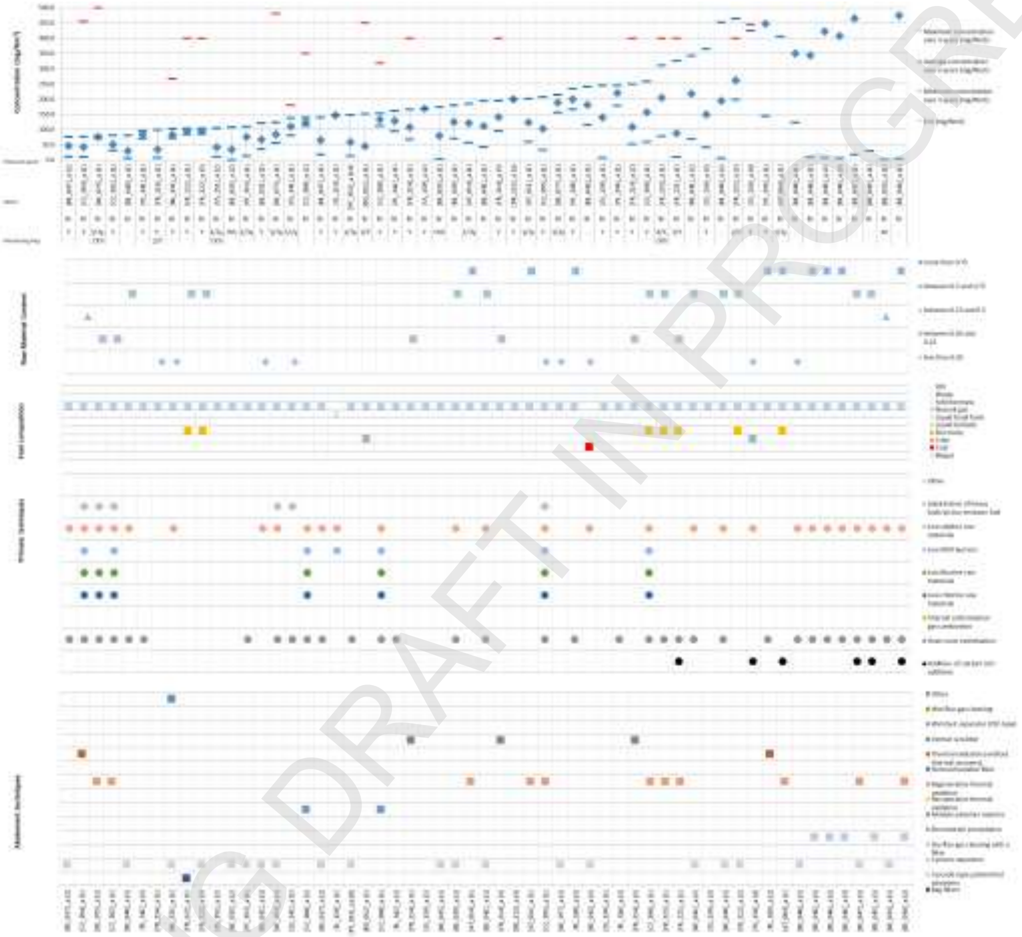
NB: For better visualisation, and given the high number of reported data, emission points with maximum concentration values in the range of 150-500 mg/Nm^3 are shown.

Source: [35, TWG 2023]

Figure 3-103: SO$_X$ and SO$_2$ emissions to air from firing process in the wall and floor tiles sector (2/5)

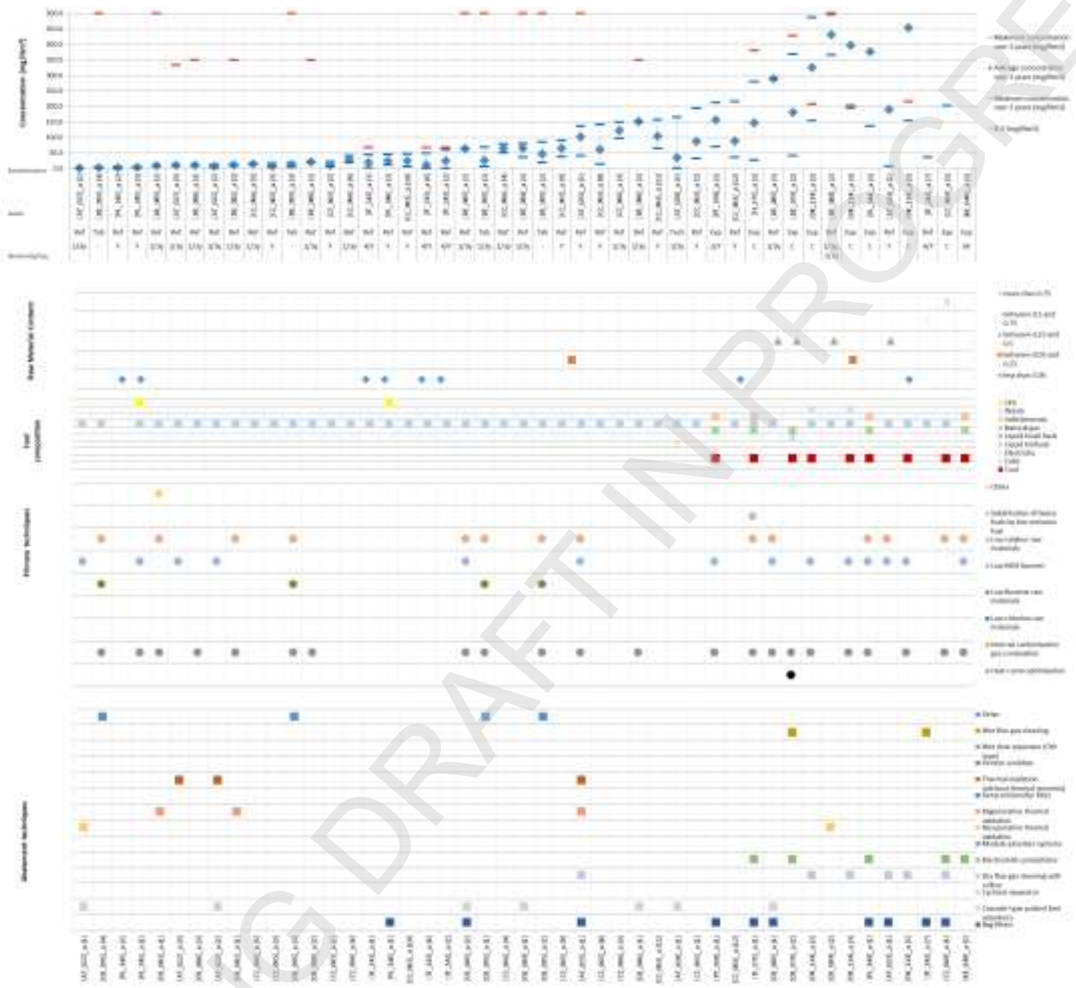
NB: For better visualisation, and given the high number of reported data, emission points with maximum concentration values less than or equal to 75 mg/Nm^3 are shown and reported abatement techniques are shown.
Source: [35, TWG 2023]

Figure 3-104: SO$_X$ and SO$_2$ emissions to air from firing processin the bricks and floor tiles sector (3/5)



NB: For better visualisation, and given the high number of reported data, emission points with maximum concentration values above 75 mg/Nm^3 are shown and reported abatement techniques are shown.
Source: [35, TWG 2023]

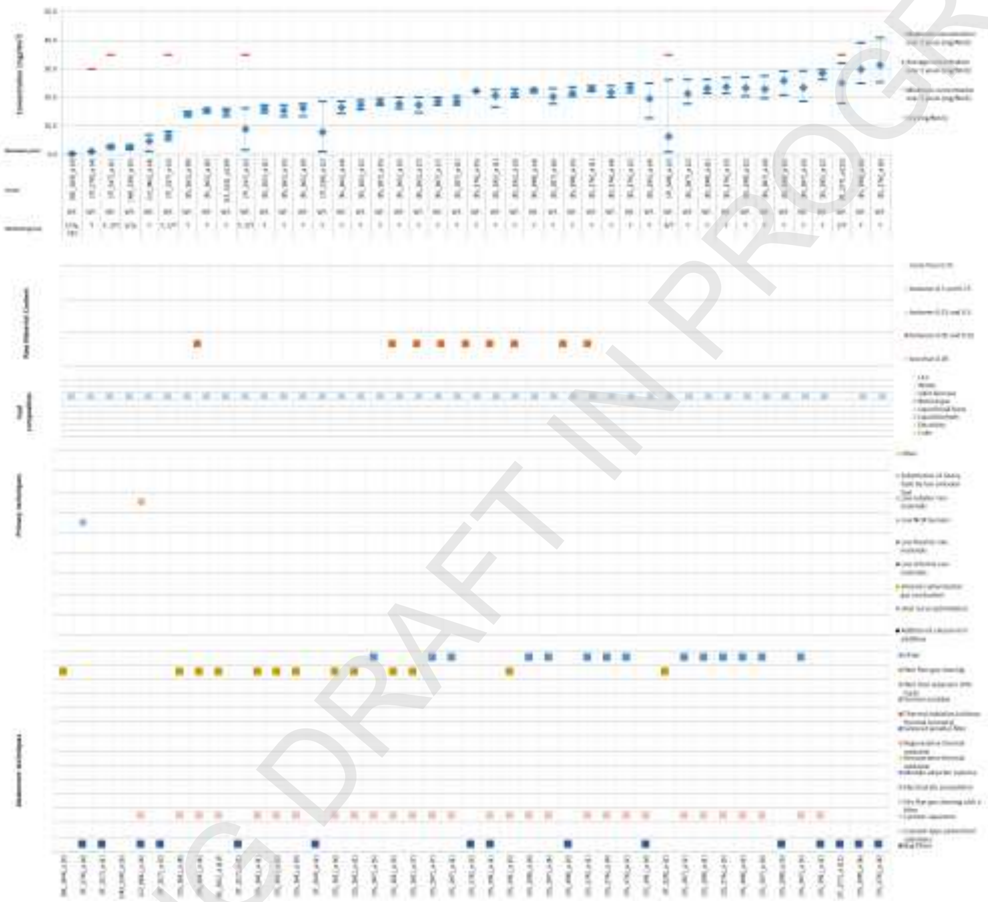
Figure 3-105: SO$_X$ and SO$_2$ emissions to air from firing processin the bricks and floor tiles sector (4/5)



Source: [35, TWG 2023]

Figure 3-106: SO$_X$ and SO$_2$ emissions to air from firing and drying-firing processes in other sectors (5/5)

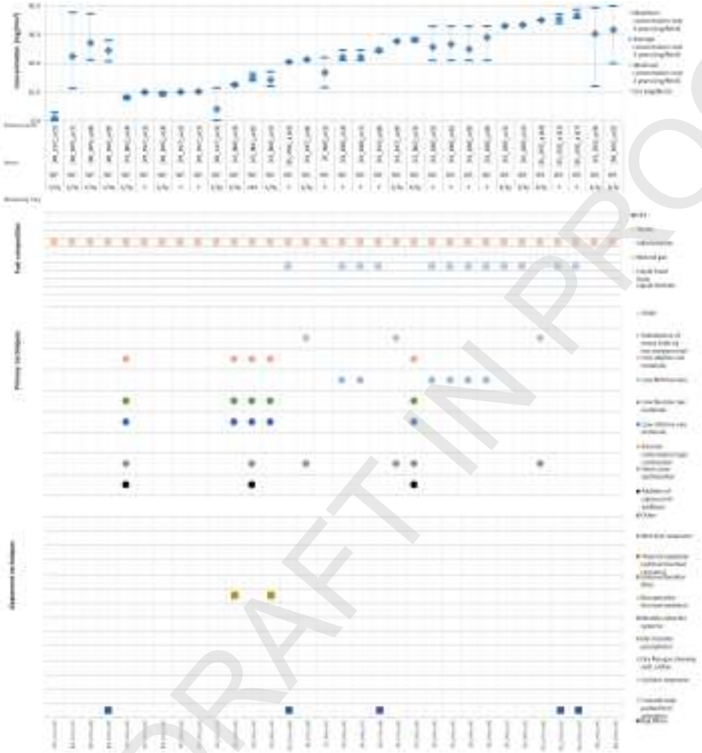
3.2.7.9 SO_X and SO_2 emissions to air from spray-drying process



Source: [35, TWG 2023]

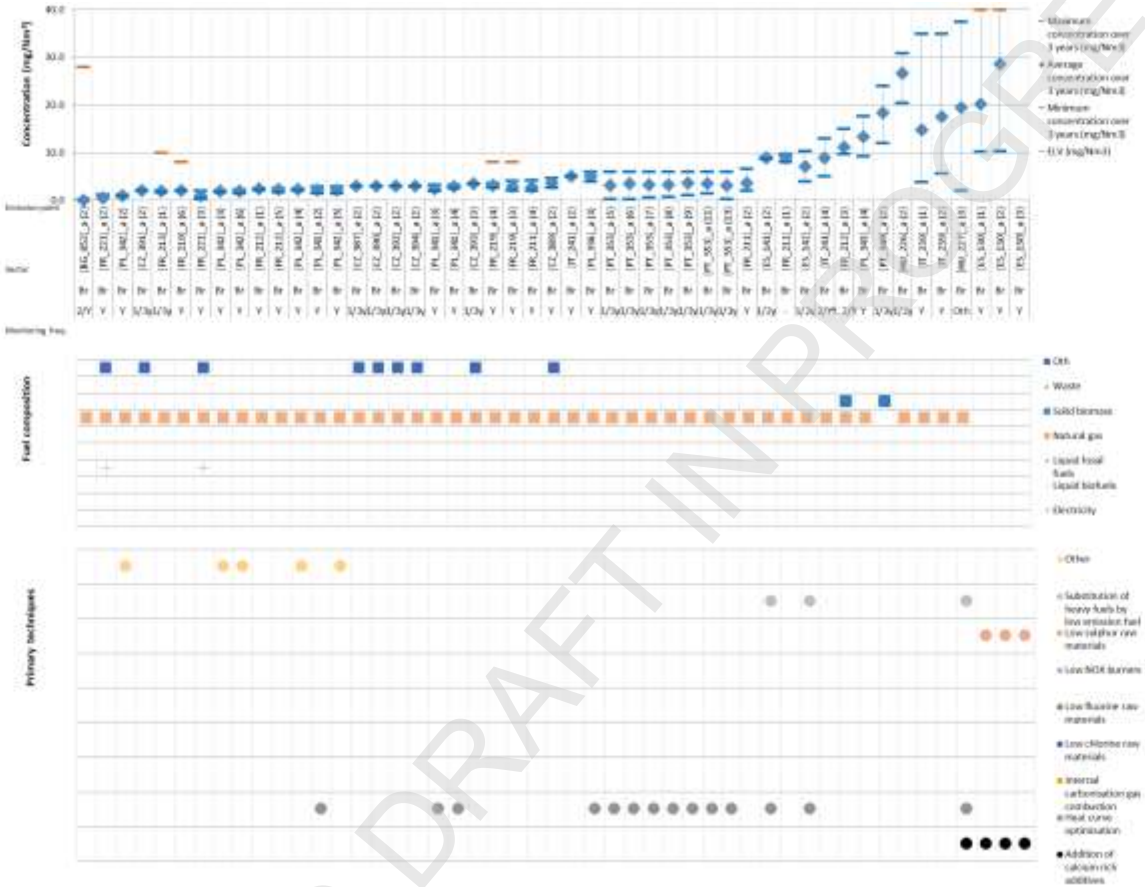
Figure 3-107: SO_X and SO_2 emissions to air from spray-drying process in the wall and floor tiles sector

3.2.7.10 NO_X emissions to air from drying process



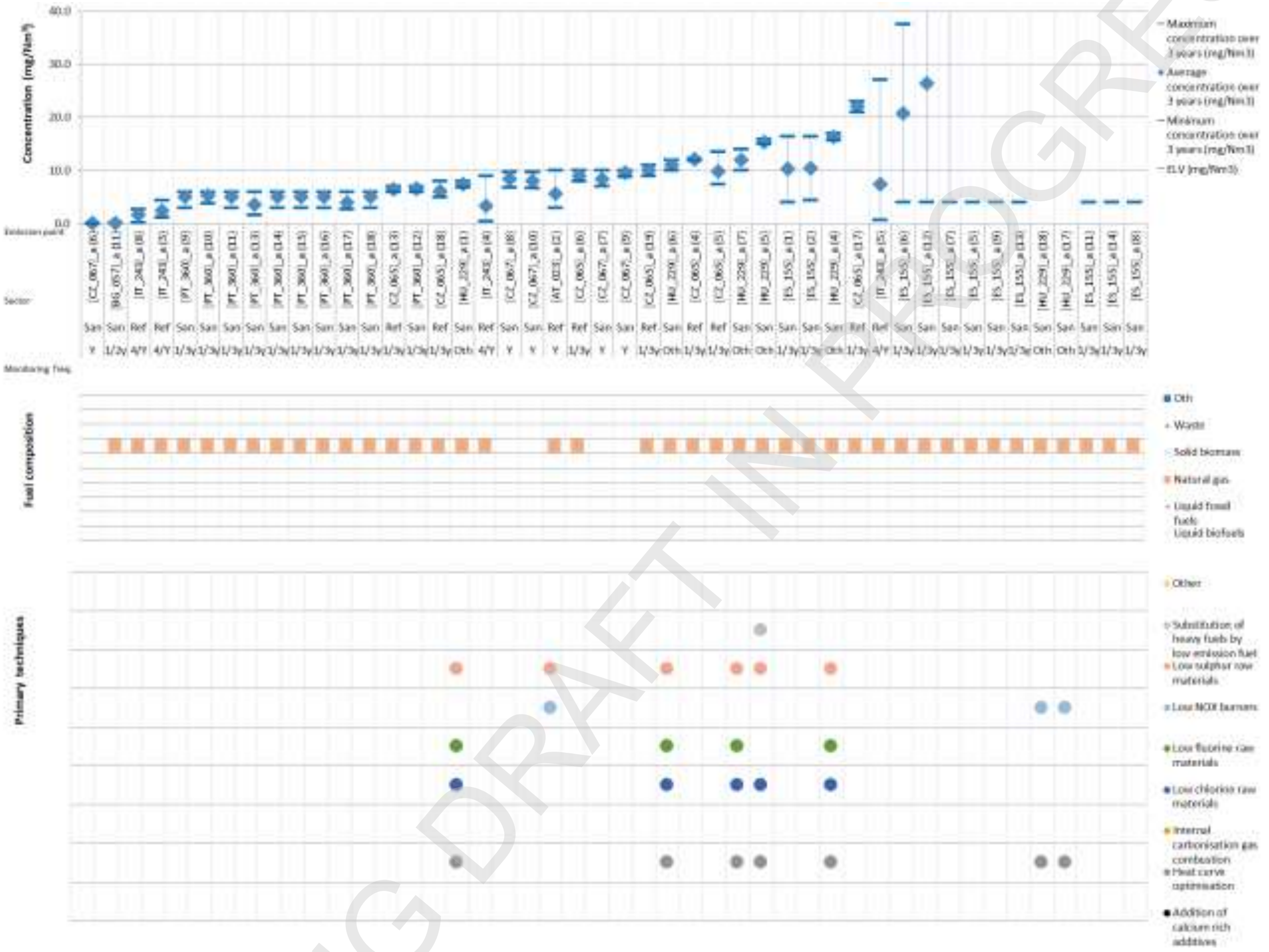
NB: For better visualisation, and given the high number of reported data, emission points with maximum concentration values above 40 mg/Nm^3 are not shown and only reported abatement techniques are shown.
Source: [35, TWG 2023]

Figure 3-108: NO_X emissions to air from drying process in the wall and floor tiles sector (1/3)



NB: NOX emissions to air from drying process in brick and roof tiles sector, most of the emission points did not report data and information on abatement techniques. Therefore, graph is not shown in this figure.
Source: [35, TWG 2023]

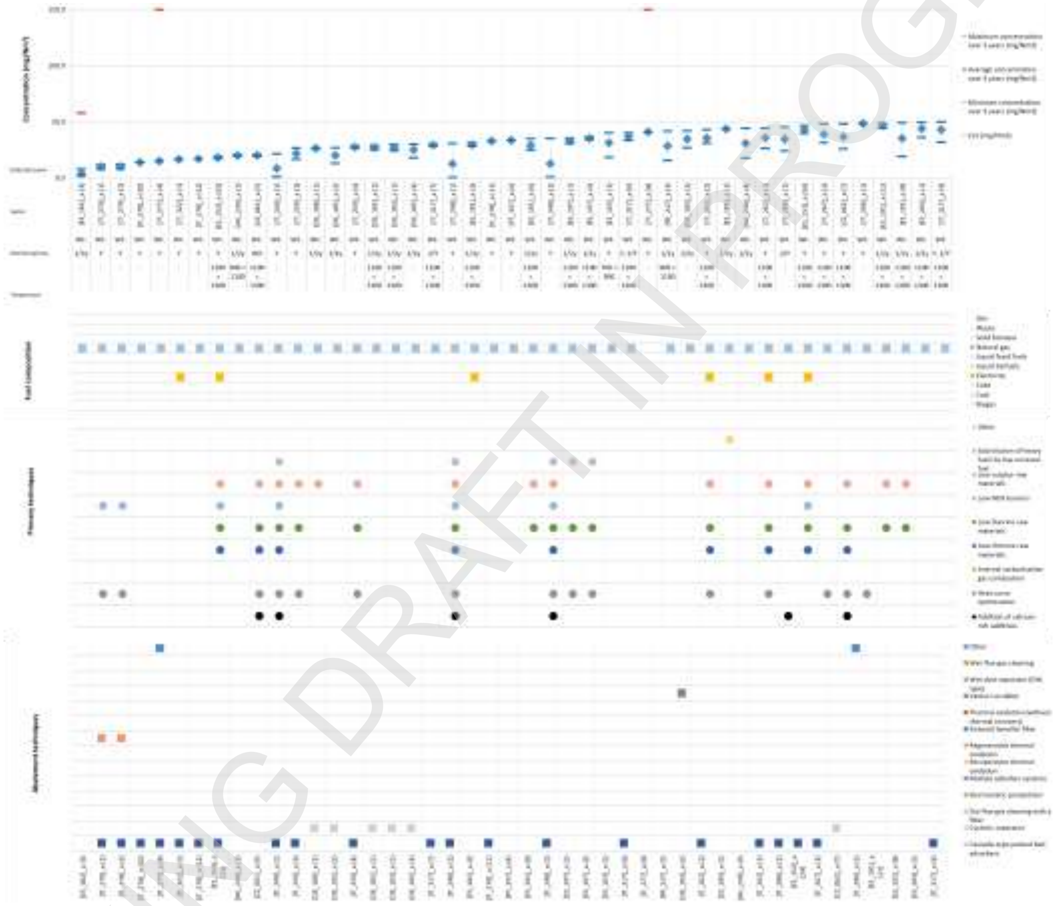
Figure 3-109: NO_X emissions to air from drying process in the brick and roof tiles sector (2/3)



NB: For NOX emissions to air from drying process in other sector, most of the emission points did not report information on applied abatement techniques. Therefore, the graph is not shown in this figure. For better visualisation, maximum concentration values above 40 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

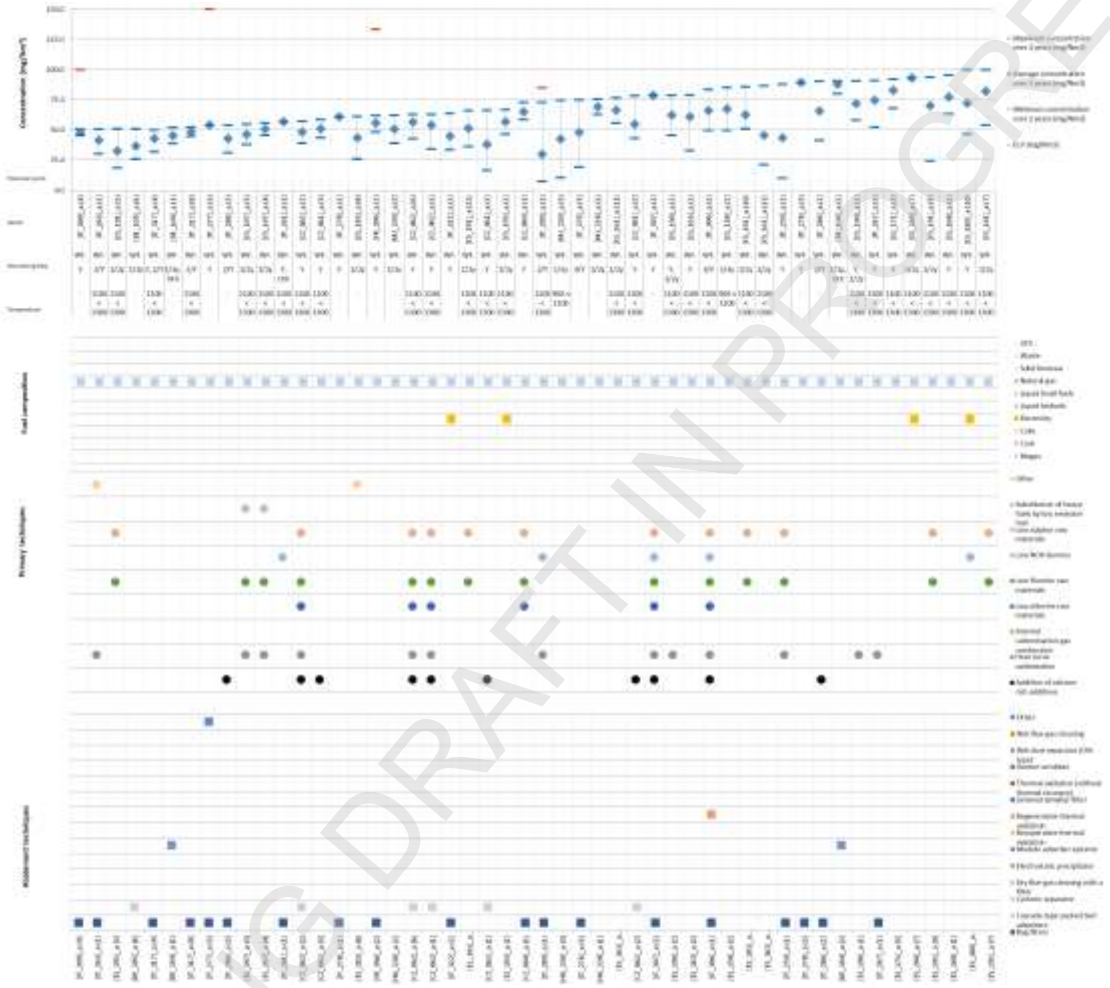
Figure 3-110: NO$_X$ emissions to air from drying process in other sectors (3/3)

3.2.7.11 NO$_X$ emissions to air from firing process



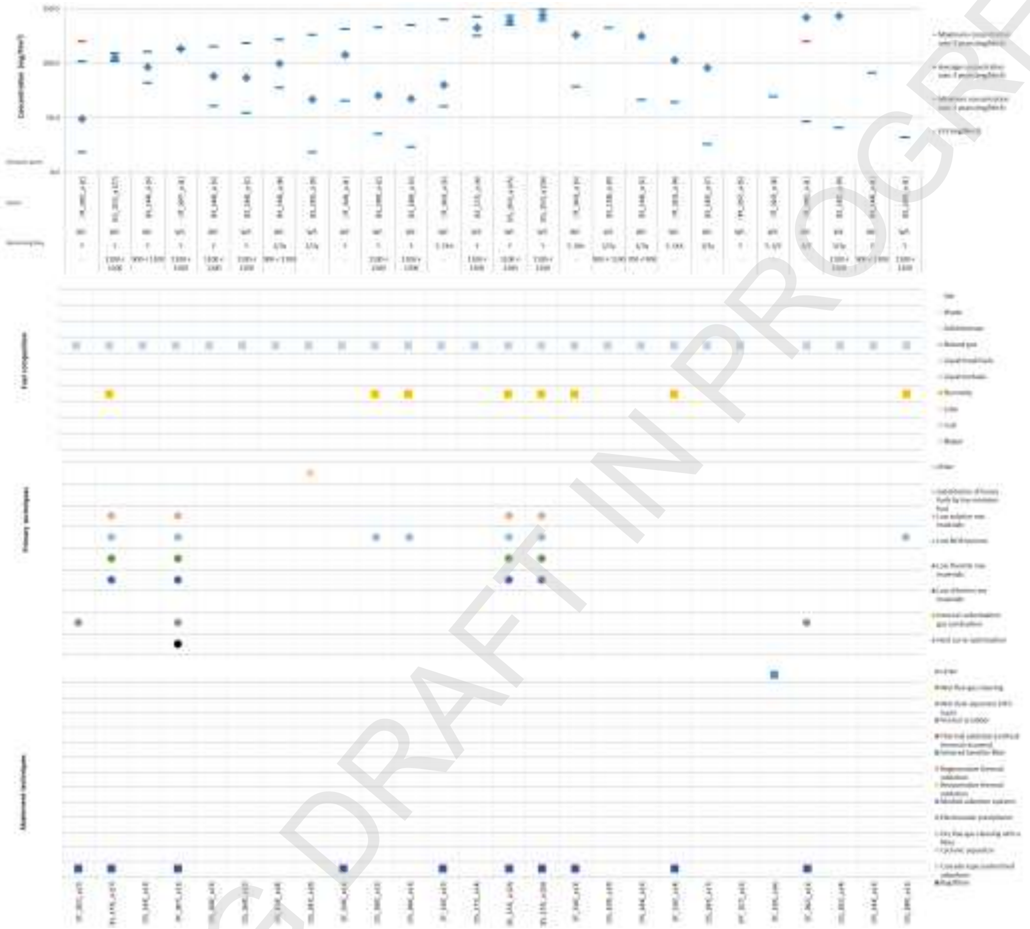
NB: For better visualisation, emission points with maximum concentration values above 50 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

Figure 3-111: NO$_X$ emissions to air from firing process in the wall and floor tiles sector (1/8)



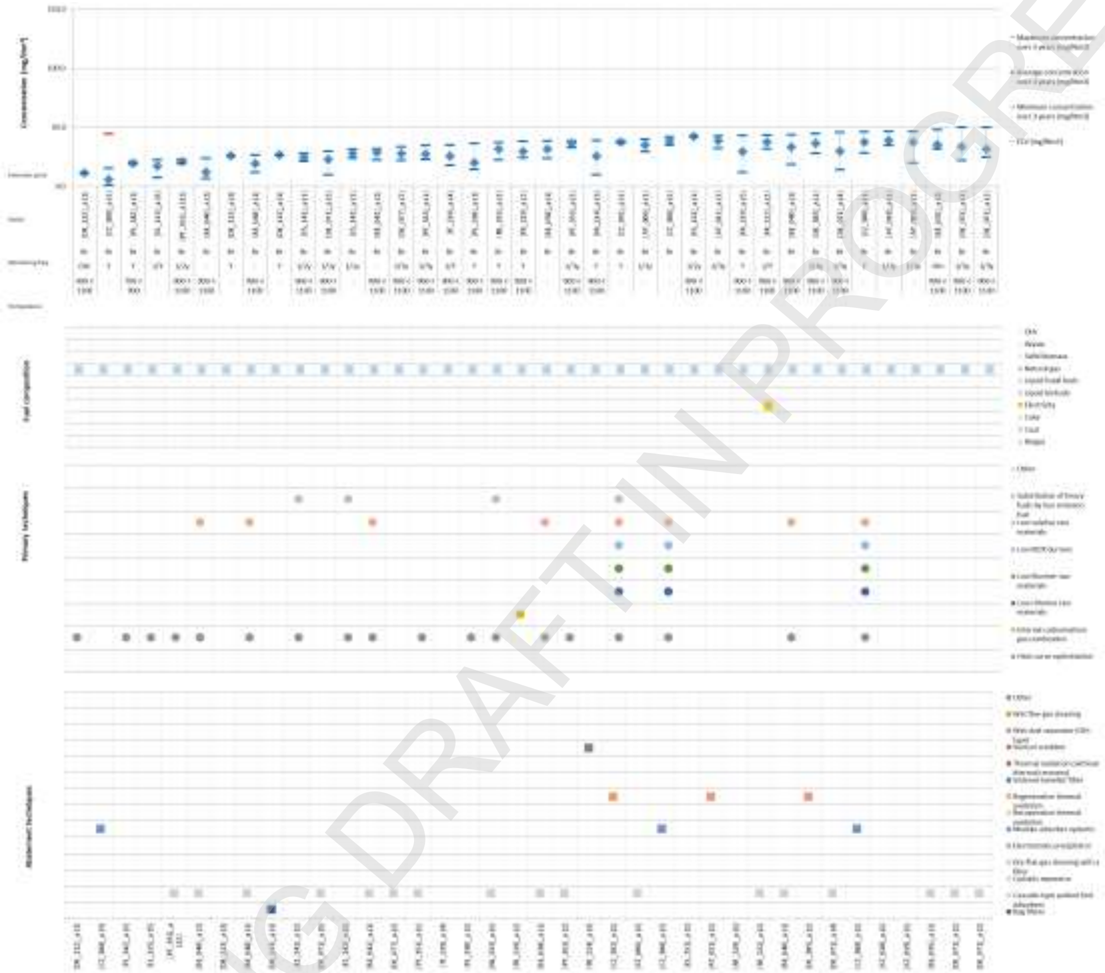
NB: For better visualisation, emission points with maximum concentration values above 150 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

Figure 3-112: NO$_X$ emissions to air from firing process in the wall and floor tiles sector (2/8)



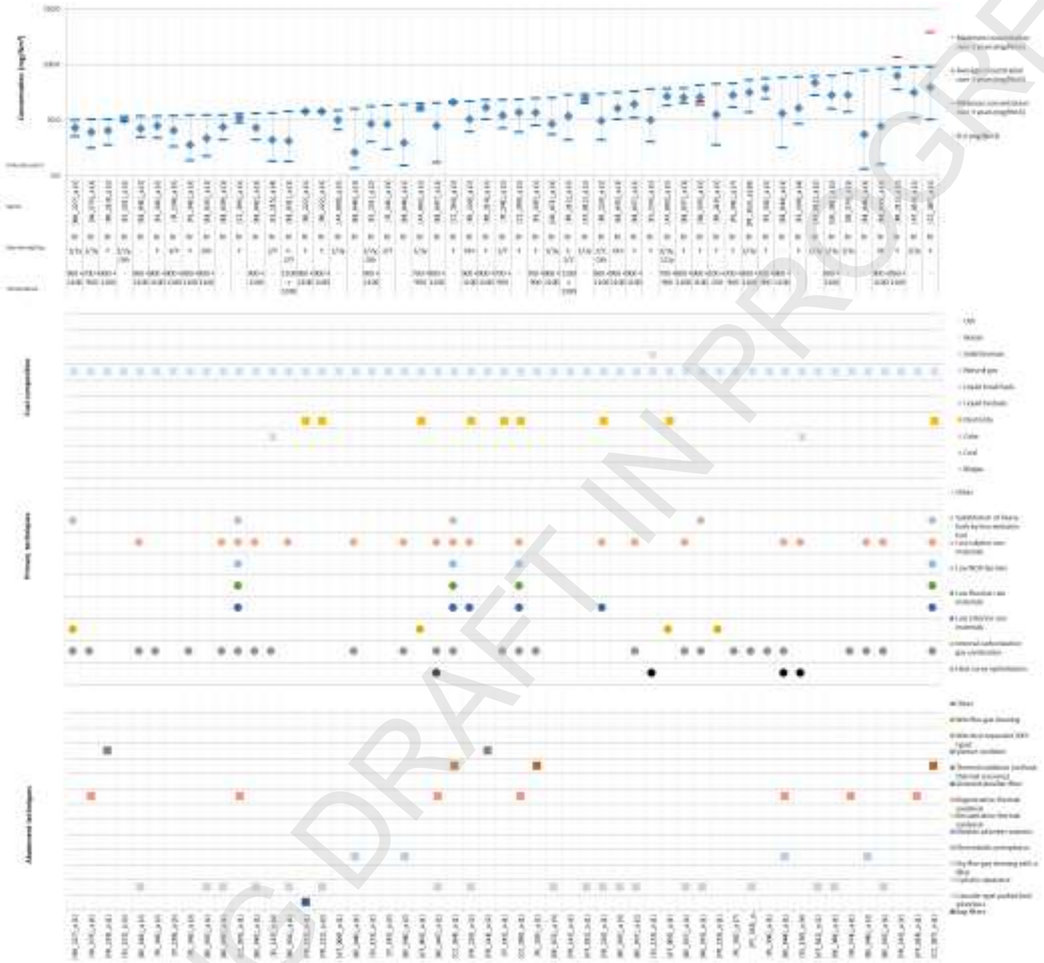
NB: For better visualisation, emission points with maximum concentration values above 150 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

Figure 3-113: NO_X emissions to air from firing process in the wall and floor tiles sector (3/8)



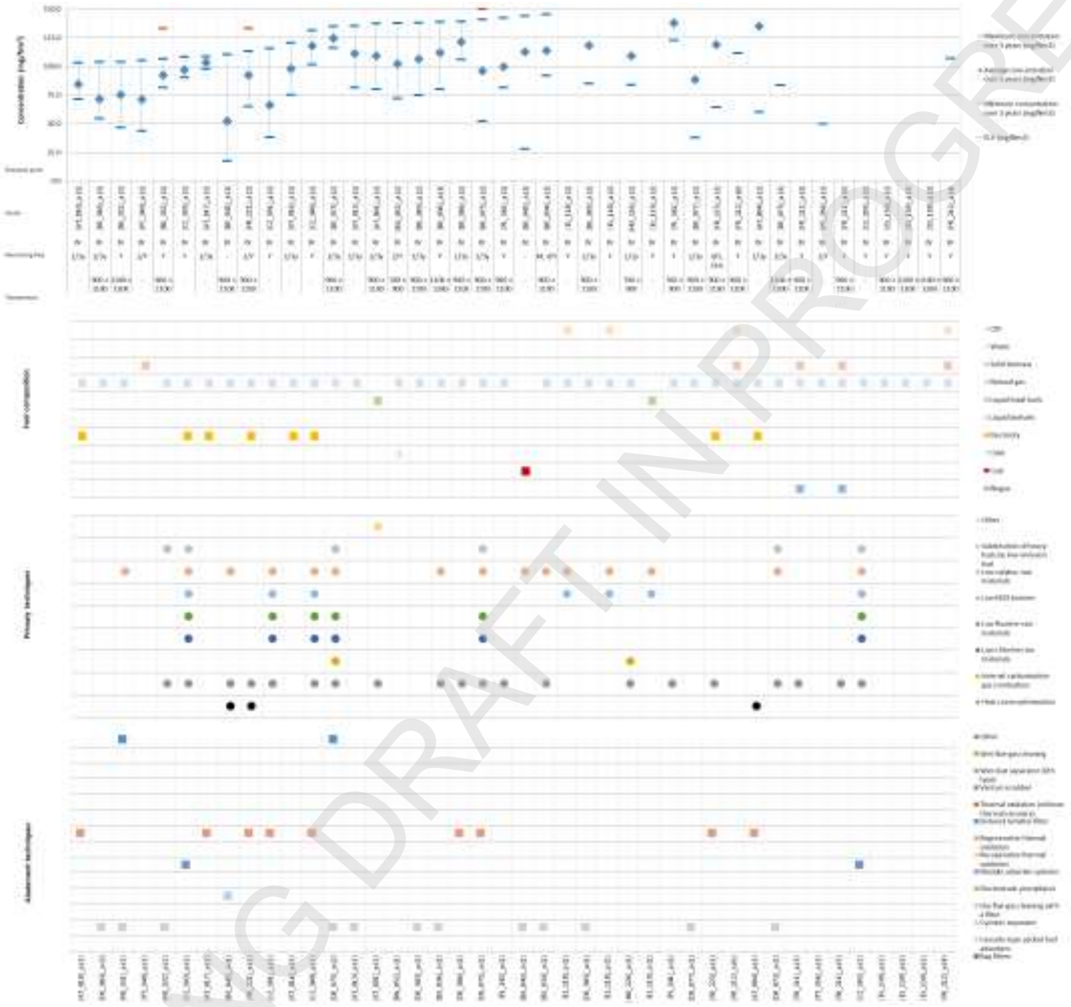
NB: For better visualisation, emission points with maximum concentration values above 75 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

Figure 3-114: NO$_X$ emissions to air from firing process in the brick and roof tiles sector (4/8)



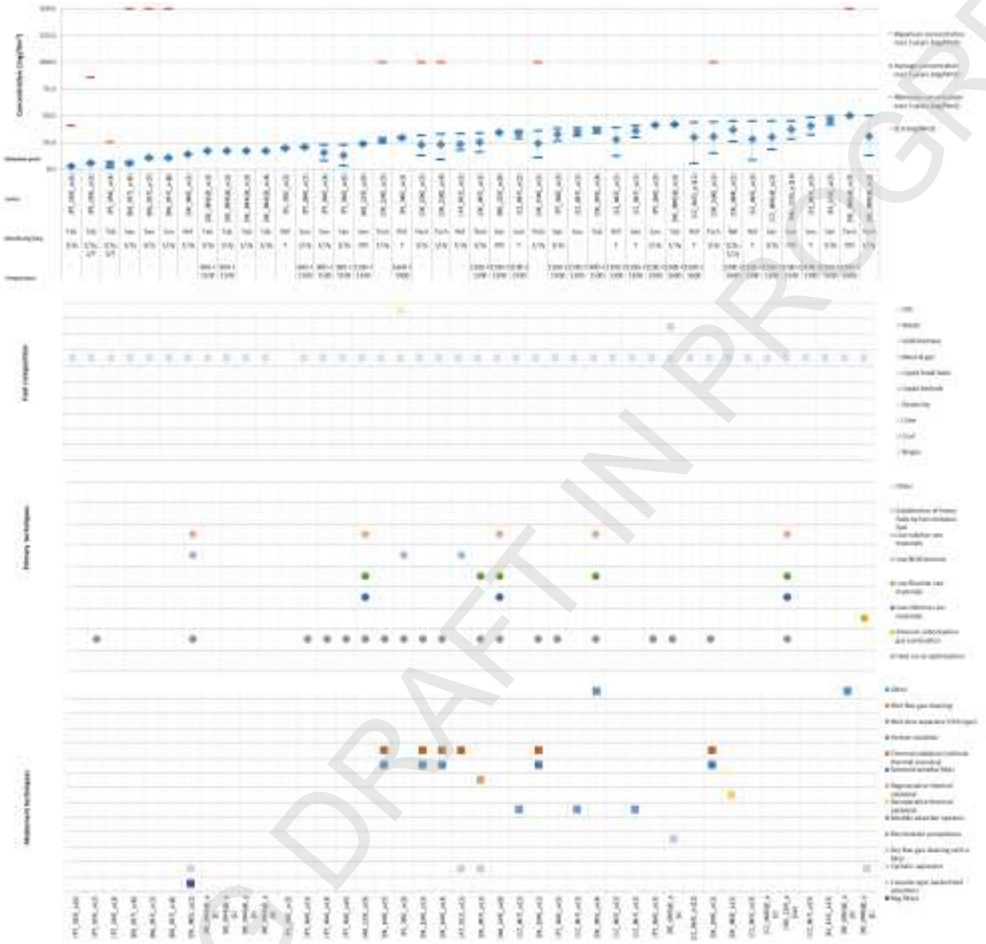
NB: For better visualisation, emission points with maximum concentration values above 150 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

Figure 3-115: NO_X emissions to air from firing process in the brick and roof tiles sector (5/8)



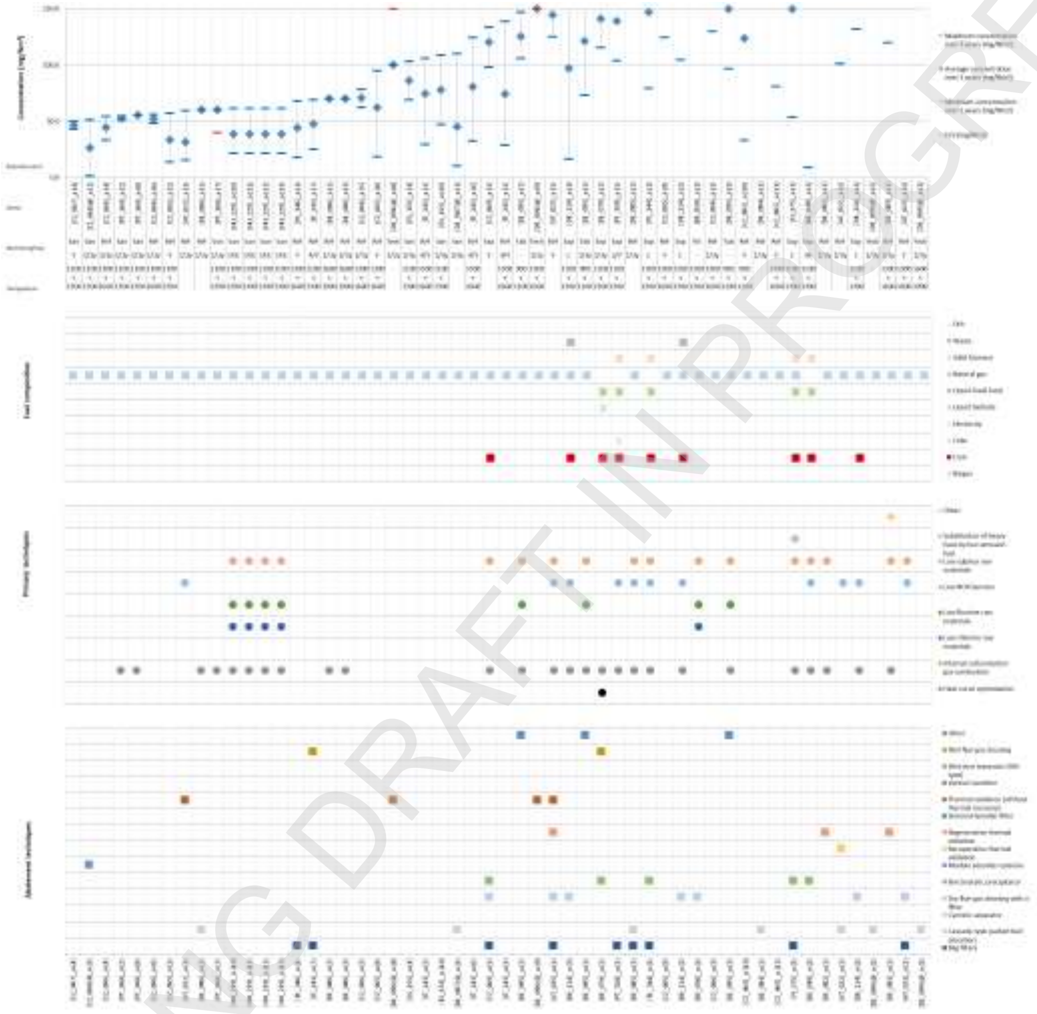
NB: For better visualisation, emission points with maximum concentration values above 150 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

Figure 3-116: NO$_X$ emissions to air from firing process in the brick and roof tiles sectors (6/8)



NB: For better visualisation, emission points with maximum concentration values above 50 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

Figure 3-117: NO$_X$ emissions to air from firing process in other sectors (7/8)

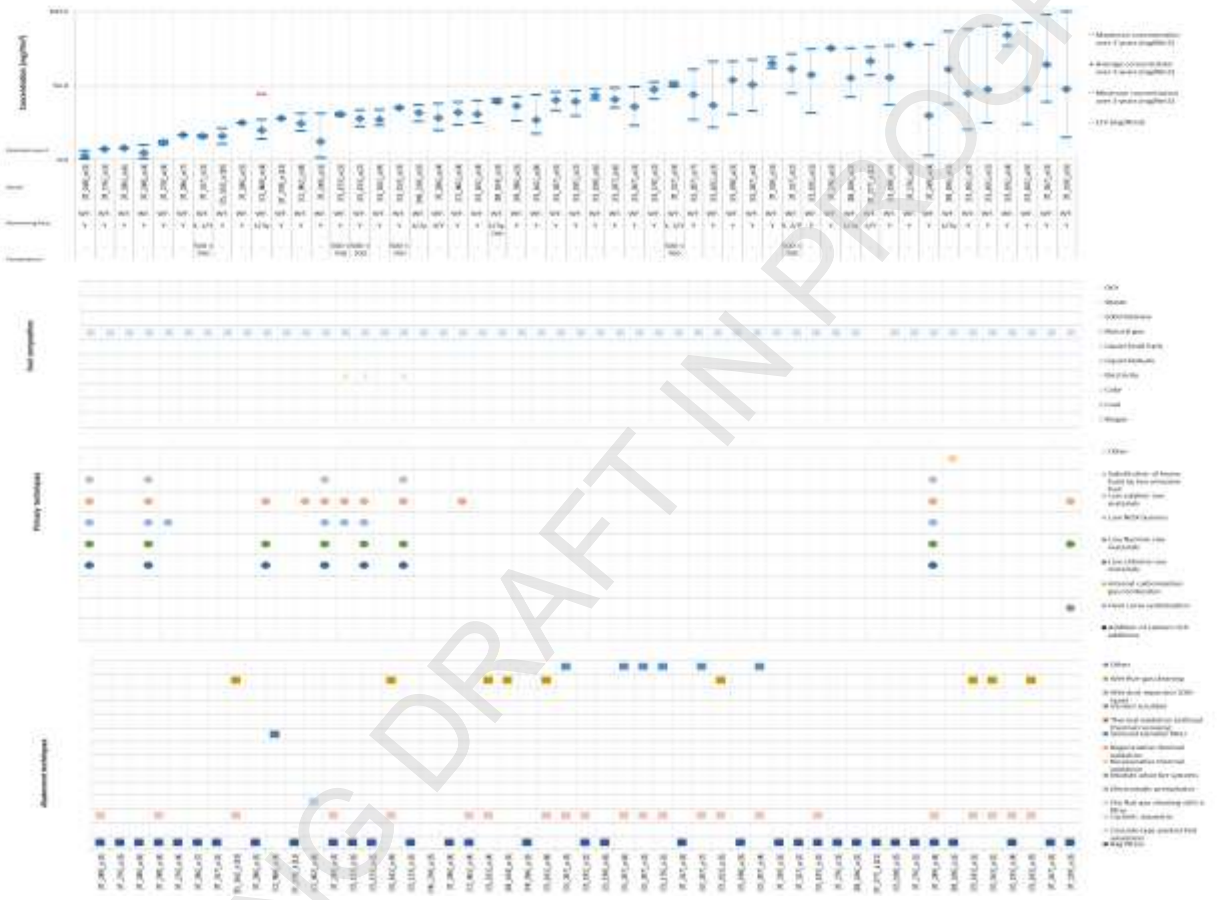


Source: [35, TWG 2023]

Figure 3-118: NO$_X$ emissions to air from firing process in other sectors (8/8)

NB: For better visualisation, emission points with maximum concentration values above 150 mg/Nm^3 are not shown.

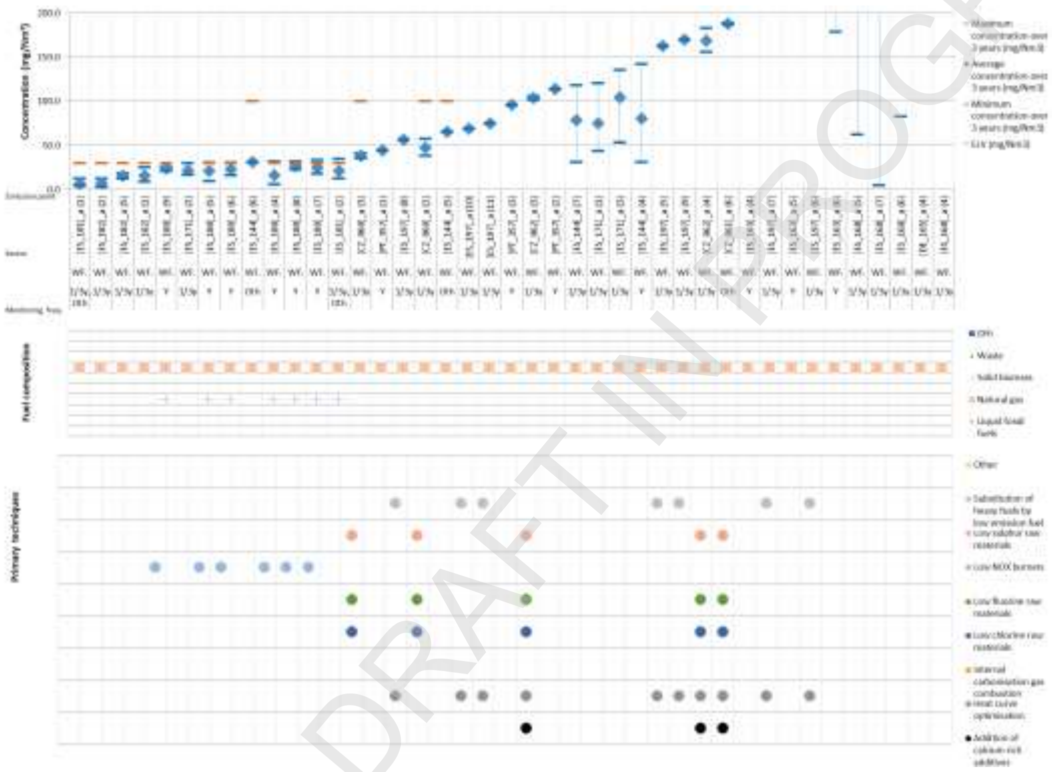
3.2.7.12 NO_X emissions to air from spray-drying process



NB: For better visualisation, emission points with maximum concentration values less than or equal to 100 mg/Nm^3 are shown.
Source: [35, TWG 2023]

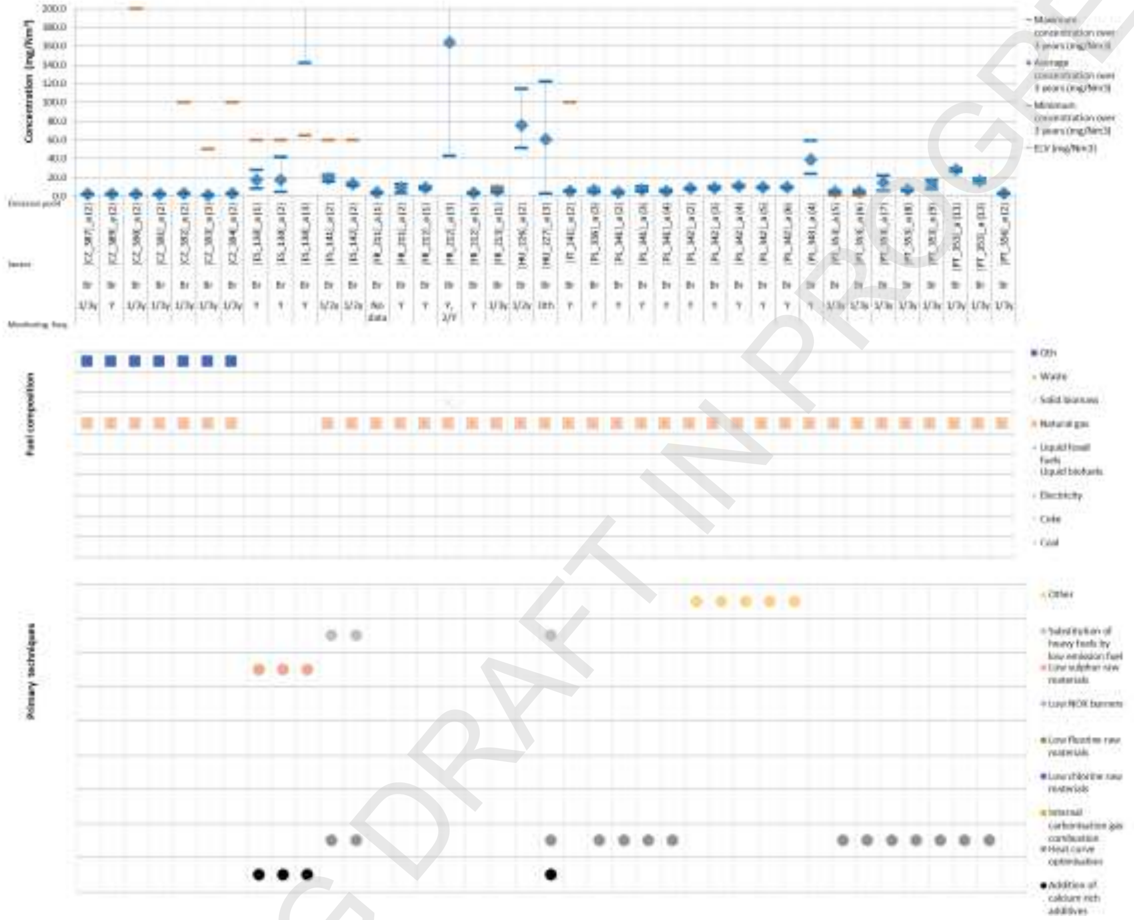
Figure 3-119: NO_X emissions to air from spray-drying process in the wall and floor tiles sector

3.2.7.13 CO emissions to air from drying process



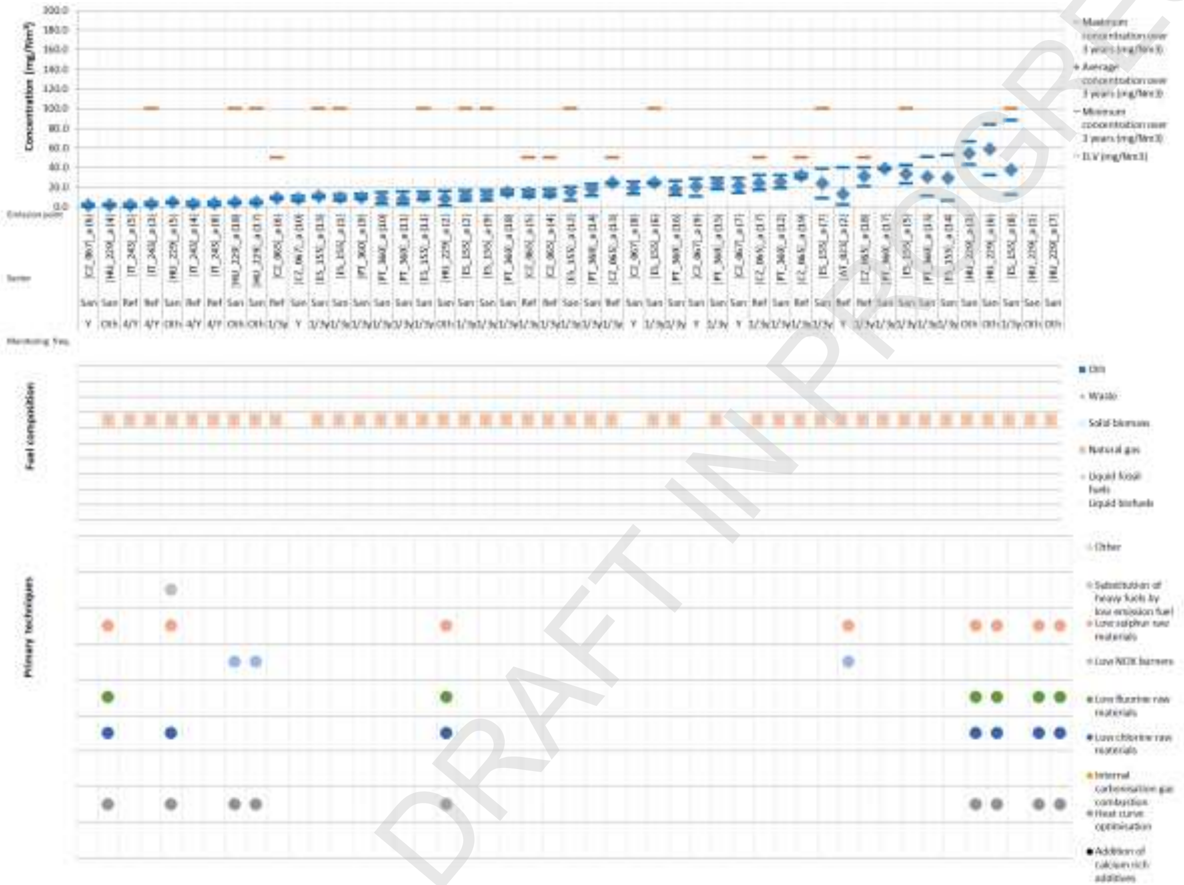
NB: For CO emissions to air from drying process in wall and floor tiles sector, most of the emission points did not report information on applied abatement techniques. Therefore, the graph is not shown in this figure. For better visualisation, maximum concentration values above 200 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

Figure 3-120: CO emissions to air from drying process in the wall and floor tiles sector (1/3)



NB: For CO emissions to air from drying process in wall and floor tiles sector, most of the emission points did not report information on applied abatement techniques. Therefore, the graph is not shown in this figure. For better visualisation, maximum concentration values above 200 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

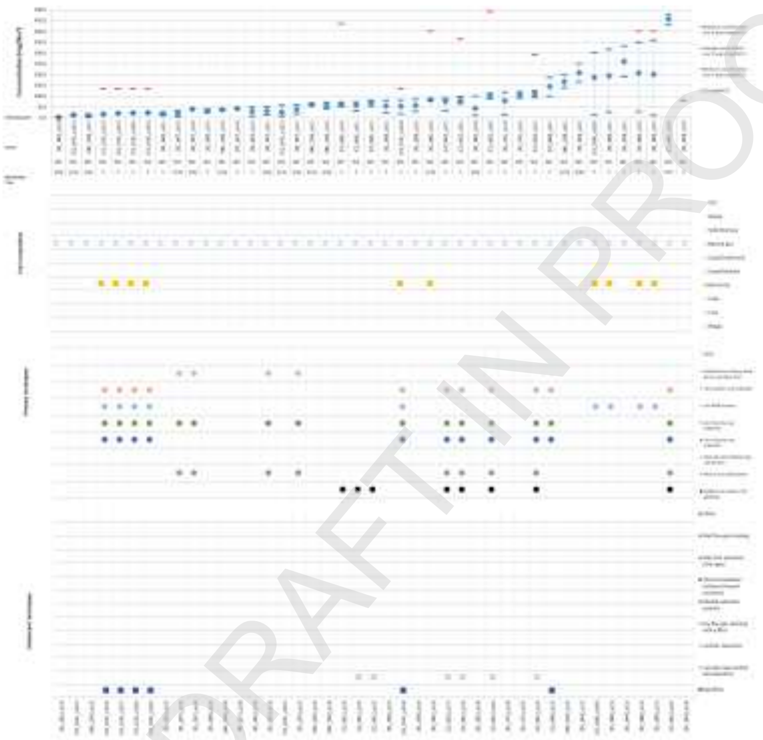
Figure 3-121: CO emissions to air from drying process in the brick and roof tiles sector (2/3)



NB: For CO emissions to air from drying process in wall and floor tiles sector, most of the emission points did not report information on applied abatement techniques. Therefore, the graph is not shown in this figure. For better visualisation, maximum concentration values above 200 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

Figure 3-122: CO emissions to air from drying process in other sectors (3/3)

3.2.7.14 CO emissions to air from firing process

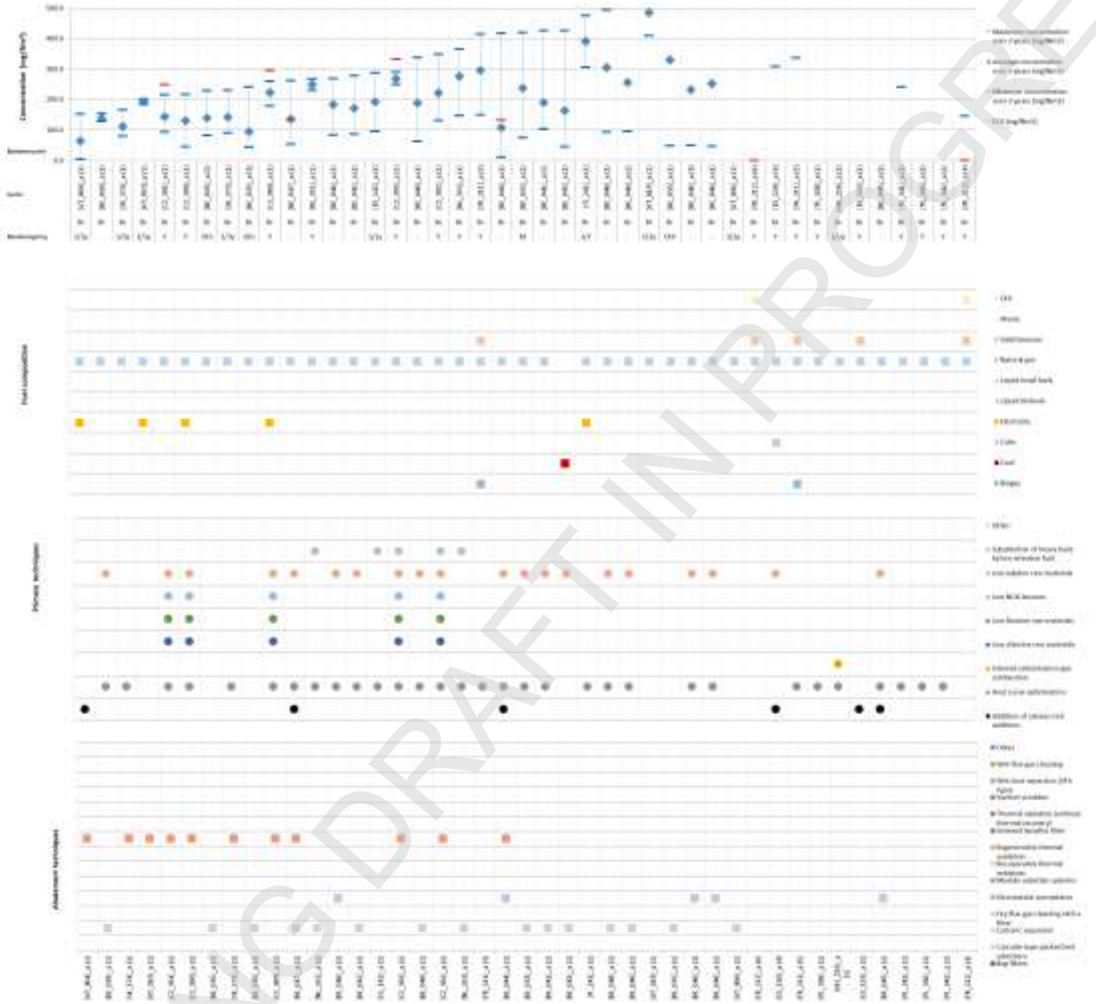


NB: For better visualisation, maximum concentration values above 500 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

Figure 3-123: CO emissions to air from firing process in the wall and floor tiles sector (1/5)

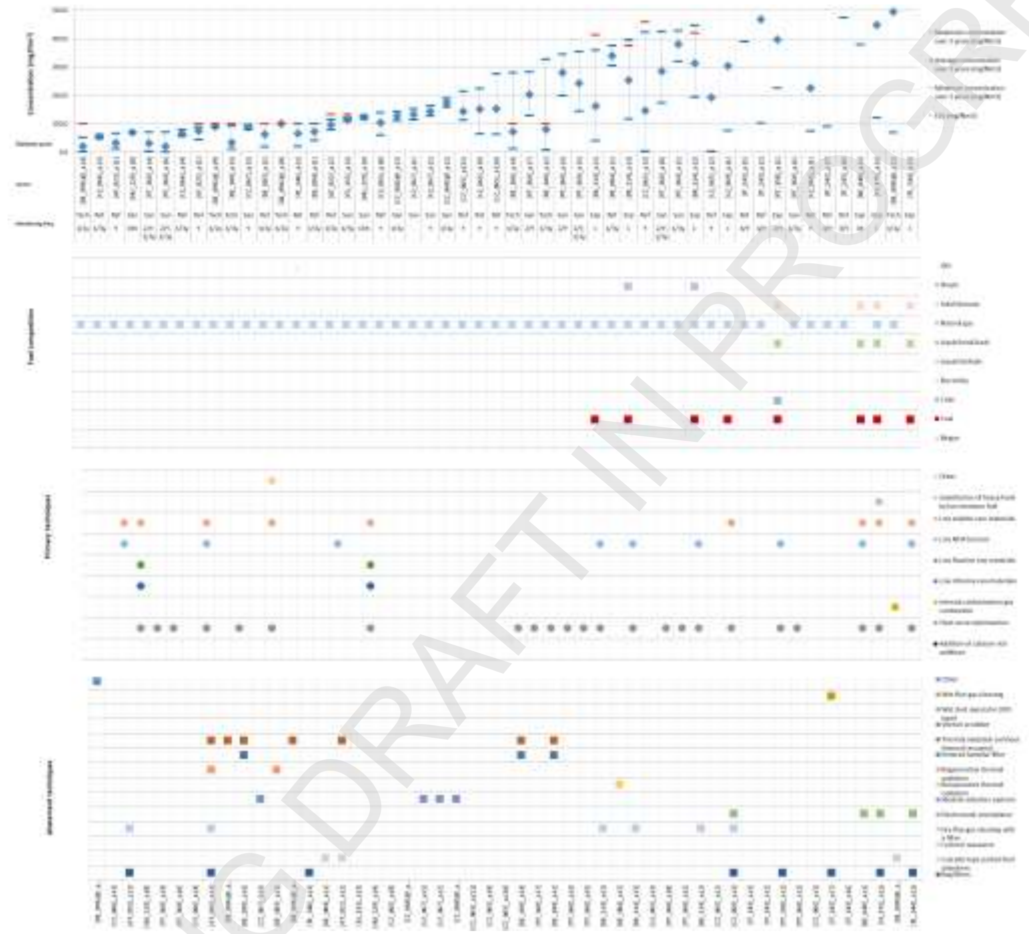
NB: For better visualisation, only emission points with maximum concentration values above 150 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

Figure 3-124: CO emissions to air from firing process in the brick and roof tiles sector (2/5)



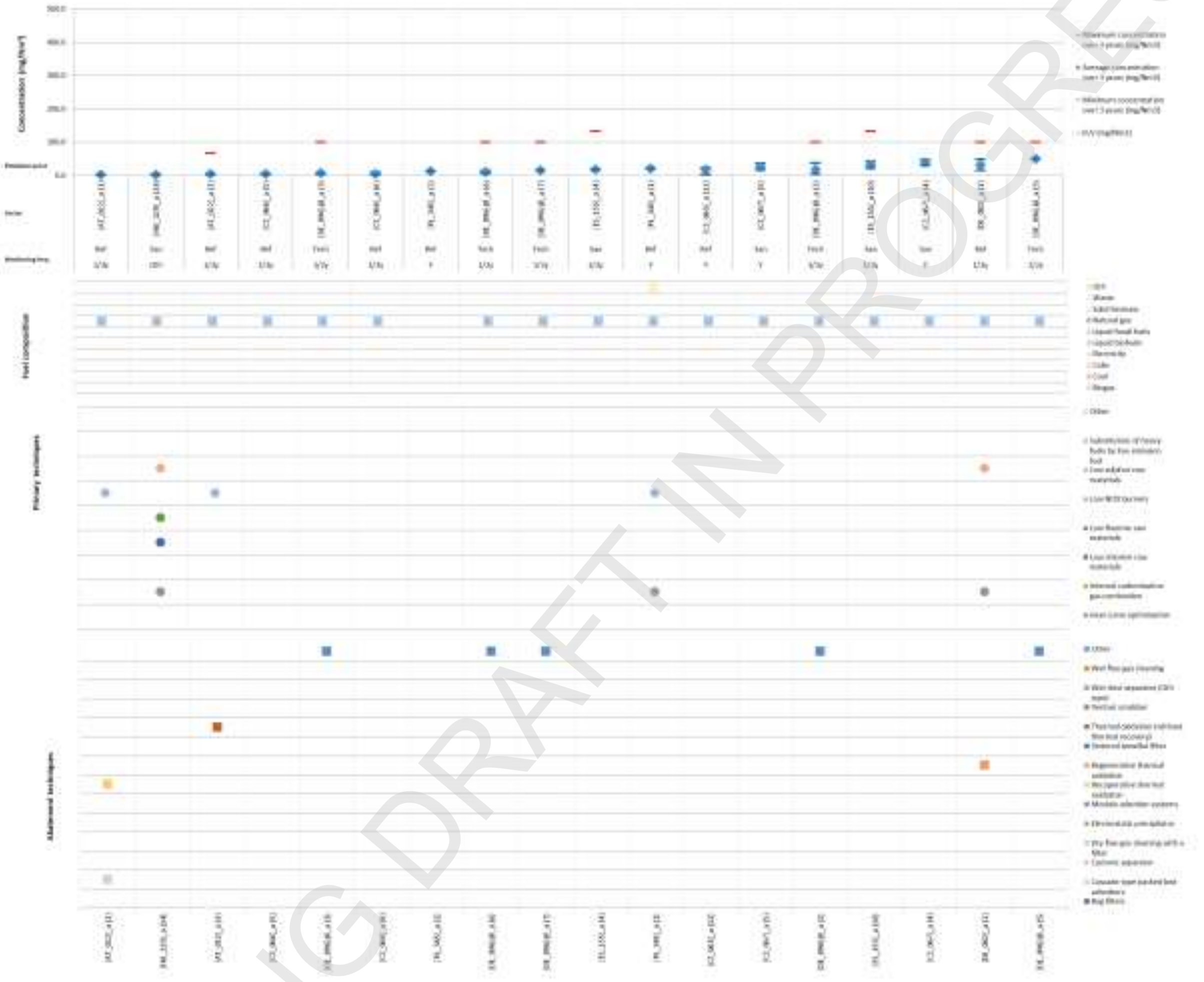
NB: For better visualisation, only emission points with maximum concentration values in the range of 150-500 mg/Nm^3 are shown.
Source: [35, TWG 2023]

Figure 3-125: CO emissions to air from firing process in the brick and roof tiles sector (3/5)



NB: For better visualisation, only emission points with maximum concentration values in the range of 50-500 mg/Nm^3 are shown.
Source: [35, TWG 2023]

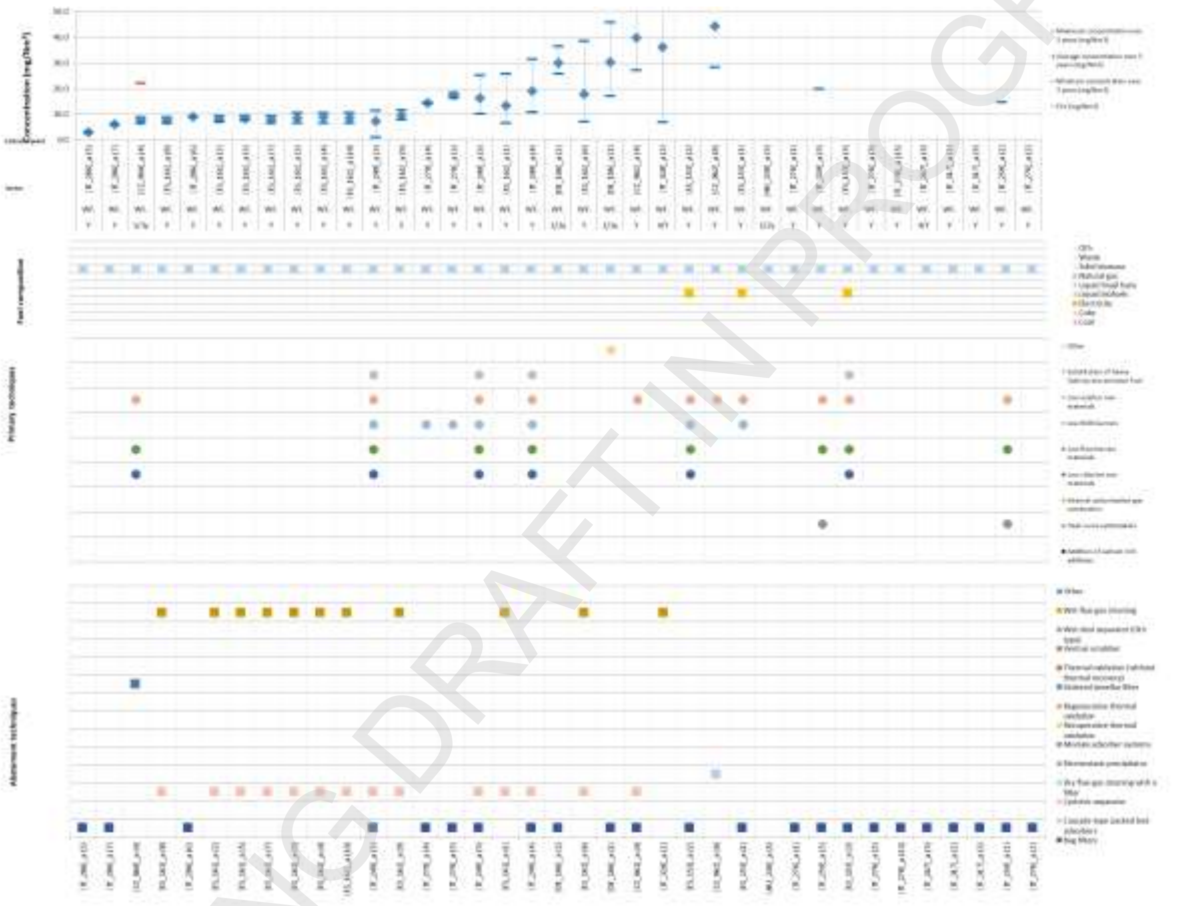
Figure 3-126: CO emissions to air from firing and drying-firing processes in other sectors (4/5)



Source: [35, TWG 2023]

Figure 3-127: CO emissions to air from firing process in other sectors (5/5)

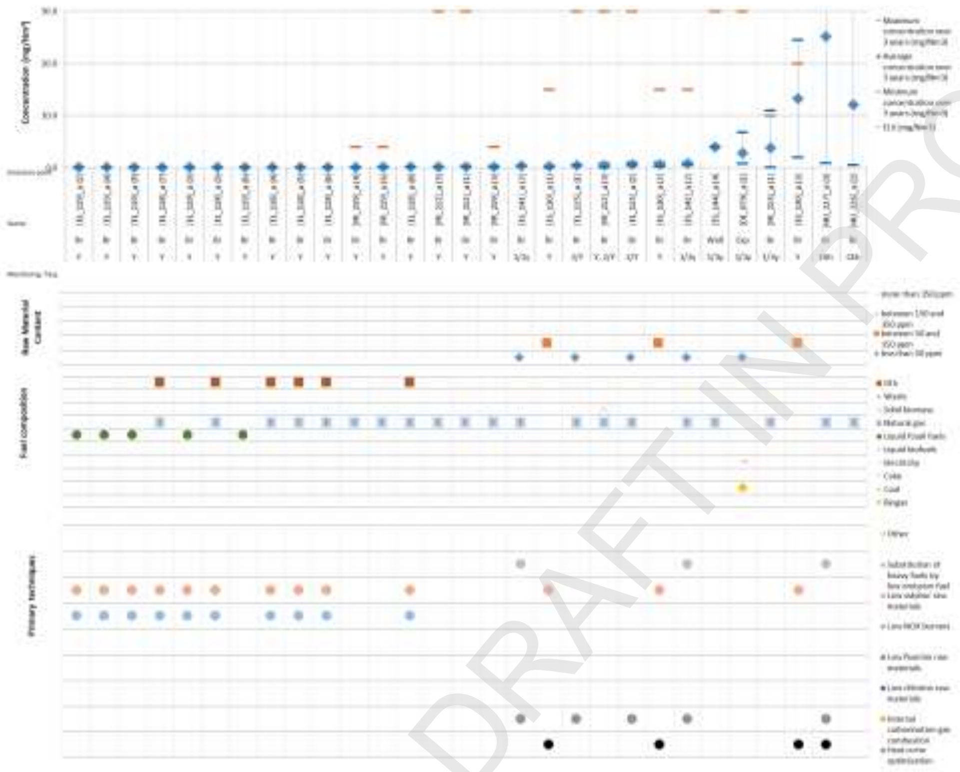
3.2.7.15 CO emissions to air from spray-drying process



Source: [35, TWG 2023]

Figure 3-128: CO emissions to air from spray-drying process

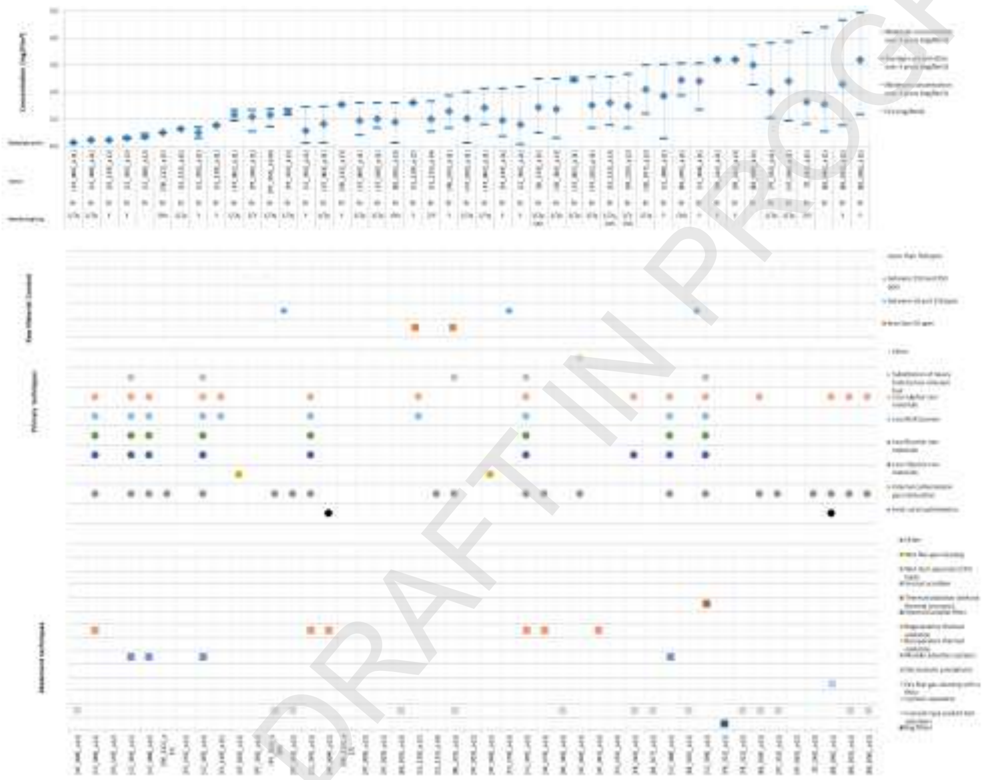
3.2.7.16 HCl emissions to air from drying process



NB: For HCl emissions to air from drying process, most of the emission points did not report information on applied abatement techniques. Therefore, the graph is not shown in this figure. For better visualisation, maximum concentration values above 50 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

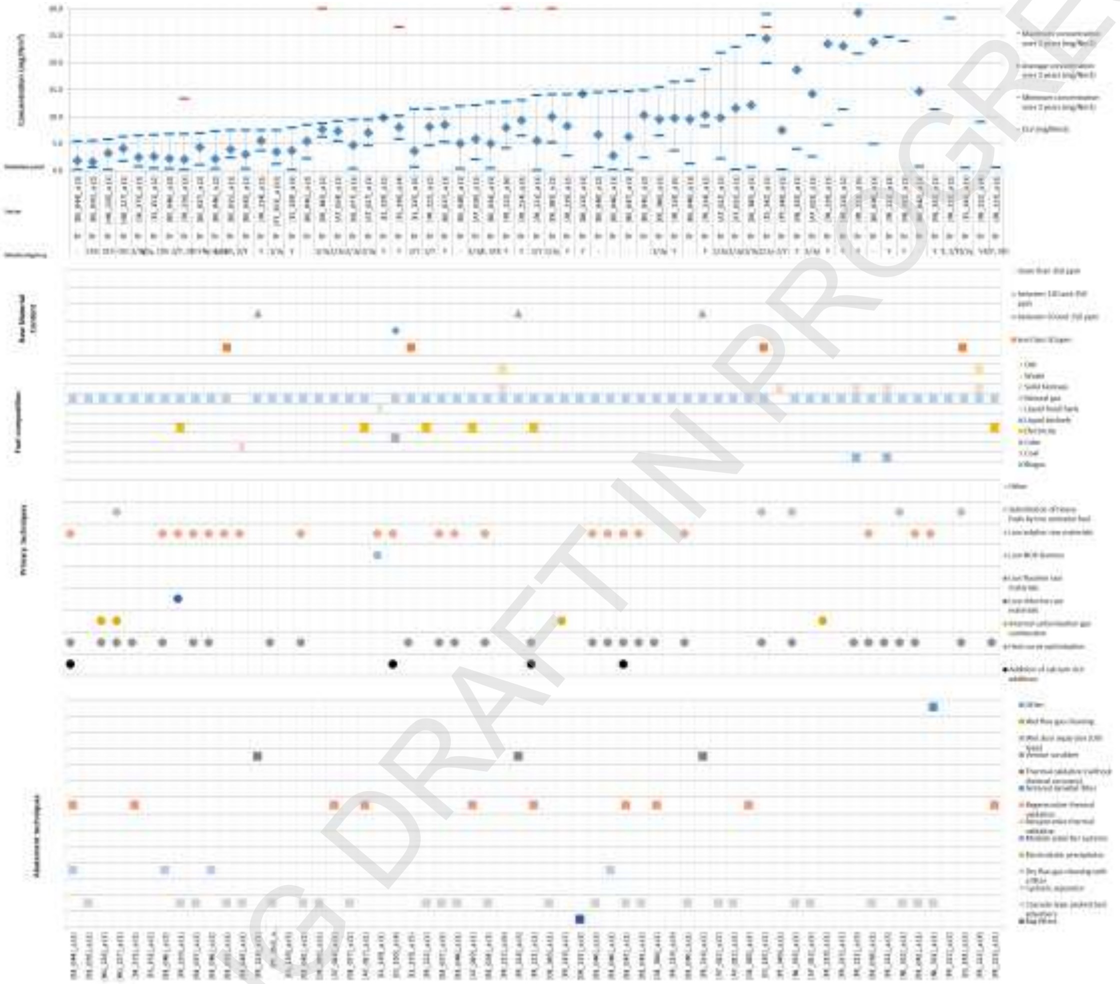
Figure 3-129: HCl emissions to air from drying process in other sectors

3.2.7.17 HCl emissions to air from firing process



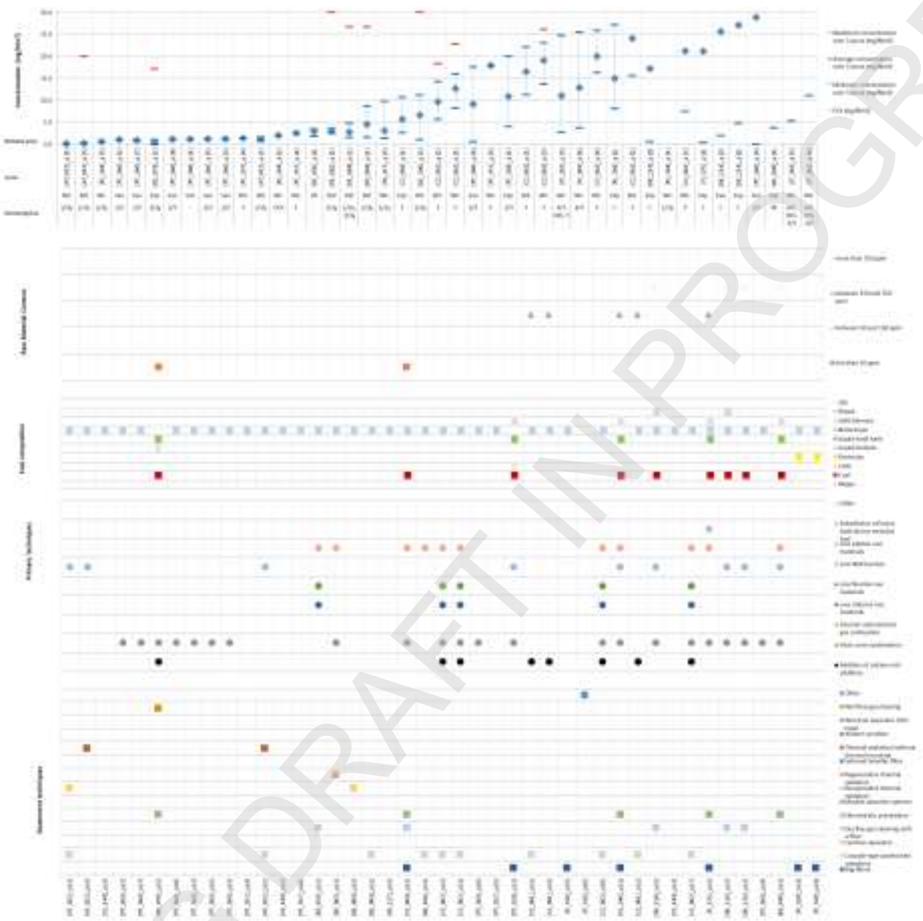
NB: For better visualisation, emission points with maximum concentration values above 5 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

Figure 3-130: HCl emissions to air from firing process in the brick and roof tiles sector (1/3)



NB: For better visualisation, emission points with maximum concentration values above 30 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

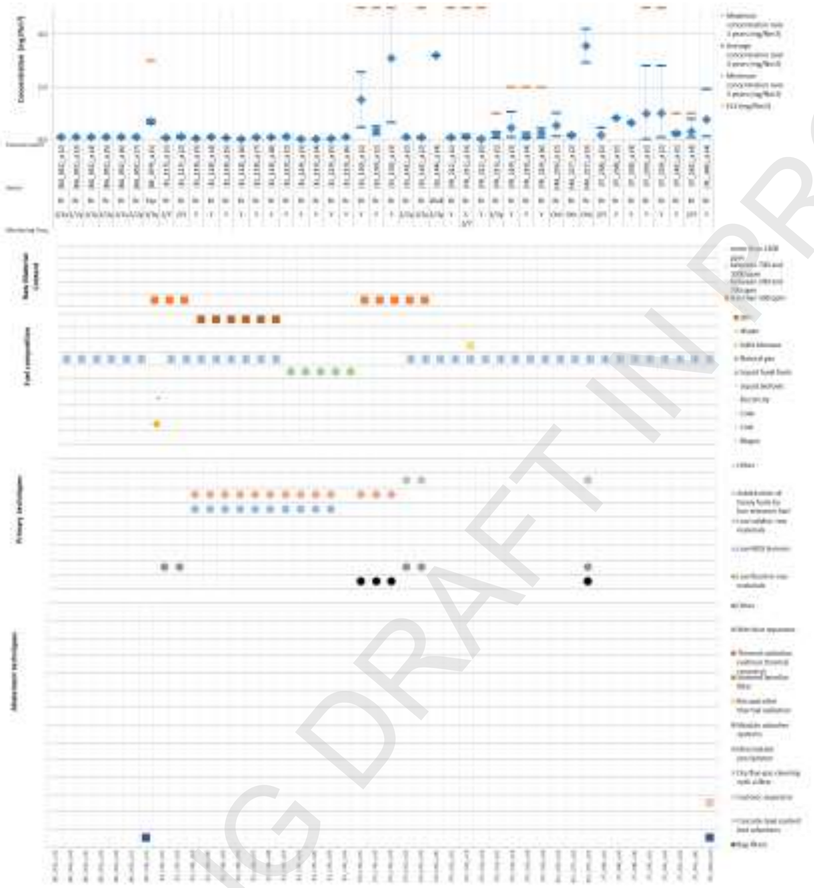
Figure 3-131: HCl emissions to air from firing process in the brick and roof tiles sector (2/3)



Source: [35, TWG 2023]

Figure 3-132: HCl emissions to air from firing and drying-firing processes in other sectors (3/3)

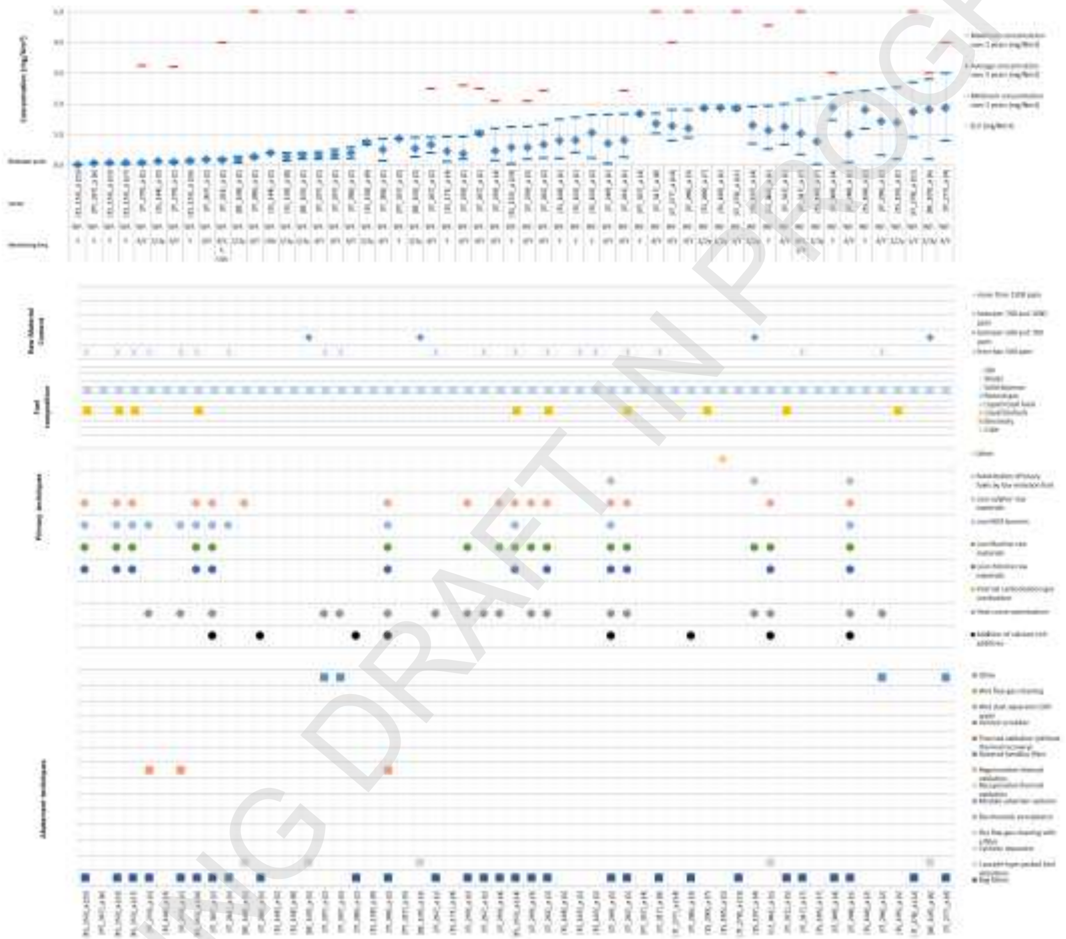
3.2.7.18 HF emissions to air from drying process



Source: [35, TWG 2023]

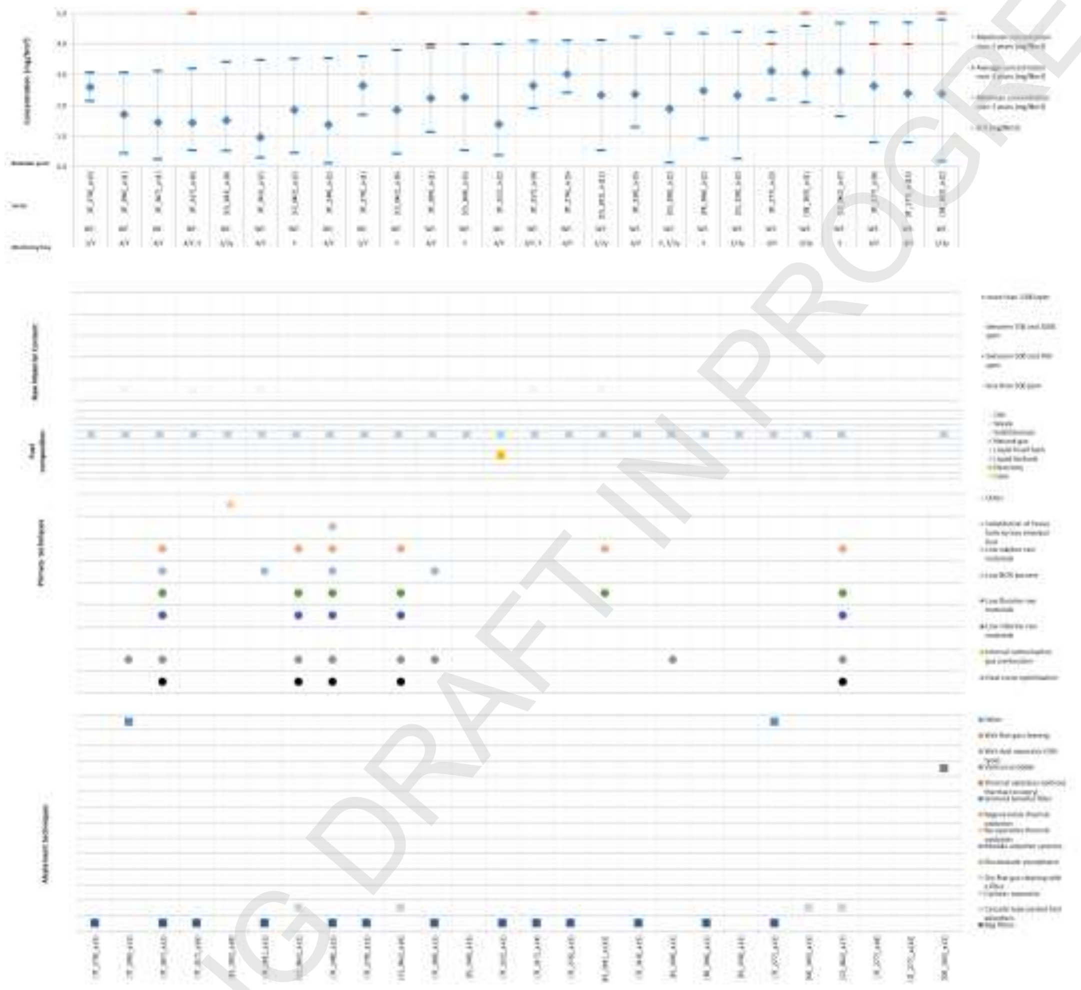
Figure 3-133: HF emissions to air from drying process

3.2.7.19 HF emissions to air from firing process



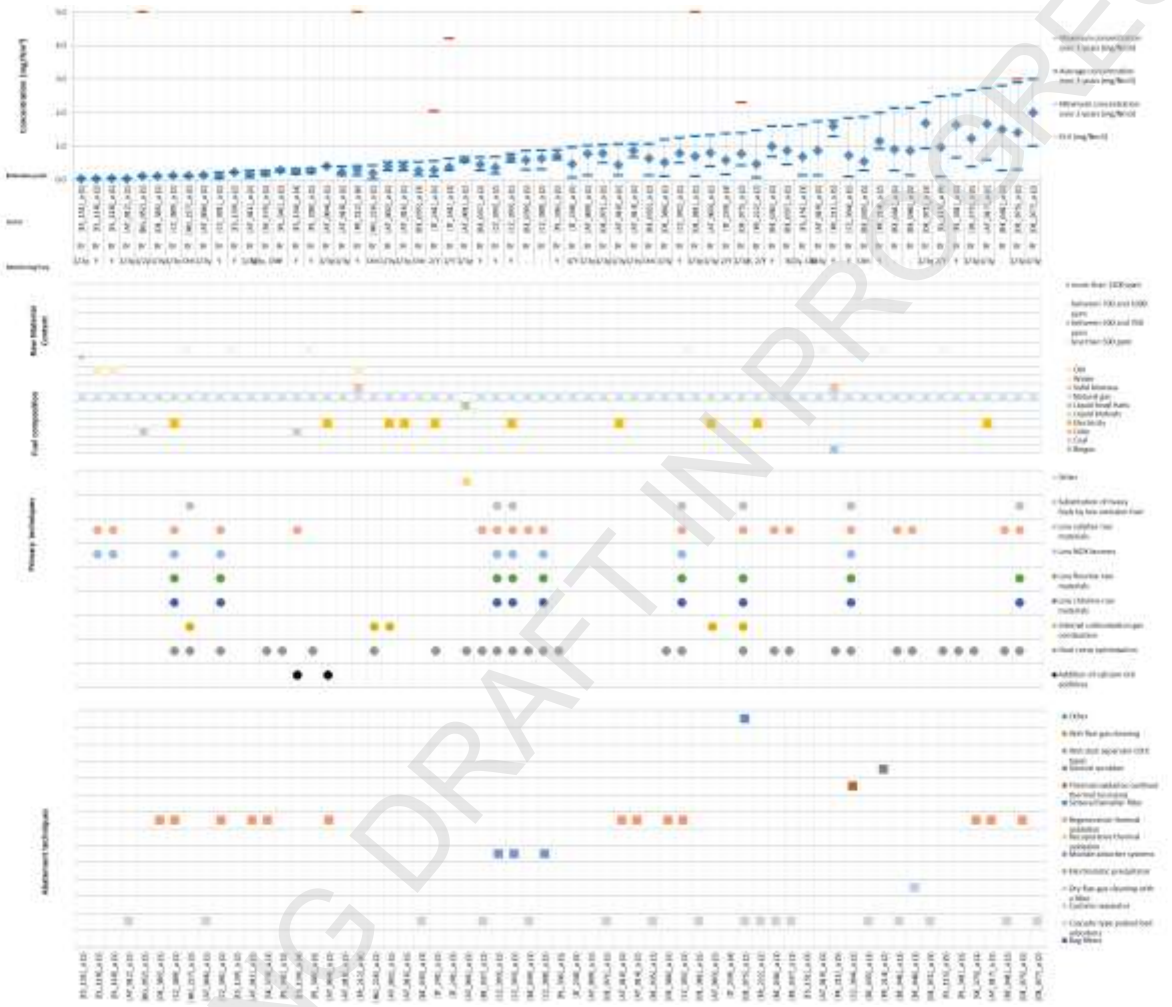
Source: [35, TWG 2023]

Figure 3-134: HF emissions to air from firing process in the wall and floor tiles sector (1/5)



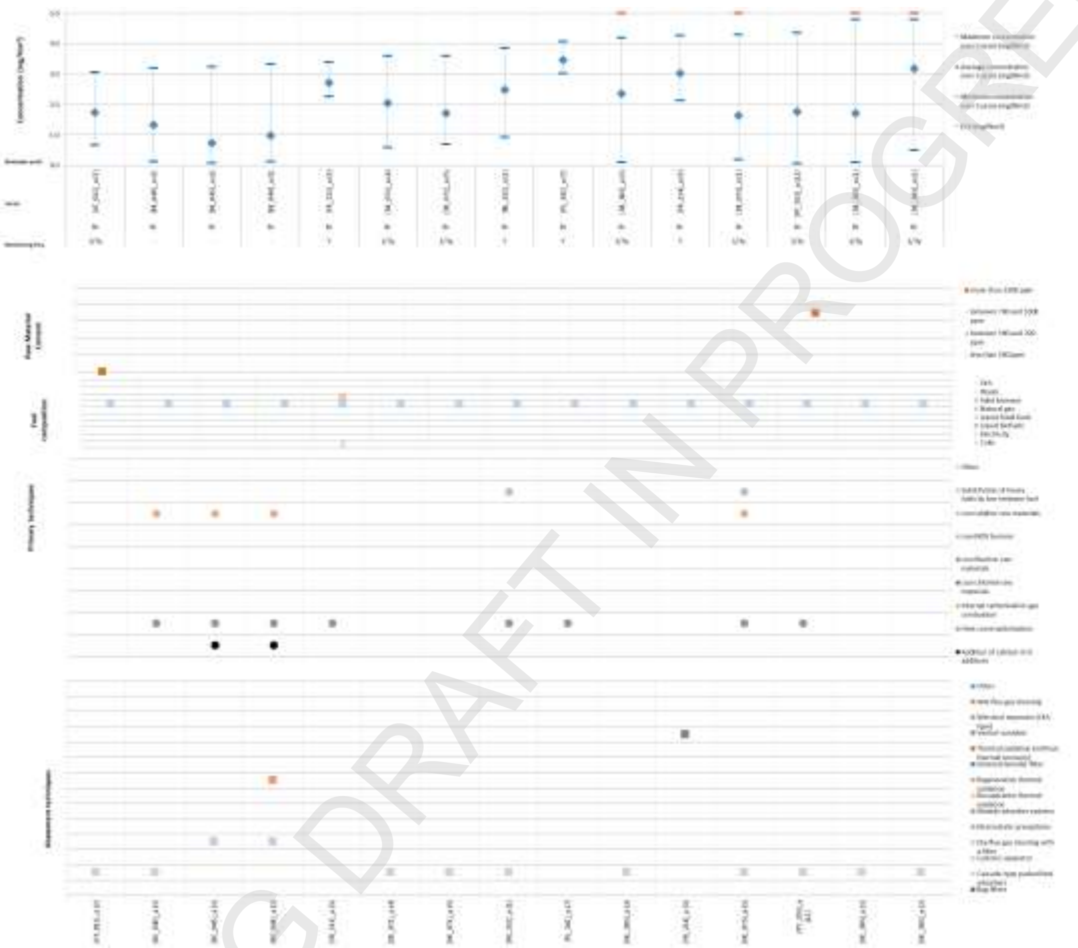
Source: [35, TWG 2023]

Figure 3-135: HF emissions to air from firing process in the wall and floor tiles sector (2/5)



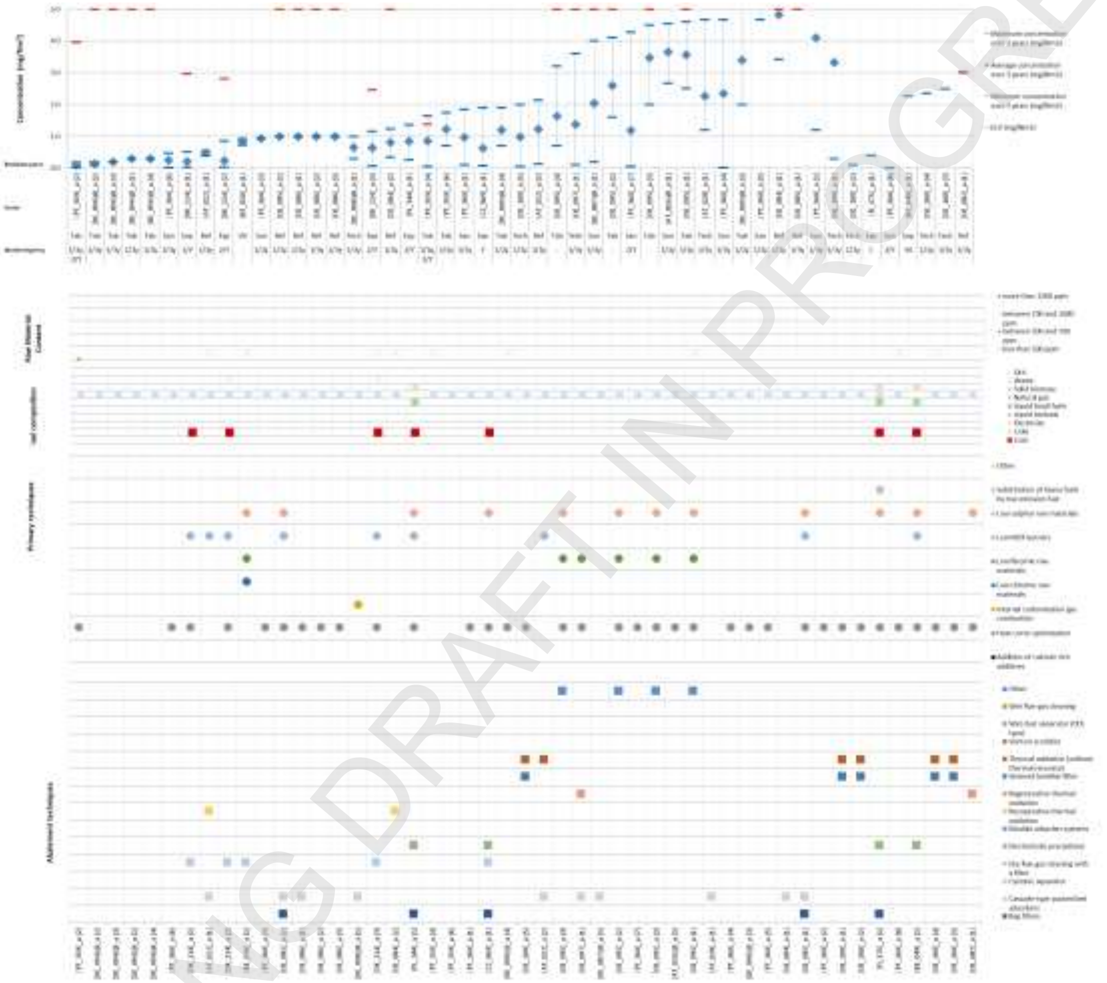
Source: [35, TWG 2023]

Figure 3-136: HF emissions to air from firing process in the brick and roof tiles sector (3/5)



Source: [35, TWG 2023]

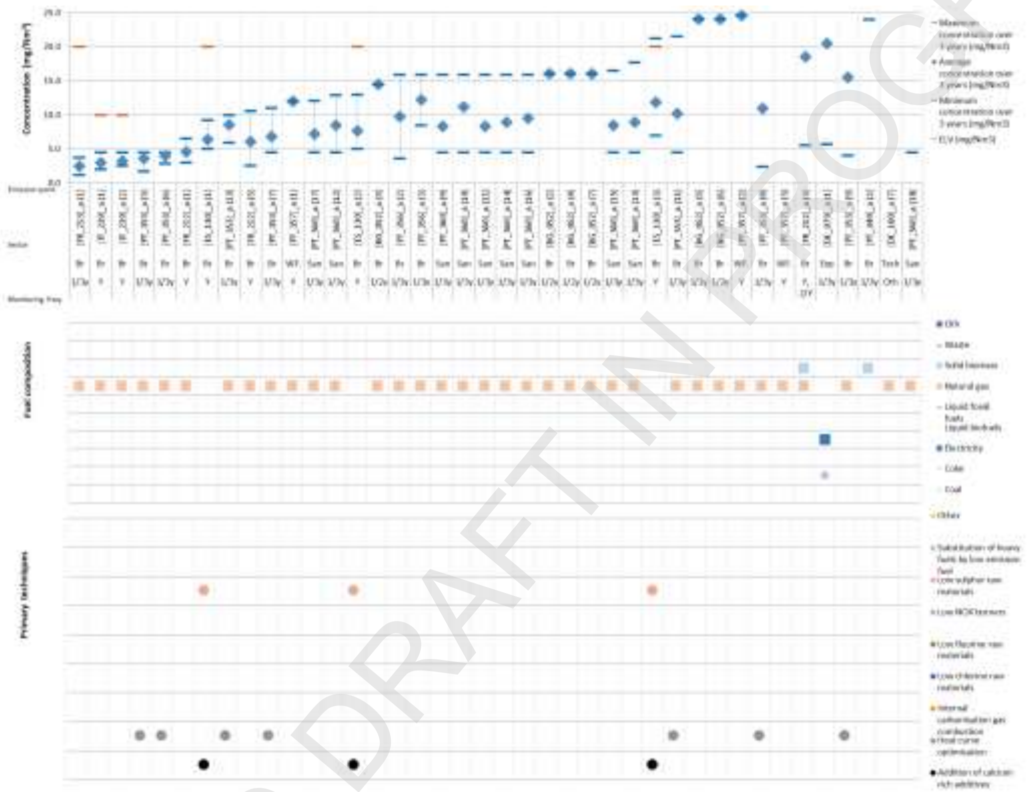
Figure 3-137: HF emissions to air from firing process in the brick and roof tiles sector (4/5)



Source: [35, TWG 2023]

Figure 3-138: HF emissions to air from firing and drying-firing processes in other sectors (5/5)

3.2.7.20 TVOC emissions to air from drying process

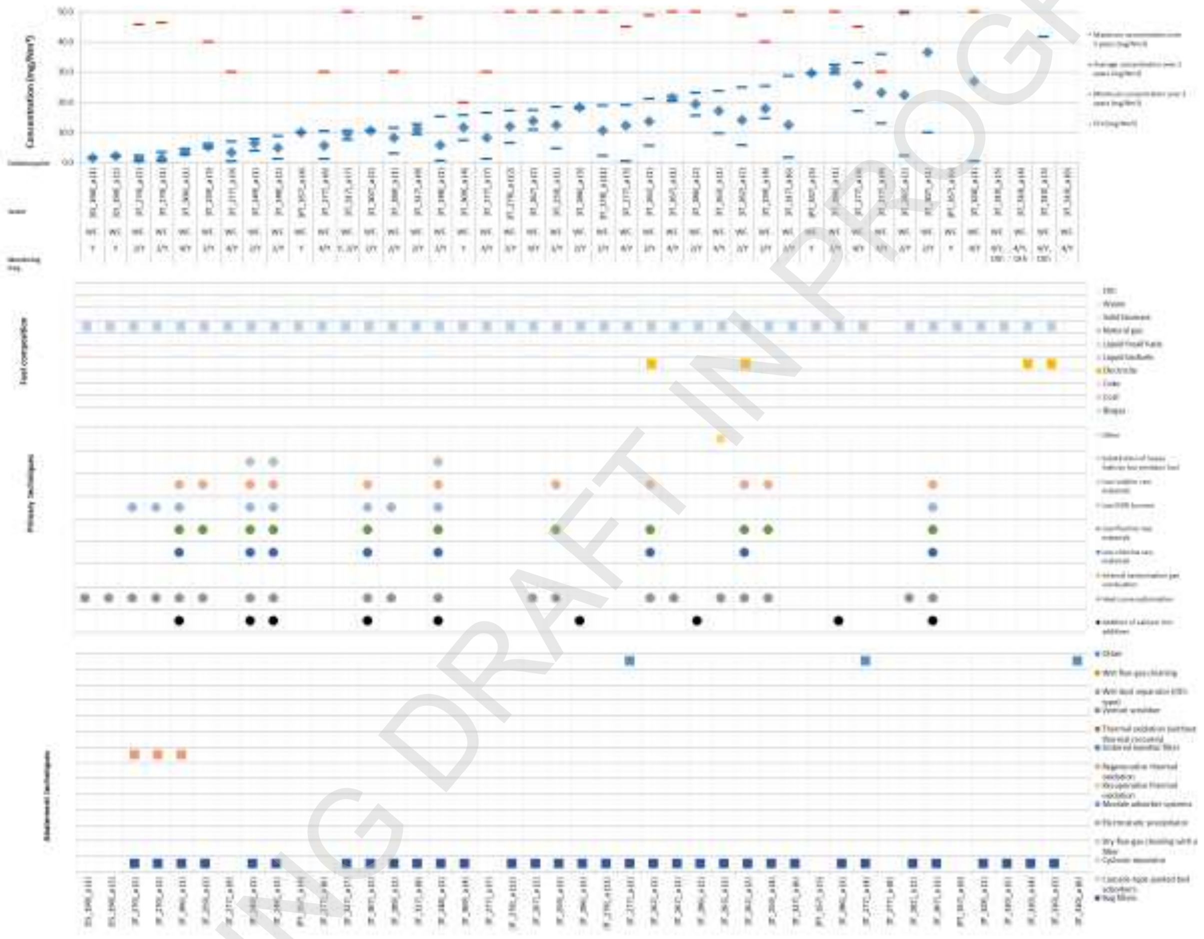


NB: For better visualisation, emission points with maximum concentration values above 25 mg/Nm^3 are not shown in the graph. Most of emission points did not report information on applied abatement techniques. Therefore, the graph is not shown.

Source: [35, TWG 2023]

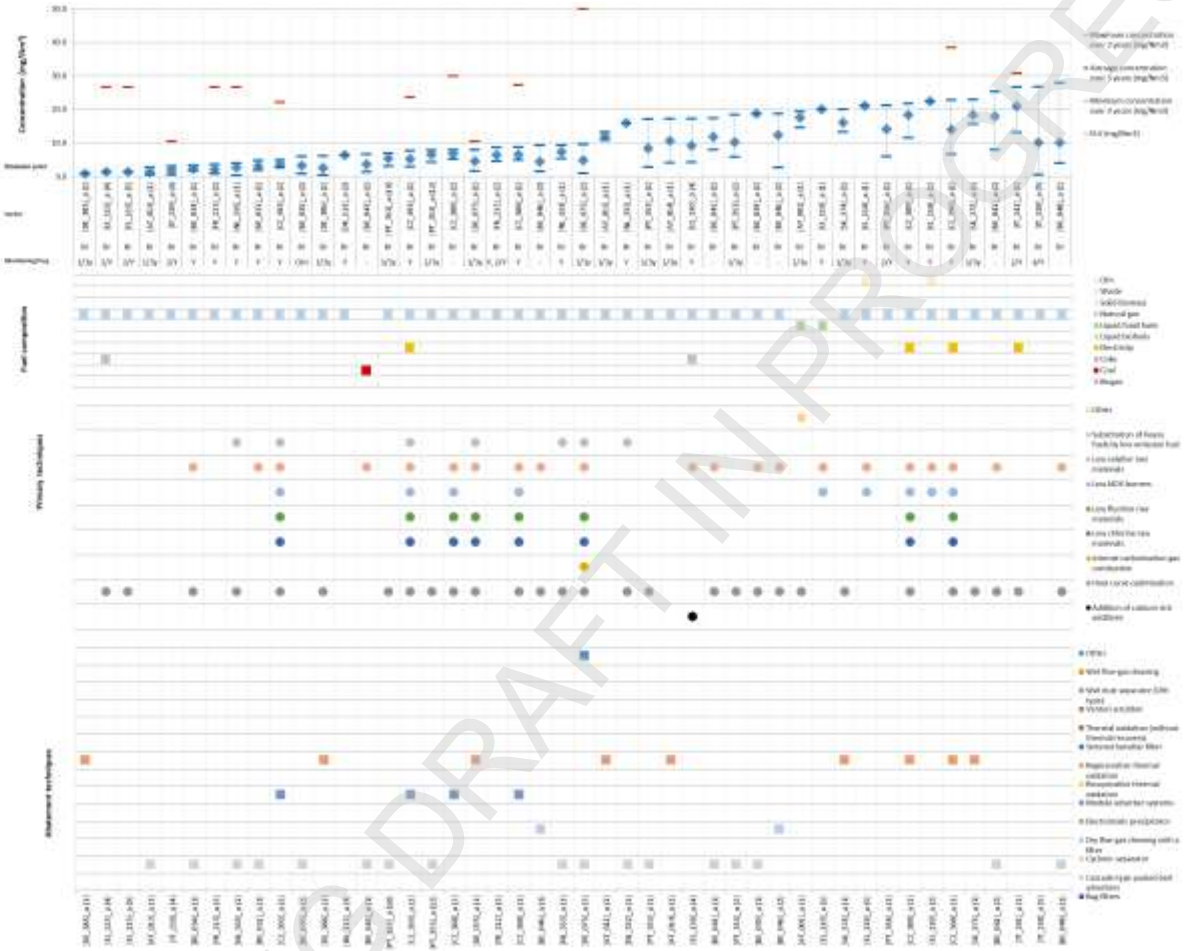
Figure 3-139: TVOC emissions to air from drying process in other sectors

3.2.7.21 TVOC emissions to air from firing process



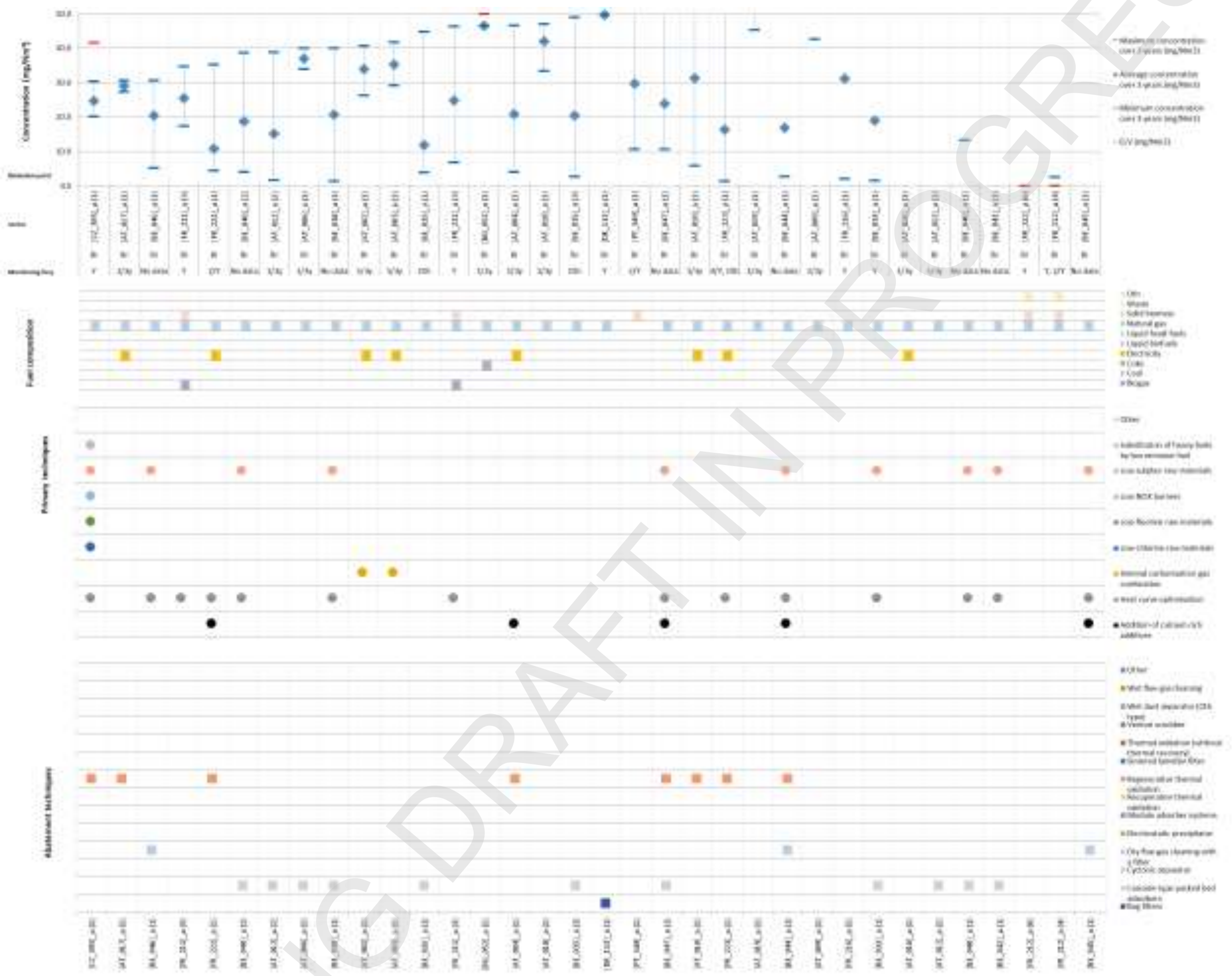
NB: For better visualisation, maximum concentration values above 50 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

Figure 3-140: TVOC emissions to air from firing process in the wall and floor tiles sector (1/4)



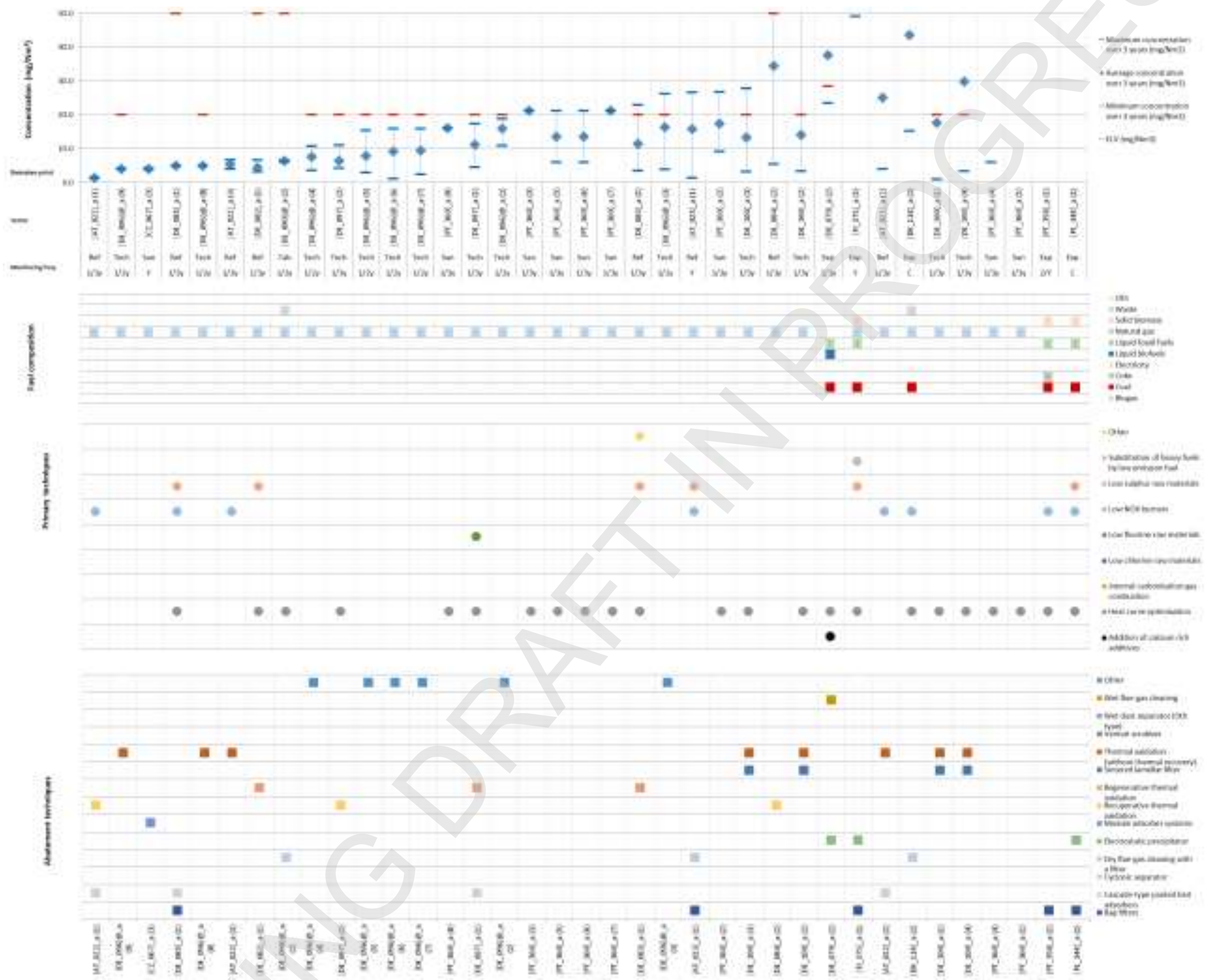
NB: For better visualisation, maximum concentration values above 50 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

Figure 3-141: TVOC emissions to air from firing process in the brick and roof tiles sector (2/4)



NB: For better visualisation, maximum concentration values above 50 mg/Nm3 are not shown.
Source: [35, TWG 2023]

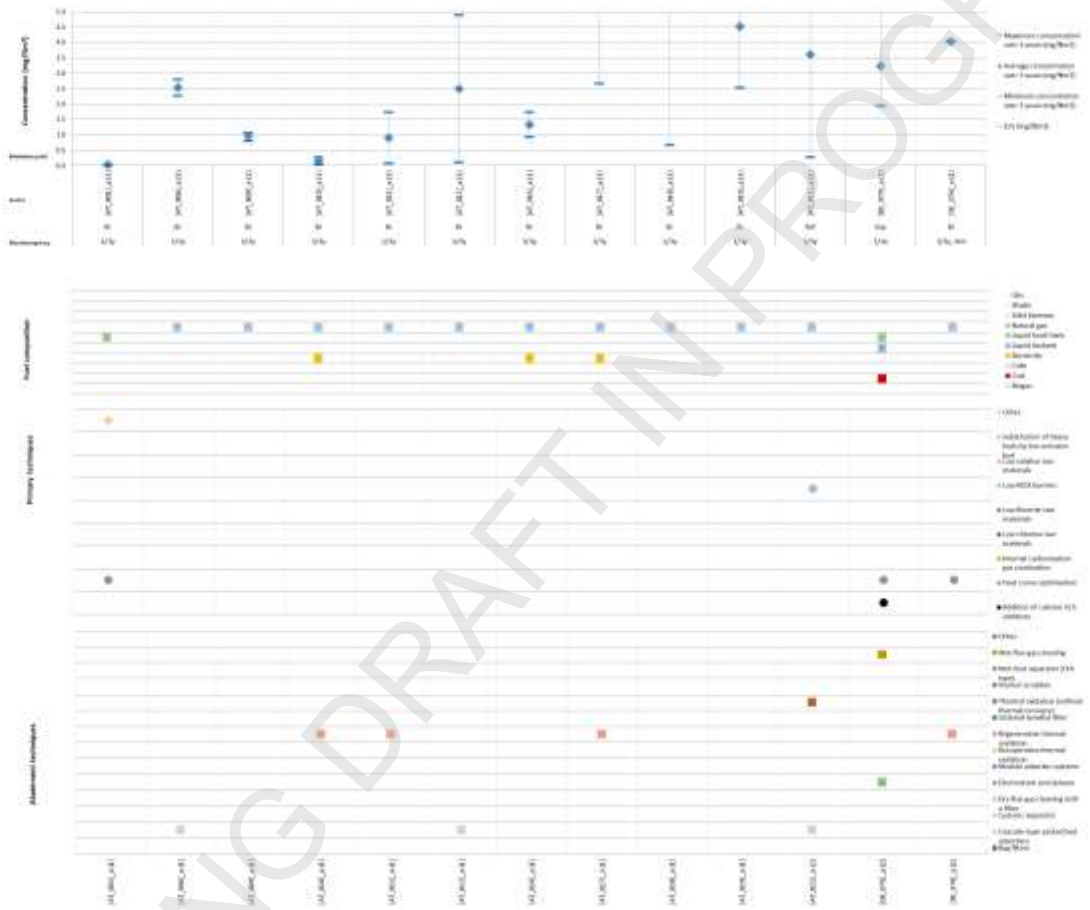
Figure 3-142: TVOC emissions to air from firing process in the brick and roof tiles sector (3/4)



NB: For better visualisation, maximum concentration values above 50 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

Figure 3-143: TVOC emissions to air from firing and drying-firing processes in other sectors (4/4)

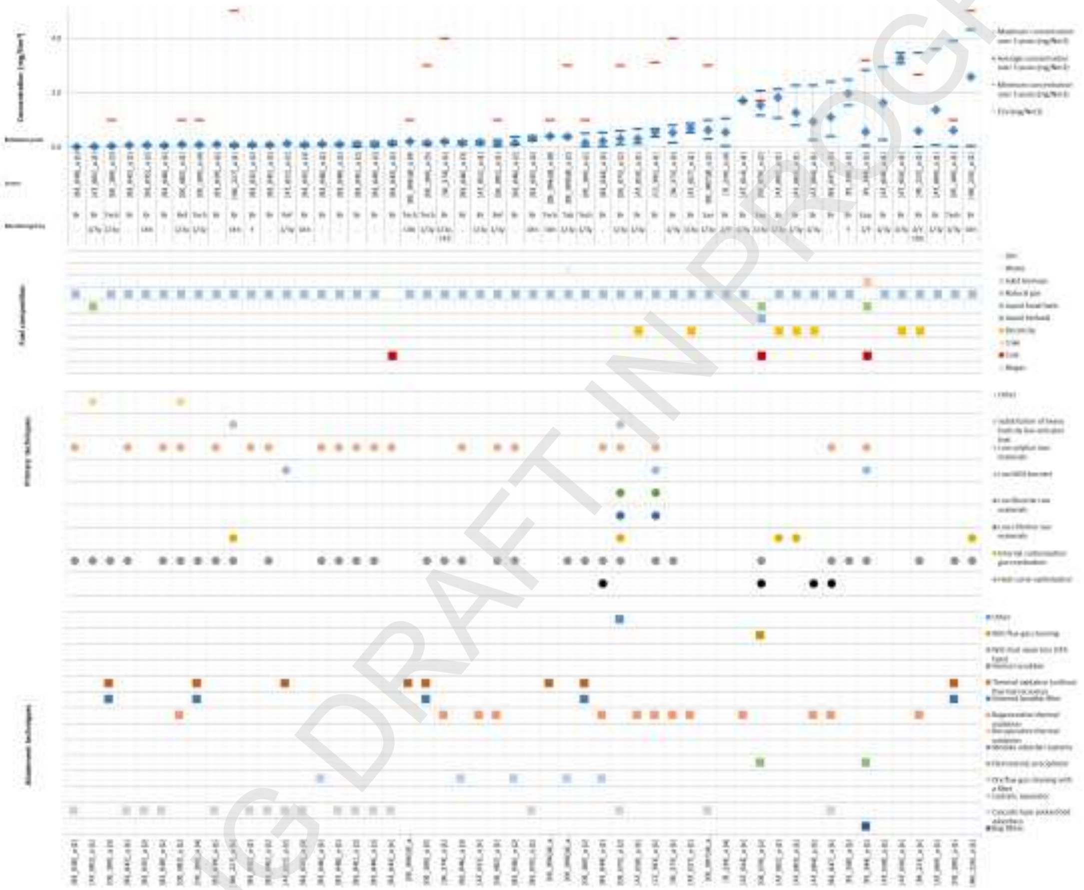
3.2.7.22 Acetaldehyde emissions to air from firing process



NB: For better visualisation, maximum concentration values above 5 mg/Nm^3 are not shown.
Source: [35, TWG 2023]

Figure 3-144: Acetaldehyde emissions to air from firing process

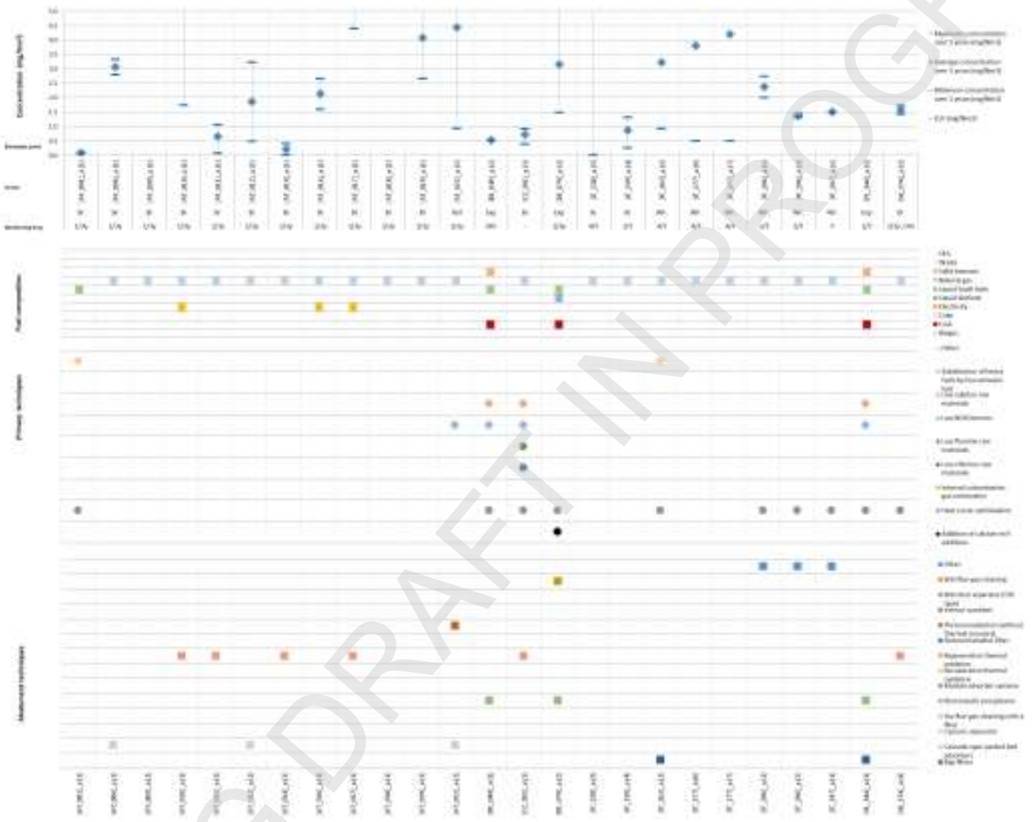
3.2.7.23 Benzene emissions to air from firing and drying-firing processes



Source: [35, TWG 2023]

Figure 3-145: Benzene emissions to air from firing and drying-firing processes

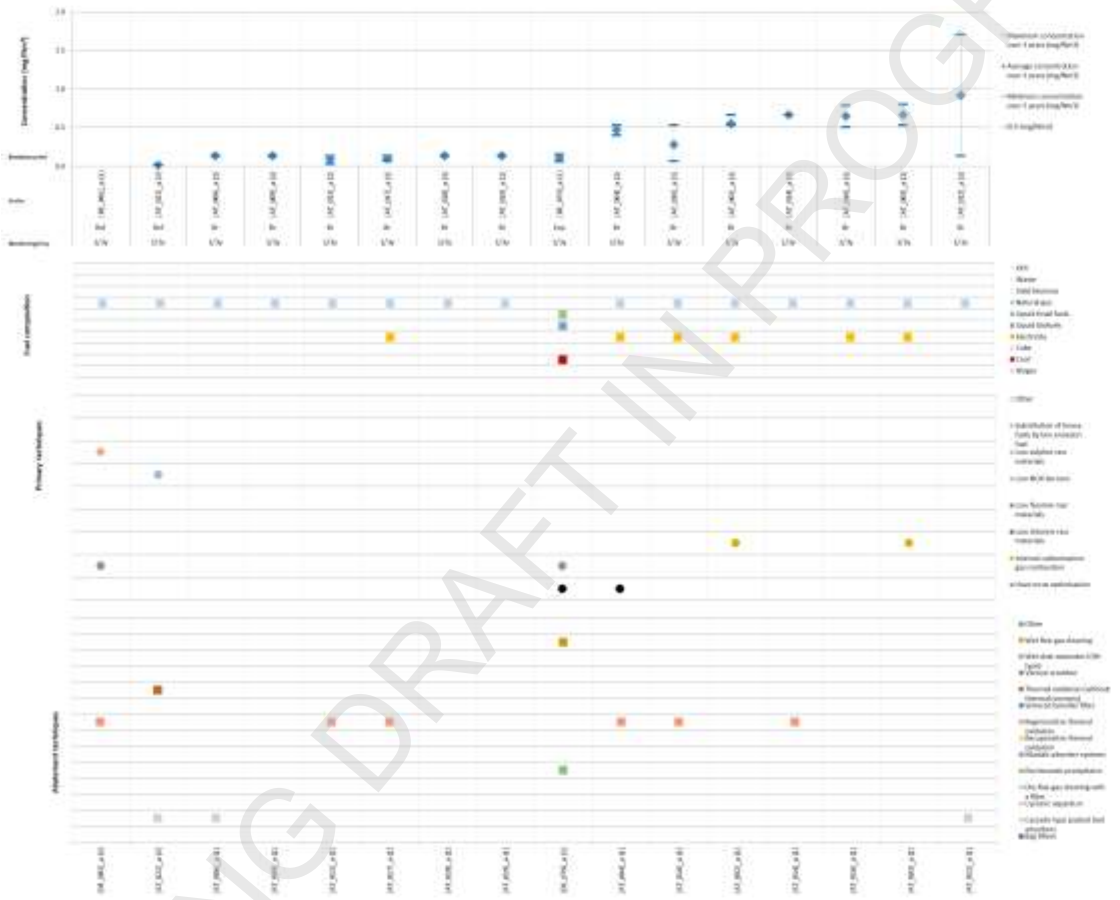
3.2.7.24 Formaldehyde emissions to air from firing process



Source: [35, TWG 2023]

Figure 3-146: Formaldehyde emissions to air from firing and drying-firing processes

3.2.7.25 Phenol emissions to air from firing and drying-firing processes



Source: [35, TWG 2023]

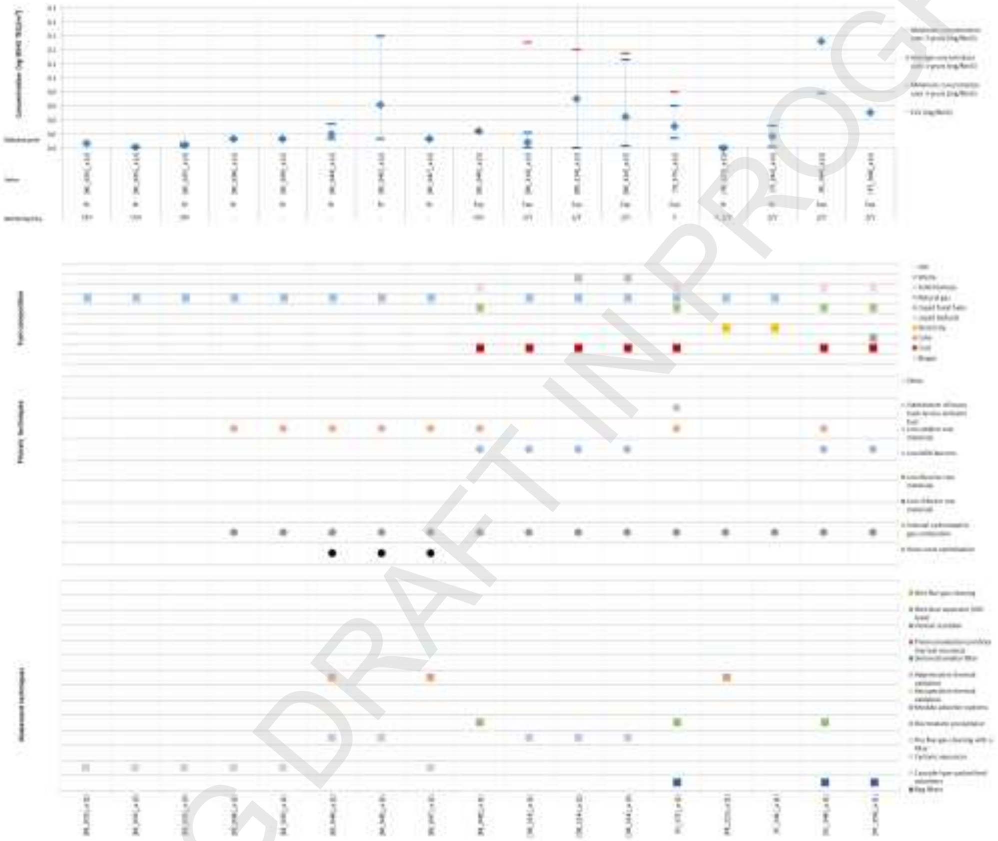
Figure 3-147: Phenol emissions to air from firing and drying-firing processes

3.2.7.26 Styrene emissions to air from firing and drying-firing processes

Source: [35, TWG 2023]

Figure 3-148: Styrene emissions to air from firing and drying-firing processes

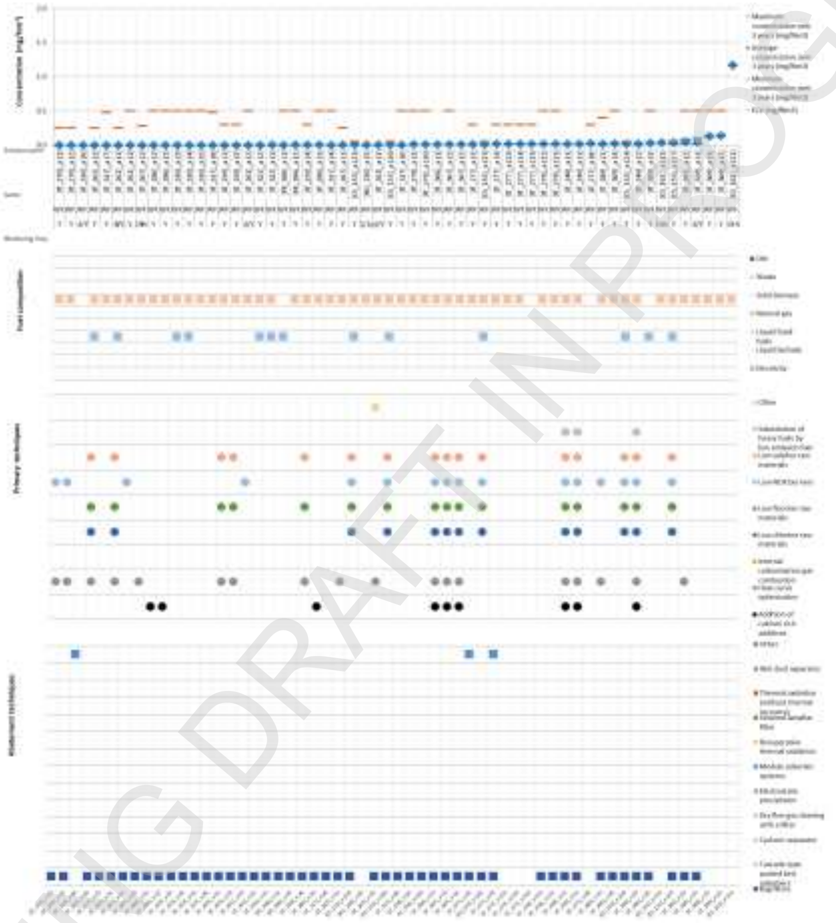
3.2.7.27 PCDD/F emissions to air from firing and drying-firing processes



Source: [35, TWG 2023]

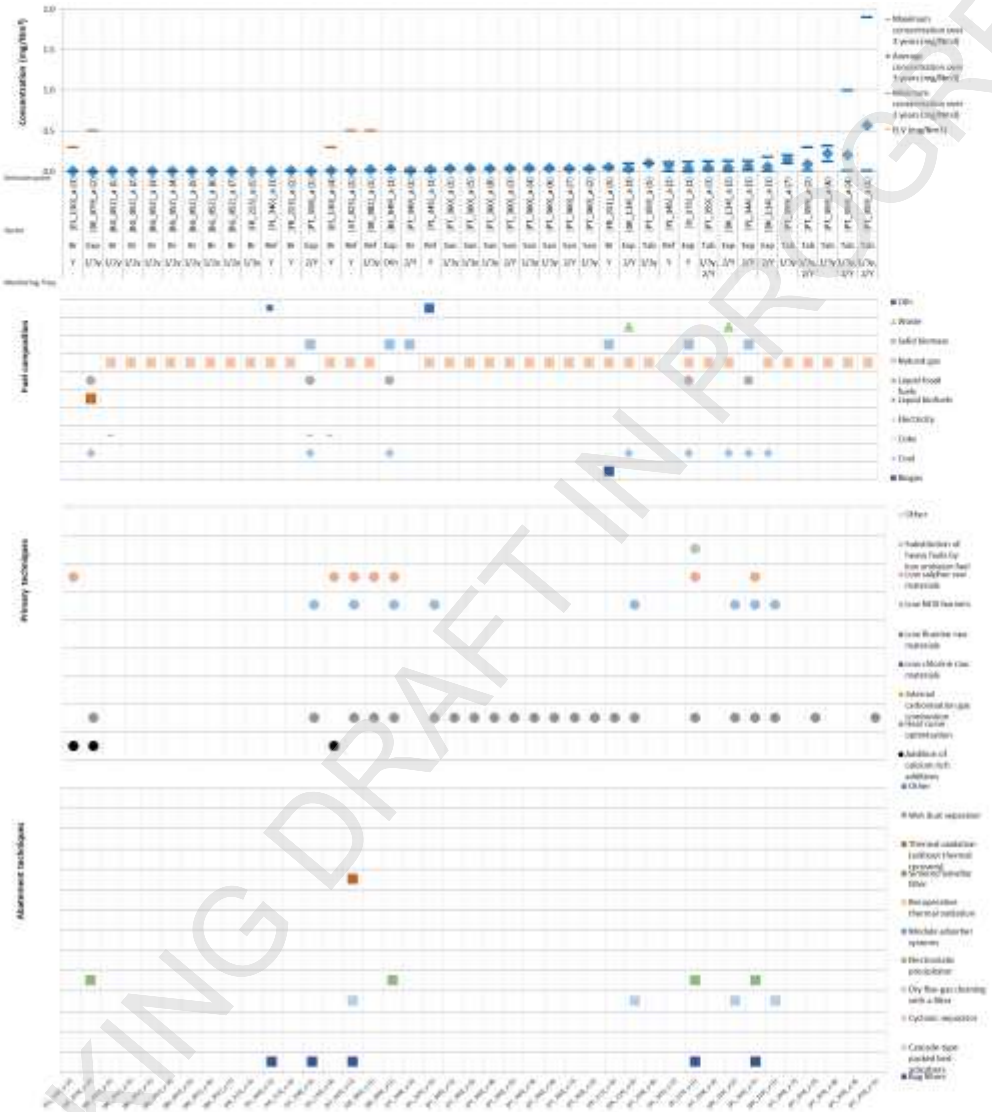
Figure 3-149: PCDD/F emissions to air from firing and drying-firing processes

3.2.7.28 Pb emissions to air from drying process



Source: [35, TWG 2023]

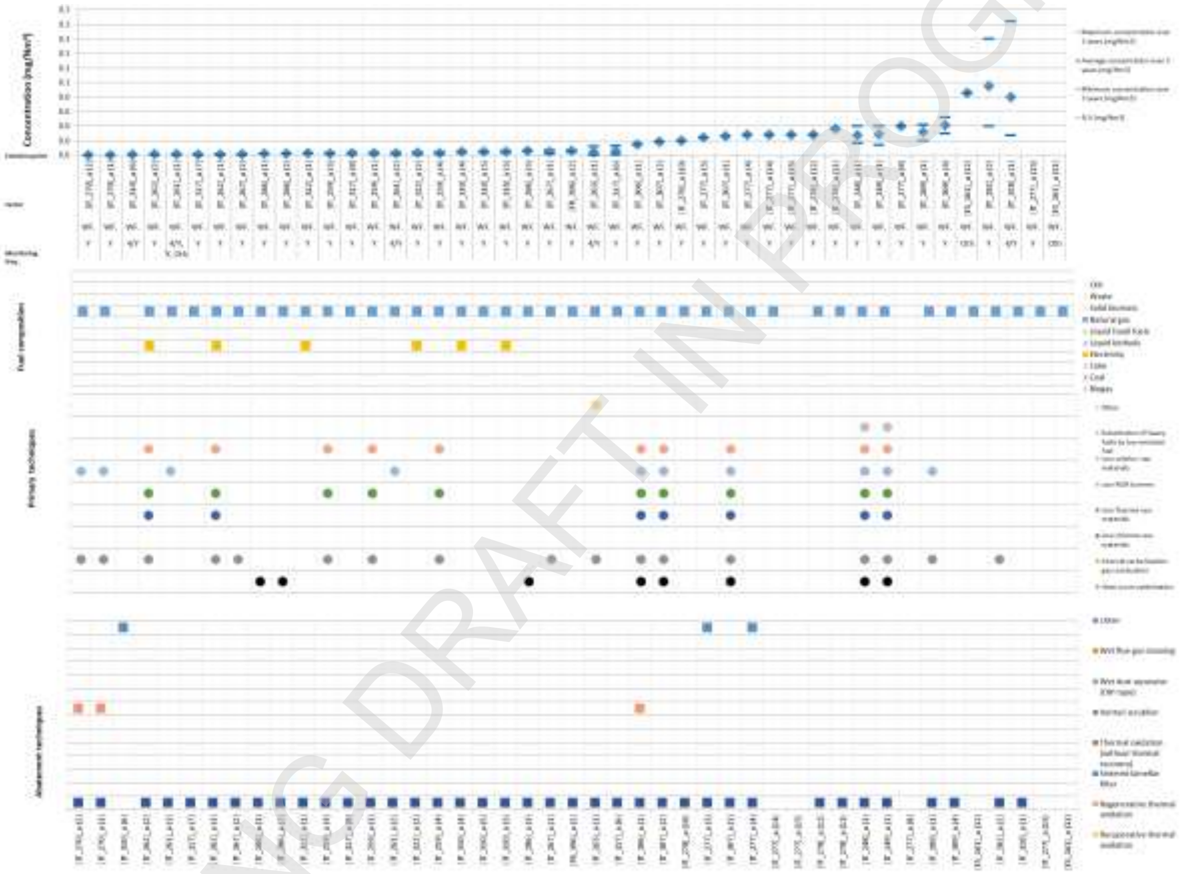
Figure 3-150: Pb emissions to air from drying process in the wall and floor tiles sector (1/2)



Source: [35, TWG 2023]

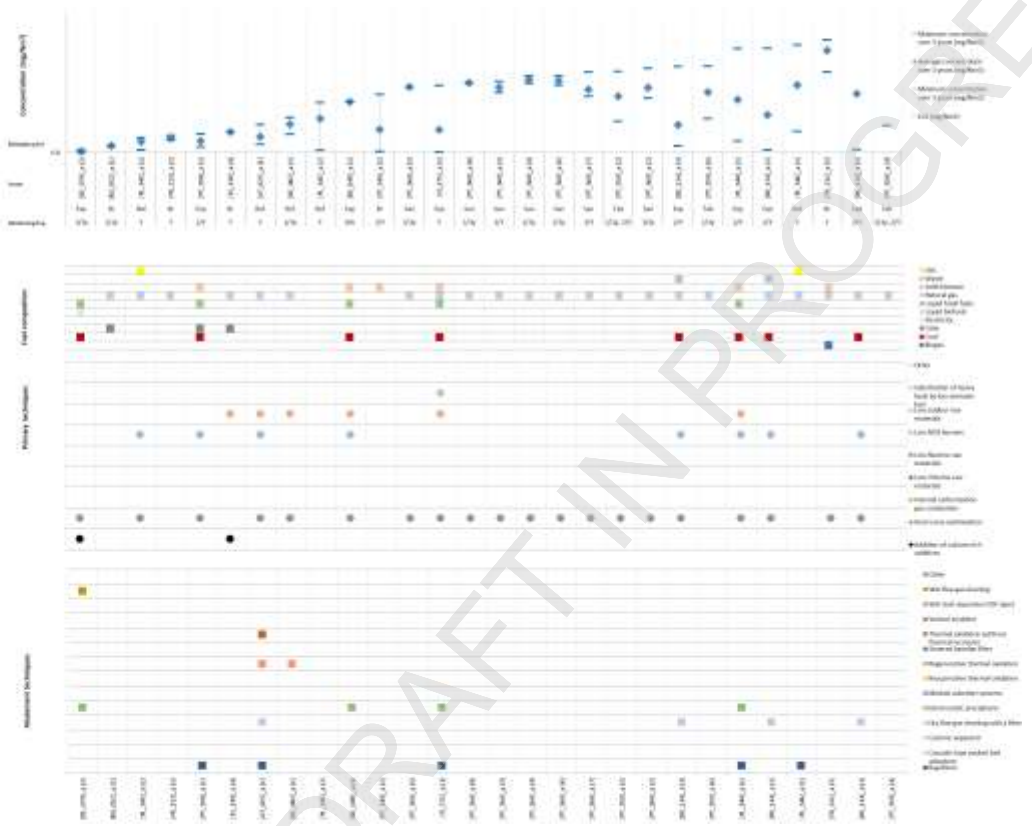
Figure 3-151: Pb emissions to air from drying process in other sectors (2/2)

3.2.7.29 Pb emissions to air from firing process



Source: [35, TWG 2023]

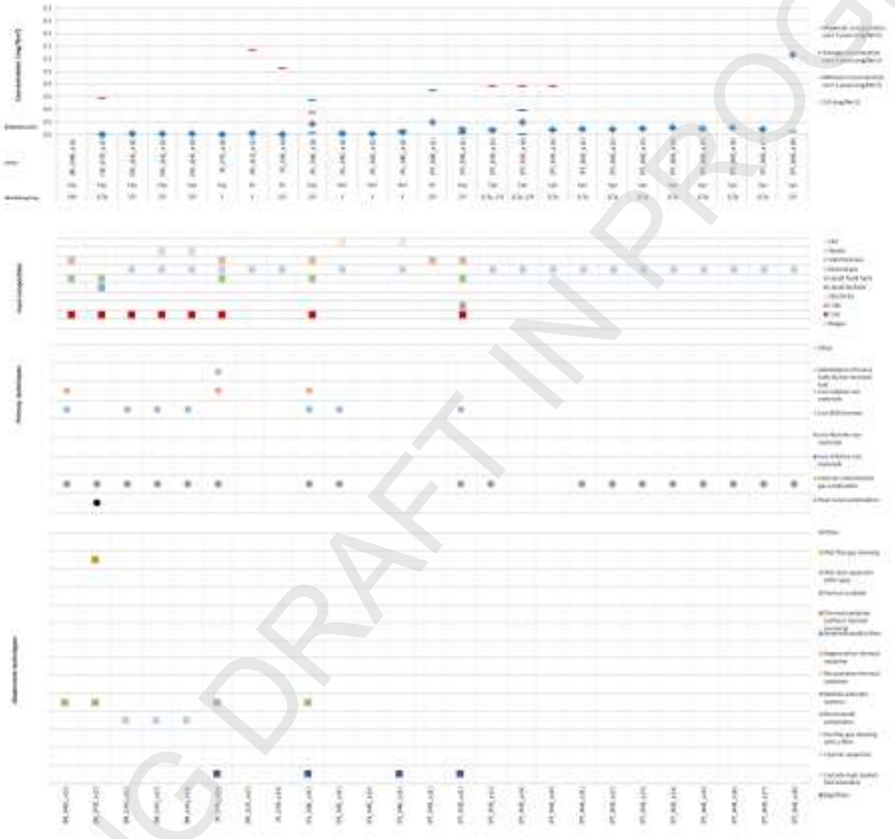
Figure 3-152: Pb emissions to air from firing process in the wall and floor tiles sector (1/2)



Source: [35, TWG 2023]

Figure 3-153: Pb emissions to air from firing and drying-firing processes in other sectors (2/2)

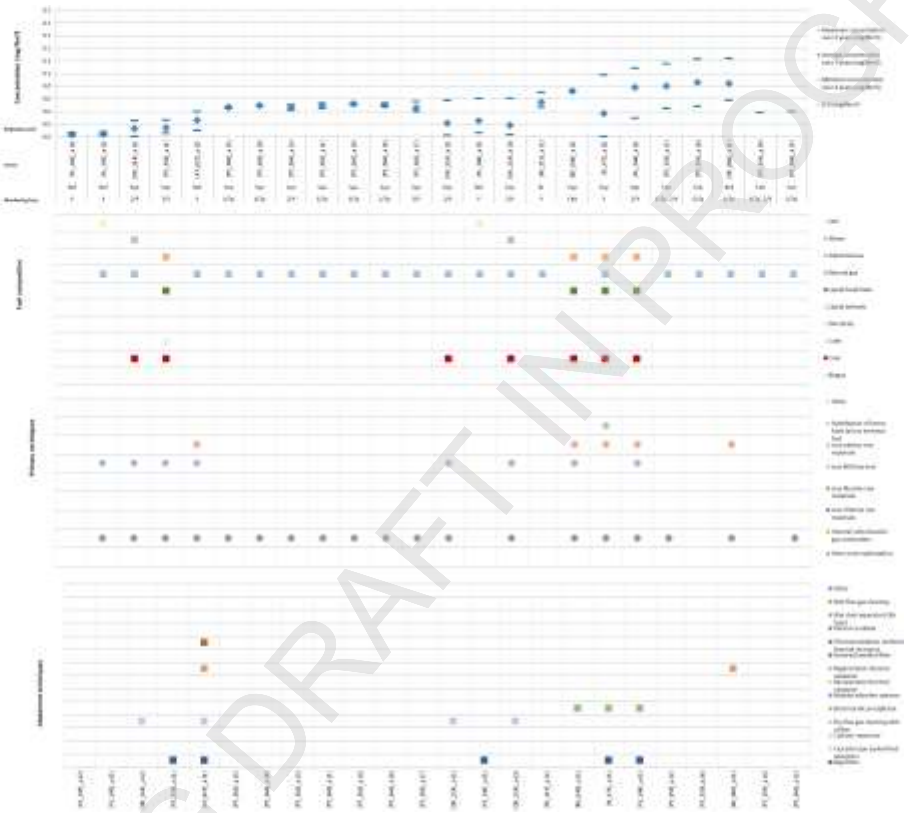
3.2.7.30 Cd emissions to air from firing and drying-firing processes



Source: [35, TWG 2023]

Figure 3-154: Cd emissions to air from firing and drying-firing processes

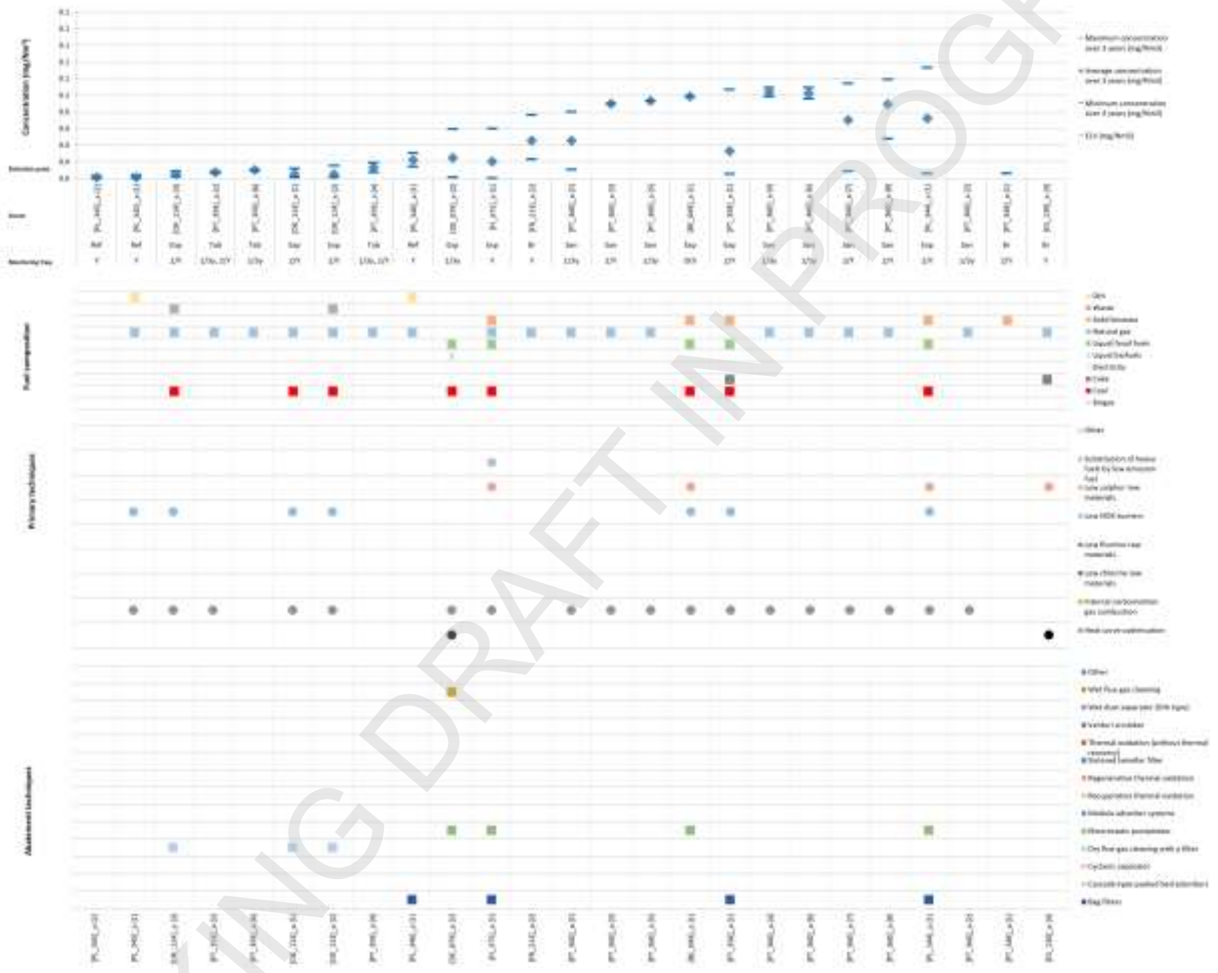
3.2.7.31 Cr emissions to air from firing and drying-firing processes



Source: [35, TWG 2023]

Figure 3-155: Cr emissions to air from firing and drying-firing processes

3.2.7.32 Ni emissions to air from firing and drying-firing processes



Source: [35, TWG 2023]

Figure 3-156: Ni emissions to air from firing and drying-firing processes

3.2.7.33 Zn emissions to air from firing and drying-firing processes

NB: Based on reported data, the abatement techniques are not specified therefore the graph is not shown in this figure.
Source: [35, TWG 2023]

Figure 3-157: Zn emissions to air from firing and drying-firing processes

3.3 Emissions to water

Water is a very important raw material in the ceramic manufacturing industries, but the amount used varies greatly between sectors and processes. The water added directly to ceramic body mixes does not lead to a waste water problem, as it ~~is~~ subsequently evaporate~~d~~s into the air during the drying and firing stages. Process waste water is generated mainly when clay materials are flushed out and suspended in flowing water during the manufacturing process and equipment cleaning, but emissions to water also occur during the operation of wet off-gas scrubbers.

Process waste water occurs in small quantities in the manufacture of bricks and roof tiles, vitrified clay pipes and refractory products, if surface treatment such as glazing and engobing, or wet grinding is carried out. Additional amounts of water arise in the cleaning ~~process~~ of the mixing, engobing and glazing units, and of the moulds. In expanded clay aggregates production, usually no process waste water is generated~~,~~; only the cooling water for the kiln system passes through an oil separator and is returned to the cooling circuit.

In the wall and floor tiles, table- and ornamentalware, sanitaryware, technical ceramics and inorganic bonded abrasives sectors, process waste water occurs mainly as cleaning water in preparation units, in casting units, in the glazing and decoration process or as grinding water in subsequent treatment.

Effluents which arise as a result of compound processing and equipment cleaning usually contain the same raw materials and auxiliary materials as those used in the process concerned. As a rule, these compounds are water-insoluble.

The waste water in the process mostly shows turbidity and colouring owing to the very fine suspended particles of glaze and clay minerals. From a chemical point of view, these are characterised by the presence of:

- suspended solids: clays, frits and insoluble silicates in general;
- dissolved anions: sulphates;
- suspended and dissolved heavy metals: e.g. lead and zinc;
- boron in small quantities;
- traces of organic matter (screen printing vehicles and glues used in glazing operations).

3.3.1 General overview

The following section presents a general overview of the collected data on emissions to water. The 199 questionnaires represent a total of 106 EPs Water and 87 of these reported concentration data. For emissions to water, the questionnaire allowed the reporting of data, aside from the key environmental parameters, on contextual information such as:

- type of waste water discharge;
- characteristics of waste water;
- monitoring frequency and abatement techniques.

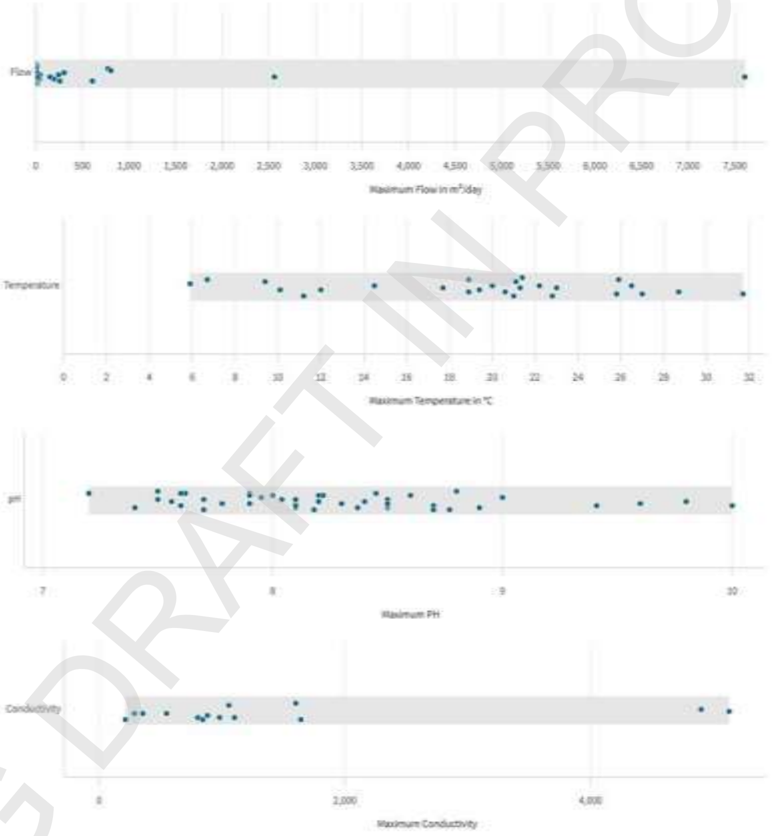
The number of emission points to water by plant can be found in the Annex, Section 4.2.

3.3.2 Type of waste water discharge

Out of 87 EPs Water, 76 EPs Water reported data about the type of waste water discharge. A total of 58 EPs Water correspond to direct discharge. Indirect discharge to urban waste water treatment plants was reported for 14 EPs Water and 4 other EPs Water reported indirect discharge to an industrial waste water treatment plant. With regards to the type of waste water treatment plant, 5 EPs Water reported that they correspond to combined waste water treatment with other waste water streams not originating from ceramics, 27 EPs Water to a dedicated waste water treatment plant, 4 EPs Water to an independently operated waste water treatment plant according to Article 6.11 of Annex I to the IED and 29 EPs Water to another option.

3.3.3 Characteristics of waste water

Figure 3-158 shows the distribution of maximum values that the EPs Water reported for waste water flow, temperature, pH and conductivity.



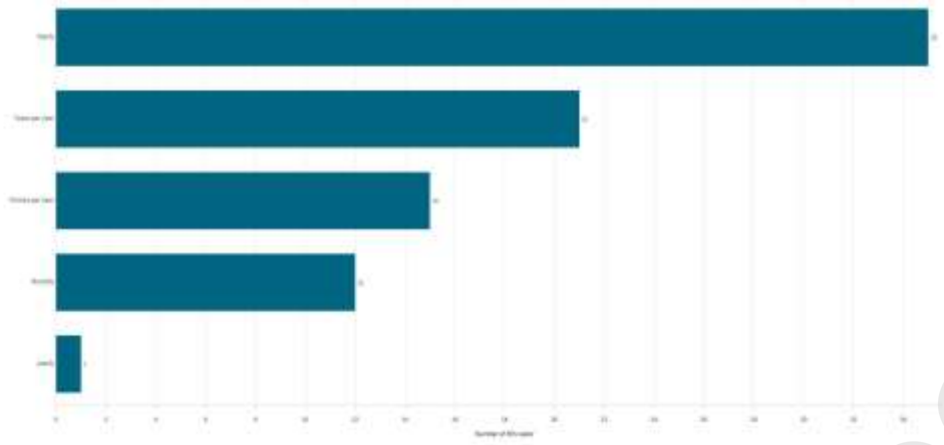
Source: [35, TWG 2023]

Figure 3-158: Distribution of maximum values for waste water characteristics

3.3.4 Monitoring frequency

The monitoring frequency in EPs Water varies from daily to once every 3 years. The most common monitoring frequencies for EPs Water are yearly and twice per year.

Figure 3-159 presents the most commonly reported monitoring frequencies reported by EPs Water for various substances/parameters included in the data collection.

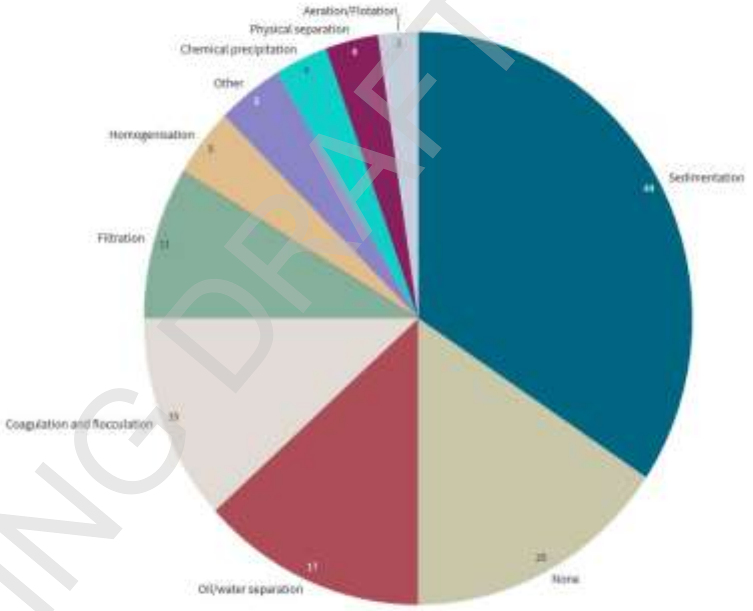


Source: [35, TWG 2023]

Figure 3-159: Monitoring frequency by EPs Water

3.3.5 Abatement techniques

Figure 3-160 presents the abatement techniques employed for EPs Water. The majority of EPs Water reported at least one applied abatement technique.



Source: [35, TWG 2023]

Figure 3-160: Abatement techniques by EPs Water

3.3.6 Analysis of key parameters

For the substances/parameters identified as key environmental issues in the scope of the CER BREF review, the next sections include the reported information for each substance/parameter as follows:

- Number of plants;

- Number of EPs Water;
- Number of EPs Water by type of waste water discharge (direct or indirect);
- Number of EPs Water by monitoring frequency;
- Number of EPs Water by main sector;
- Number of EPs Water by associated process(es);
- Distribution of maximum concentrations reported.

The number of plants that reported type of waste water discharge (i.e. direct and indirect) are shown in the tables below. The plants that reported no discharge and did not report information on the type of discharge are not shown. Therefore, the numbers in the introductory tables for each parameter may not match when summed up.

The figures for each parameter below present only the most commonly reported monitoring frequency, main sector and associated process(es). For better visualisation, the abatement techniques applied and type of waste water discharge by EPs Water are shown in separate graphs and figures in Section 3.1.7.

3.3.6.1 Adsorbable organically bound halogens (AOX)

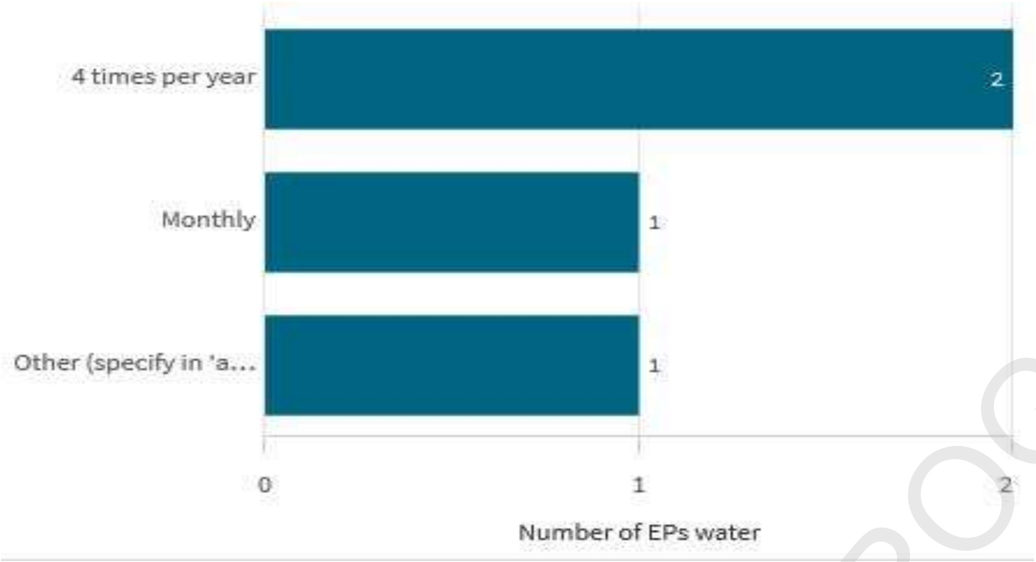
AOX emissions to water may originate from the raw materials used (e.g. formed through the reaction of chlorine with organic substances/parameters). Therefore, AOX may be a relevant parameter for waste water released from cleaning and surface treatment applications. [35, TWG 2023], [44, COM 2020].

Table 3-27 presents a summary of reported data for AOX emissions. The reported levels for AOX emissions are presented in Section 3.3.7.1.

Table 3-27: Summary of data for AOX emissions

AOX emissions	
Number of plants	5
Number of EPs Water	5
Direct discharge	3
Indirect discharge	1
Source: [35, TWG 2023]	

Figure 3-161, Figure 3-162, Figure 3-163 and Figure 3-164 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.

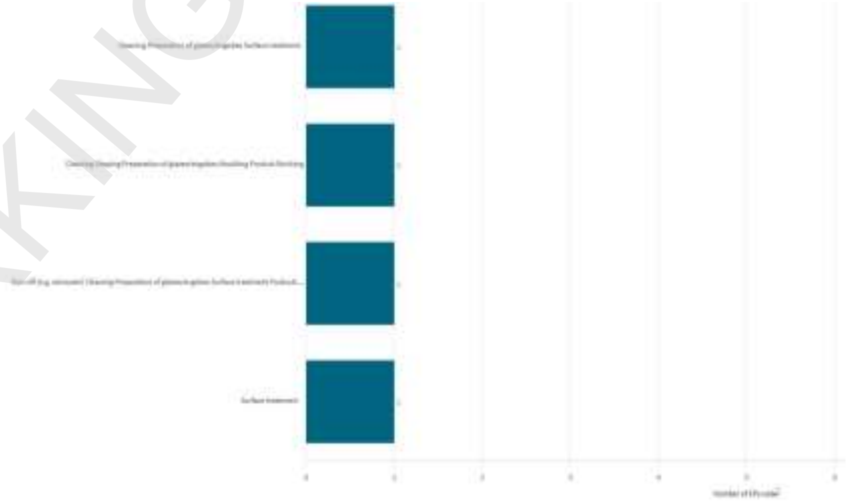


Source: [35, TWG 2023]

Figure 3-161: Monitoring frequency for AOX emissions

Source: [35, TWG 2023]

Figure 3-162: Number of AOX emission points by main sector



Source: [35, TWG 2023]

Figure 3-163: Number of emission points for AOX by associated process(es)

Source: [35, TWG 2023]

Figure 3-164: Distribution of maximum concentrations for AOX emissions

3.3.6.2 Total organic carbon (TOC) and Chemical oxygen demand (COD)

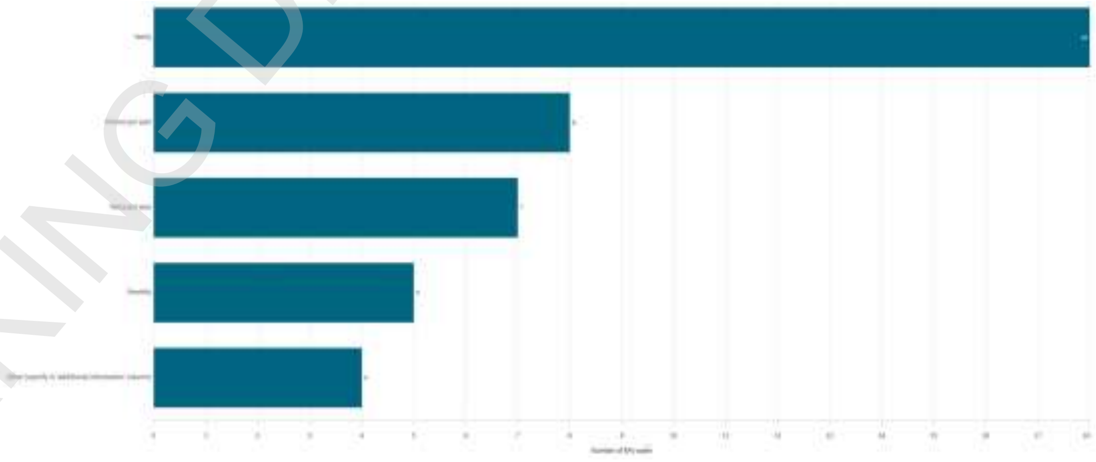
Organic matter may be released in waste water from the production of ceramics due to impurities in the raw materials and the use of organic substances/additives.

Table 3-28 presents a summary of reported data for TOC and COD emissions. The reported levels for COD emissions are presented in Section 3.3.7.2.

Table 3-28: Summary of data for TOC and COD emissions

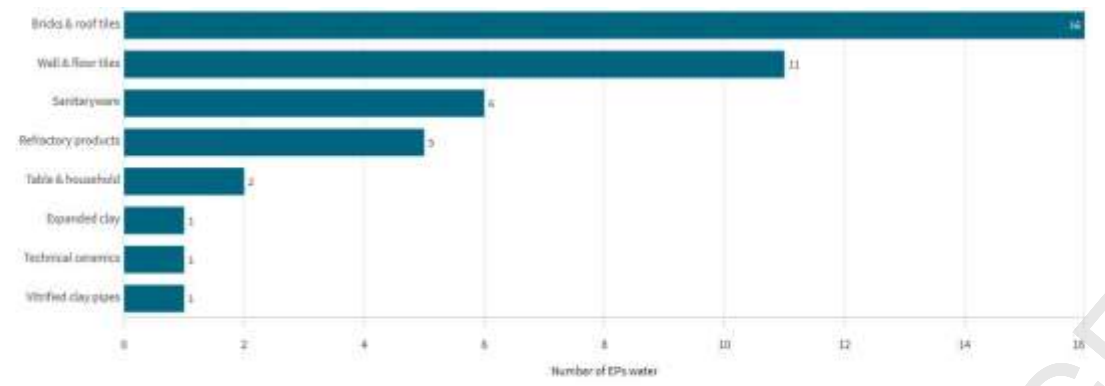
	TOC emissions	COD emissions
Number of plants	3	32
Number of EPs Water	4	41
Direct discharge	1	27
Indirect discharge	3	7
Source: [35, TWG 2023]		

Figure 3-165, Figure 3-166, Figure 3-167 and Figure 3-168 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



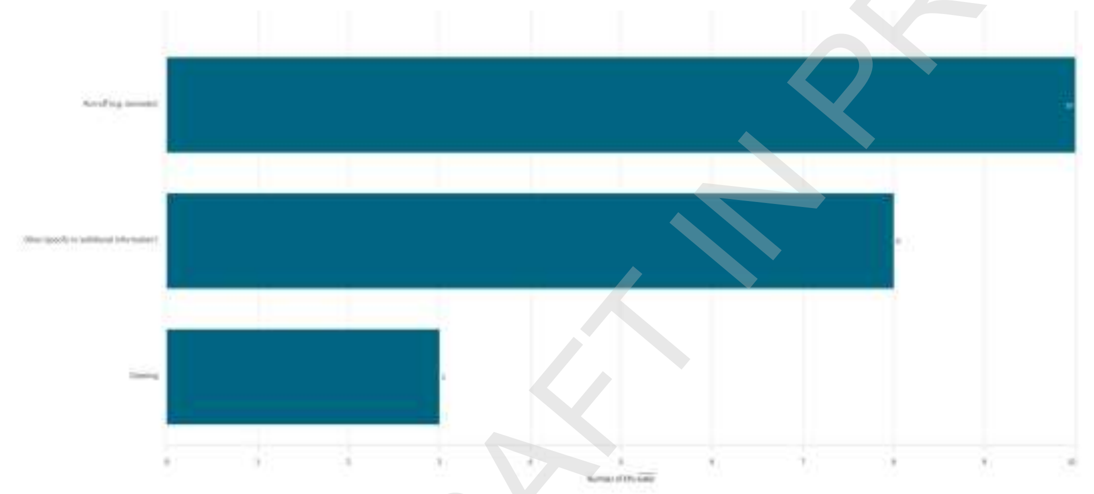
Source: [35, TWG 2023]

Figure 3-165: Monitoring frequency for TOC and COD emissions



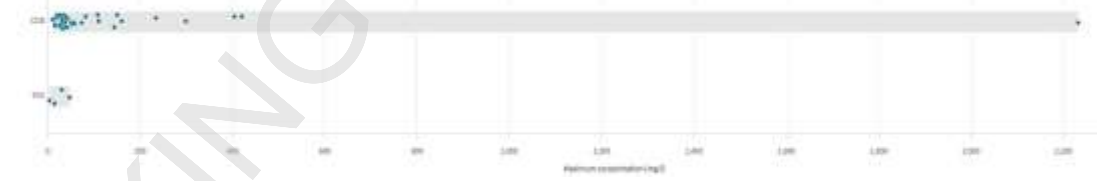
Source: [35, TWG 2023]

Figure 3-166: Number of TOC and COD emission points by main sector



Source: [35, TWG 2023]

Figure 3-167: Number of TOC and COD emission points by associated process(es)



Source: [35, TWG 2023]

Figure 3-168: Distribution of maximum concentrations for TOC and COD emissions

3.3.6.3 Hydrocarbon oil index (HOI) and Oils/Total hydrocarbons

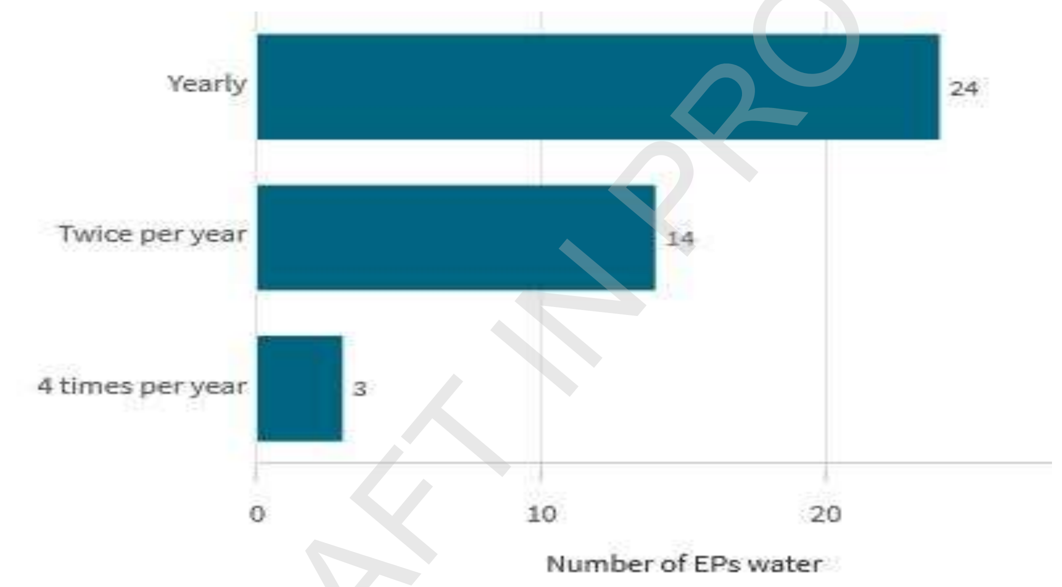
Total hydrocarbons may be released in run-off water from storage areas and in cleaning water. The reported levels for HOI are presented in Section 3.3.7.4.

Table 3-29 presents a summary of reported data for HOI and Oils/Total hydrocarbons emissions.

Table 3-29: Summary of data for HOI and Oils/Total hydrocarbons emissions

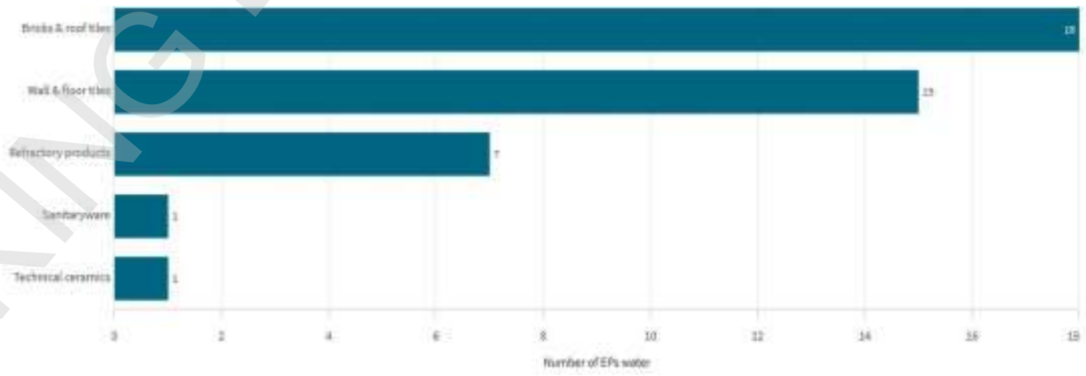
	HOI emissions	**Oils/ Total hydrocarbons emissions**
Number of plants	10	14
Number of EPs to Water	19	23
Direct discharge	15	17
Indirect discharge	4	-
Source: [35, TWG 2023]		

Figure 3-169, Figure 3-170, Figure 3-171 and Figure 3-172 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



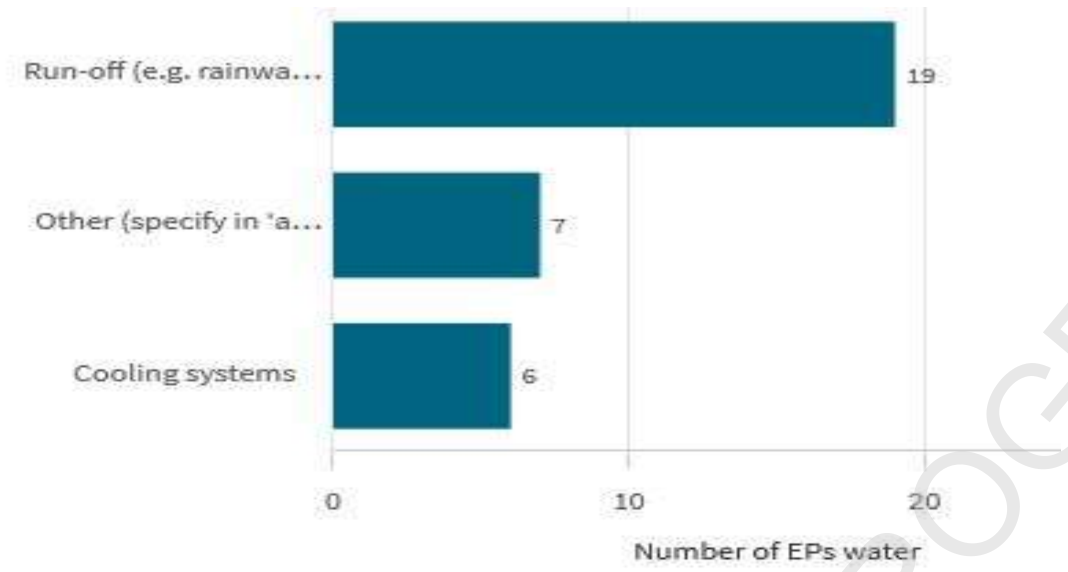
Source: [35, TWG 2023]

Figure 3-169: Monitoring frequency for HOI and Oils/Total hydrocarbons emissions



Source: [35, TWG 2023]

Figure 3-170: Number of emission points for HOI and Oils/Total hydrocarbons emissions by main sector



Source: [35, TWG 2023]

Figure 3-171: Number of HOI and Oils/Total hydrocarbons emission points by associated process(es)

Source: [35, TWG 2023]

Figure 3-172: Distribution of maximum concentrations for HOI and Oils/Total hydrocarbons emissions

3.3.6.4 Total suspended solids (TSS)

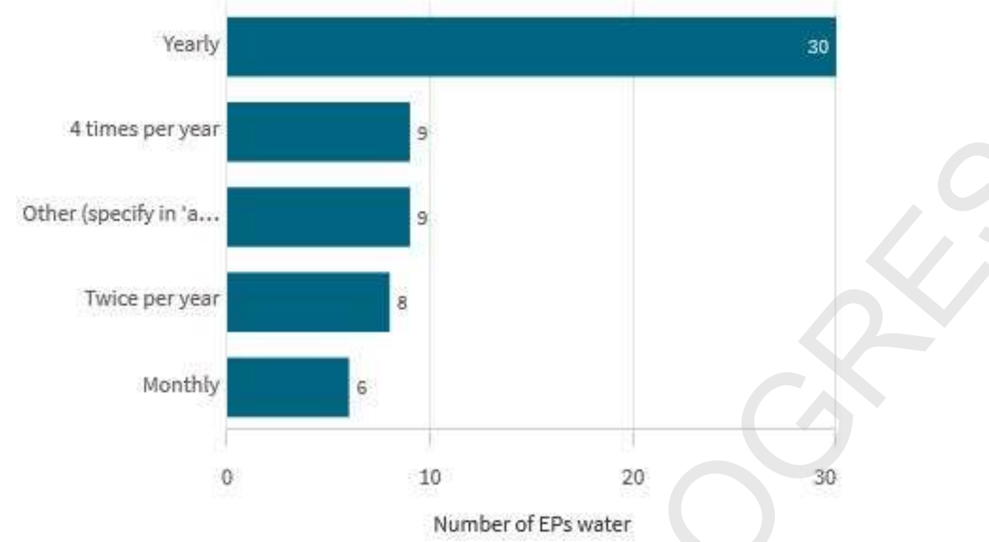
TSS emissions may originate from the raw materials used.

Table 3-30 presents a summary of reported data for TSS emissions. The reported levels of TSS emissions are presented in Section 3.3.7.5.

Table 3-30: Summary of data for TSS emission points

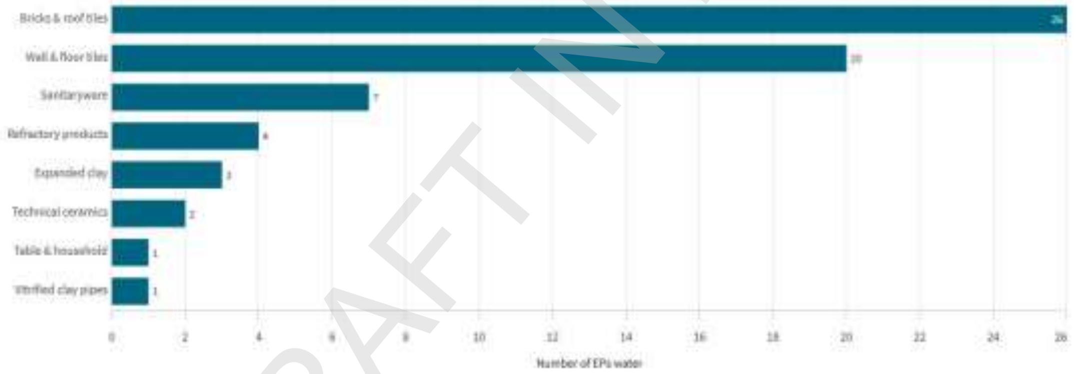
TSS emissions	
Number of plants	43
Number of EPs Water	64
Direct discharge	45
Indirect discharge	9
Source: [35, TWG 2023]	

Figure 3-173, Figure 3-174, Figure 3-175 and Figure 3-176 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



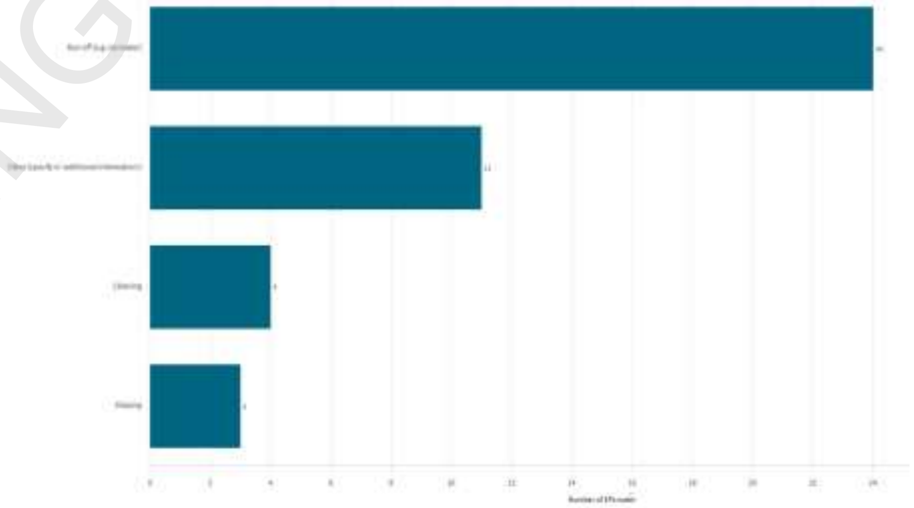
Source: [35, TWG 2023]

Figure 3-173: Monitoring frequency for TSS emissions



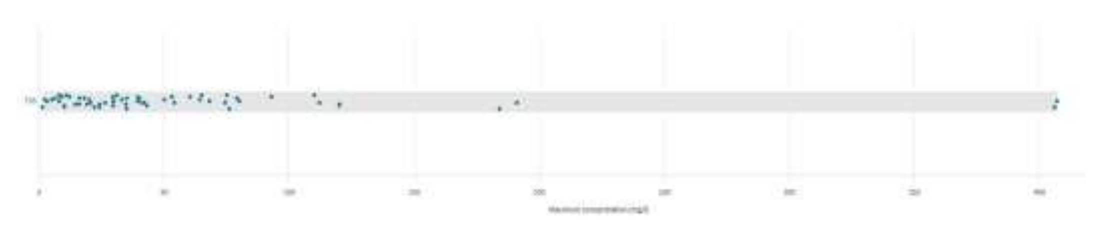
Source: [35, TWG 2023]

Figure 3-174: Number of TSS emission points by main sector



Source: [35, TWG 2023]

Figure 3-175: Number of TSS emission points by associated process(es)



Source: [35, TWG 2023]

Figure 3-176: Distribution of maximum concentrations for TSS emissions

3.3.6.5 Boron and its compounds (B)

Emissions of Boron and its compounds (B) may be released in the manufacturing of bricks and roof tiles, wall and floor tiles, refractory products, technical ceramics, household ceramics and sanitaryware. Boron and its compounds emissions to water may originate from glazing units since boron compounds are mainly used as fluxing agent in frits. [35, TWG 2023], [44, COM 2020].

According to the reported data for B emissions to water, only three plants and two emission points reported data on concentration values. B emissions are released e.g. during cleaning, product finishing and process(es)preparation of glazes in walls and floor tiles and sanitaryware sectors. The most commonly reported monitoring frequencies were monthly and 4 times per year. Table 3-31 presents a summary of reported data for B emissions.

Table 3-31: Summary of data for B emissions to water

B emissions	
Number of plants	2
Number of EPs Water	2
Direct discharge	1
Indirect discharge	1

Source: [35, TWG 2023]

Figure 3-177 shows the maximum concentration reported.

Source: [35, TWG 2023]

Figure 3-177: Distribution of maximum concentrations for B emissions to water

3.3.6.6 Cadmium (Cd)

[Note to the TWG: please provide further information on origin of the pollutant.]

Metal emissions to water may originate from glazing and other decoration steps. For instance, ceramic pigment systems used for the decoration might have various metal and metalloid compounds.

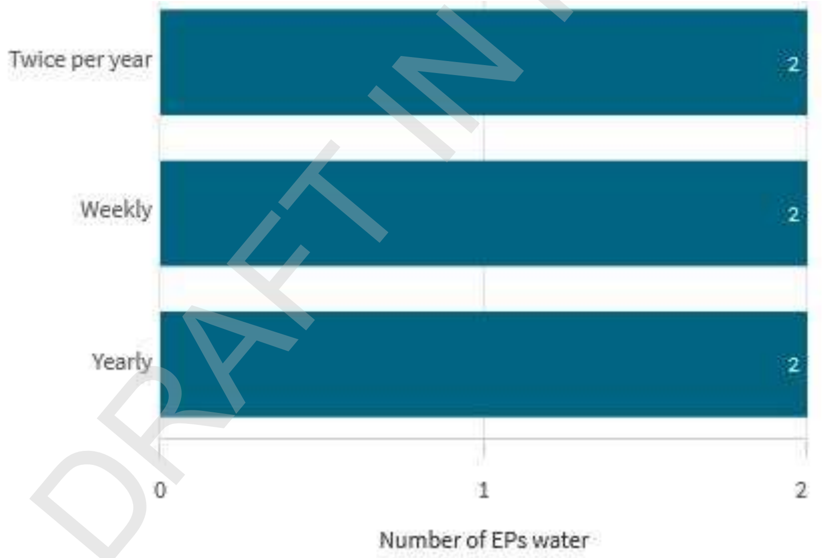
Commonly reported associated process(es) for cadmium emissions are as follows: preparation of glazes, surface treatment, shaping, moulding, product finishing, cooling system and run-off (e.g. rainwater).

Table 3-32 presents a summary of reported data for Cd emissions. The reported levels for Cd emissions to water are presented in Section 3.3.7.6.

Table 3-32: Summary of data for Cd emissions to water

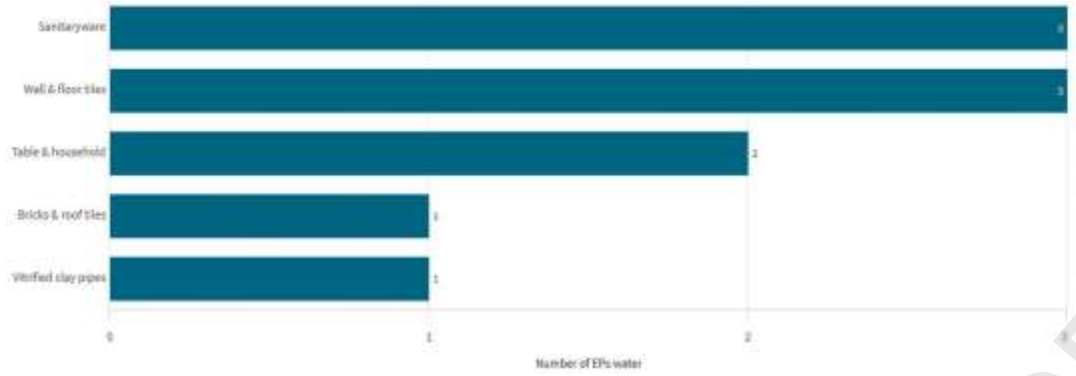
Cd emissions	
Number of plants	9
Number of EPs Water	10
Direct discharge	6
Indirect discharge	4
Source: [35, TWG 2023]	

Figure 3-178, Figure 3-179, Figure 3-180 and Figure 3-181 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



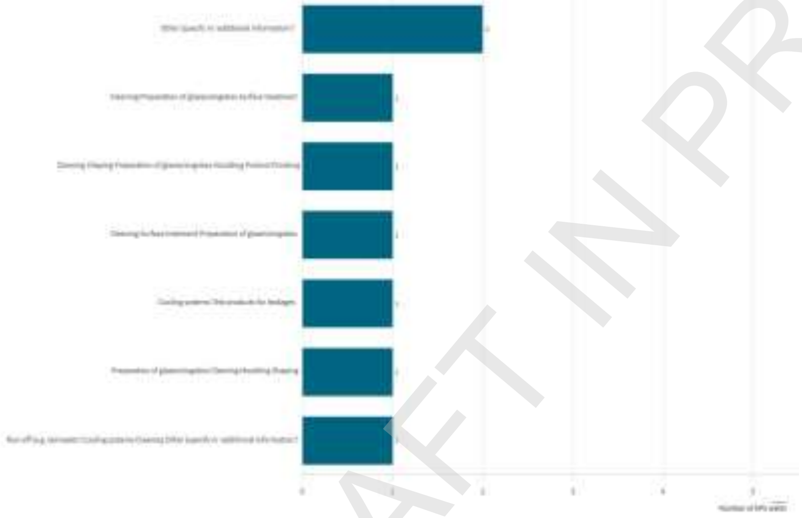
Source: [35, TWG 2023]

Figure 3-178: Monitoring frequency for Cd emissions to water



Source: [35, TWG 2023]

Figure 3-179: Number of emission points for Cd emissions to water by main sector



Source: [35, TWG 2023]

Figure 3-180: Number of emission points for Cd emissions to water by associated process(es)

Source: [35, TWG 2023]

Figure 3-181: Distribution of maximum concentrations for Cd emissions to water

3.3.6.7 Chromium (Cr)

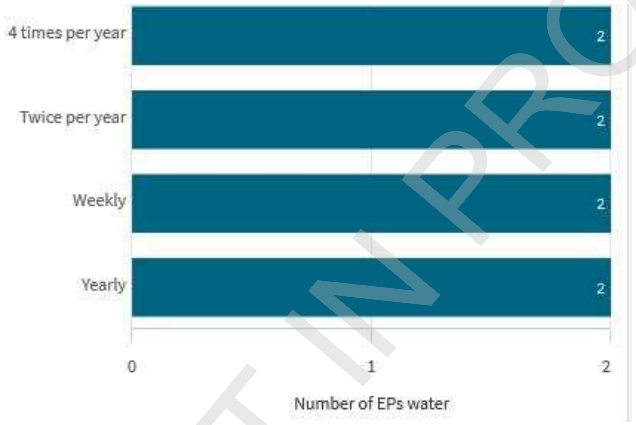
[Note to the TWG: please provide further information on origin of the pollutant.]

Metal emissions to water may originate from glazing and decoration steps. Commonly reported associated process(es) for cadmium emissions are as follows: cleaning, cooling systems, run-off. Other associated process(es) for released chromium emissions are: preparation of glazes, wet grinding/milling sawing and other steps. Table 3-33 presents a summary of reported data for Cr emissions.

Table 3-33: Summary of data for Cr emissions to water

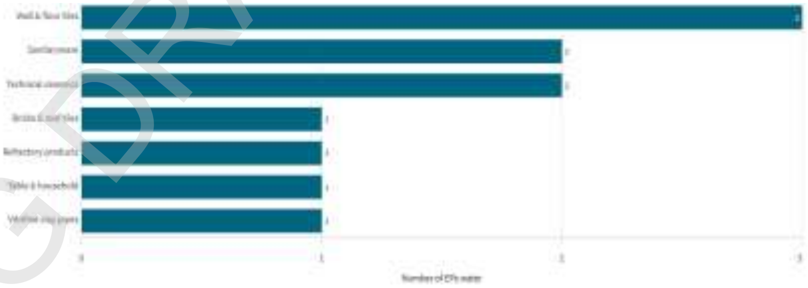
Cr emissions	
Number of plants	10
Number of EPs Water	11
Direct discharge	4
Indirect discharge	6
Source: [35, TWG 2023]	

Figure 3-182, Figure 3-183, Figure 3-184 and Figure 3-185 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



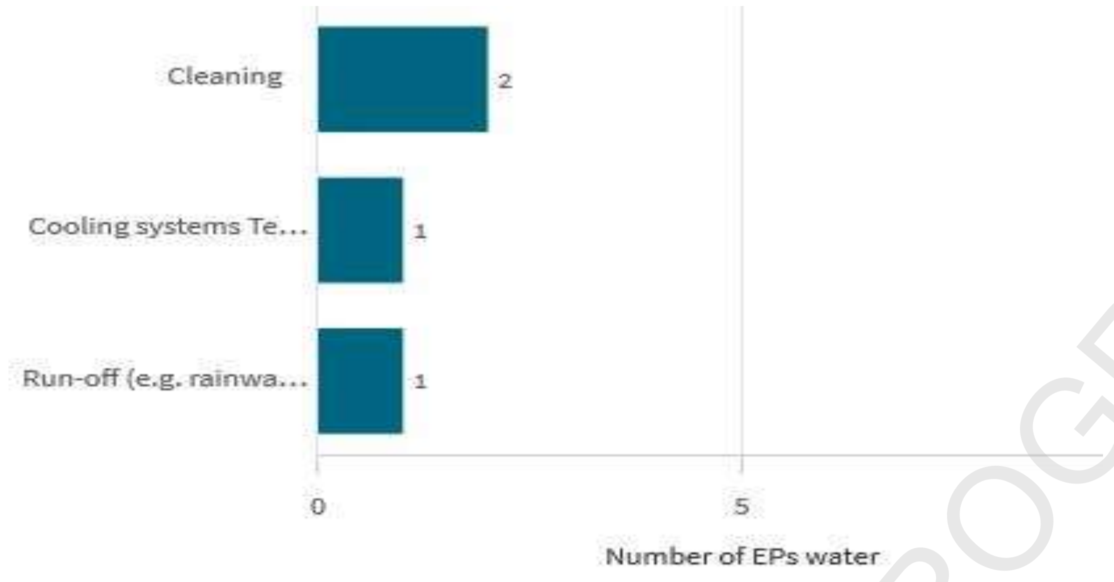
Source: [35, TWG 2023]

Figure 3-182: Monitoring frequency for Cr emissions to water



Source: [35, TWG 2023]

Figure 3-183: Number of emission points for Cr emissions to water by main sector



Source: [35, TWG 2023]

Figure 3-184: Number of emission points for Cr emissions to water by associated process(es)

Source: [35, TWG 2023]

Figure 3-185: Distribution of maximum concentrations for Cr emissions to water

3.3.6.8 Copper (Cu)

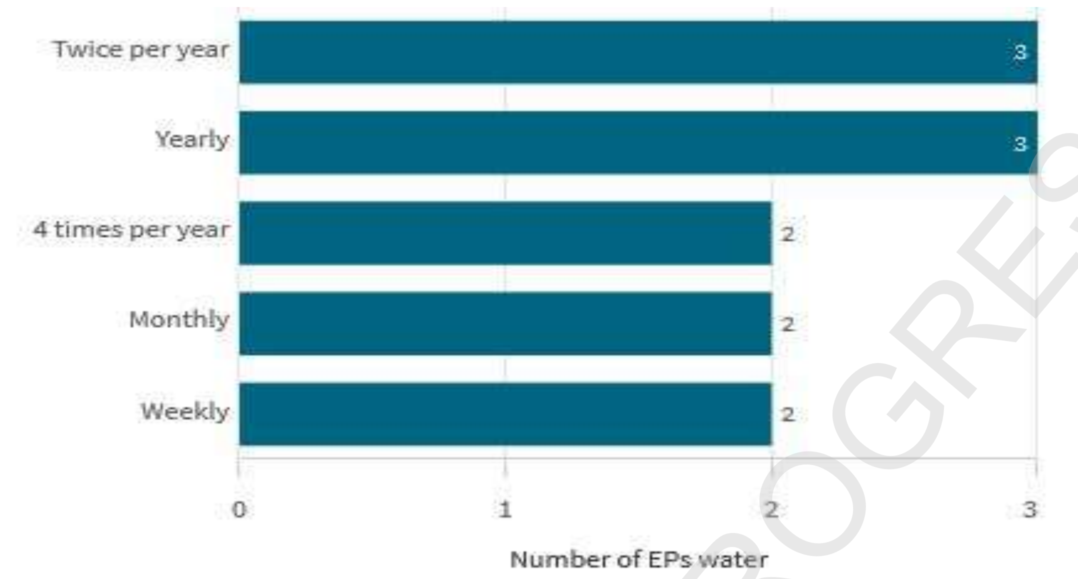
[Note to the TWG: please provide further information on origin of the pollutant.]

Metal emissions to water may originate from glazing and decoration steps. Table 3-34 presents a summary of reported data for Cu emissions.

Table 3-34: Summary of data for Cu emissions to water

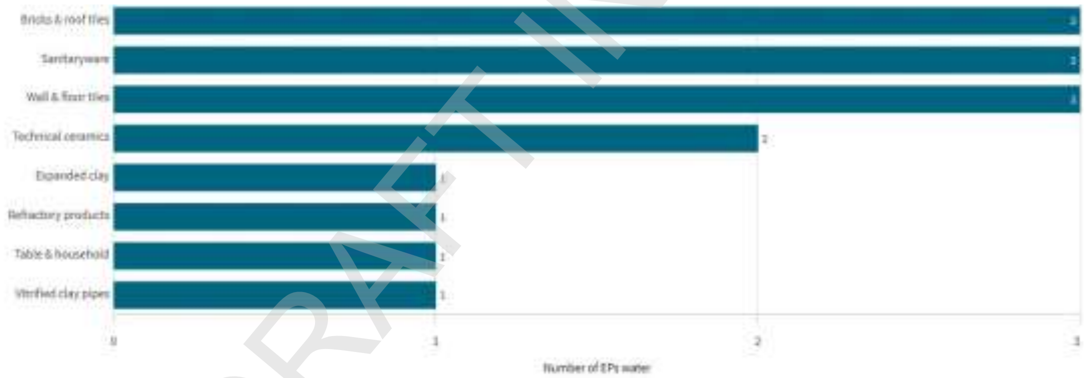
Cu emissions	
Number of plants	14
Number of EPs Water	15
Direct discharge	7
Indirect discharge	7
Source: [35, TWG 2023]	

Figure 3-186, Figure 3-187, Figure 3-188 and Figure 3-189 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



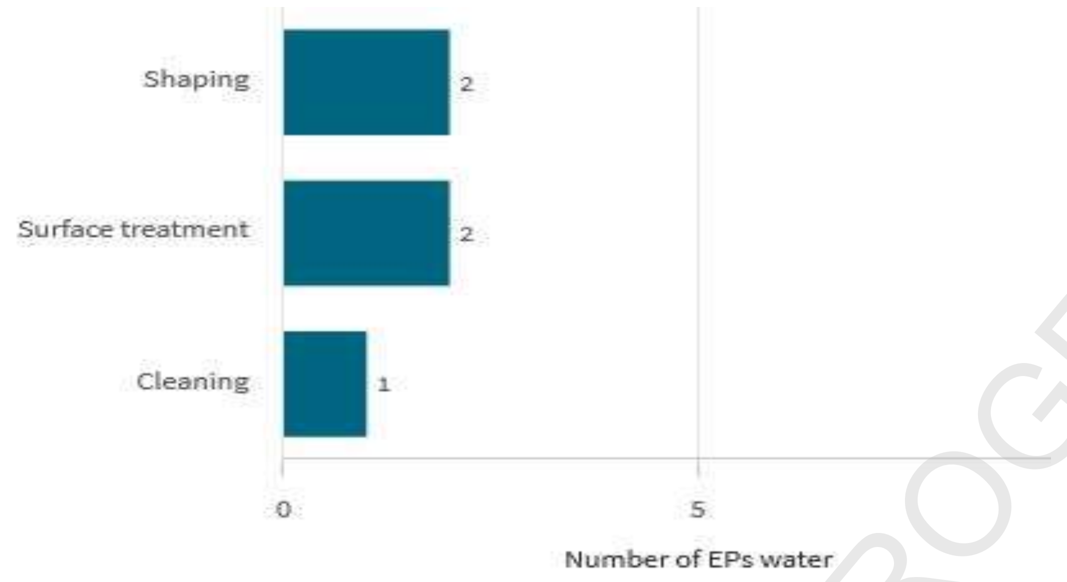
Source: [35, TWG 2023]

Figure 3-186: Monitoring frequency for Cu emissions to water



Source: [35, TWG 2023]

Figure 3-187: Number of emission points for Cu emissions to water by main sector



Source: [35, TWG 2023]

Figure 3-188: Number of emission points for Cu emissions to water by associated process(es)

Source: [35, TWG 2023]

Figure 3-189: Distribution of maximum concentrations for Cu emissions to water

3.3.6.9 Lead (Pb)

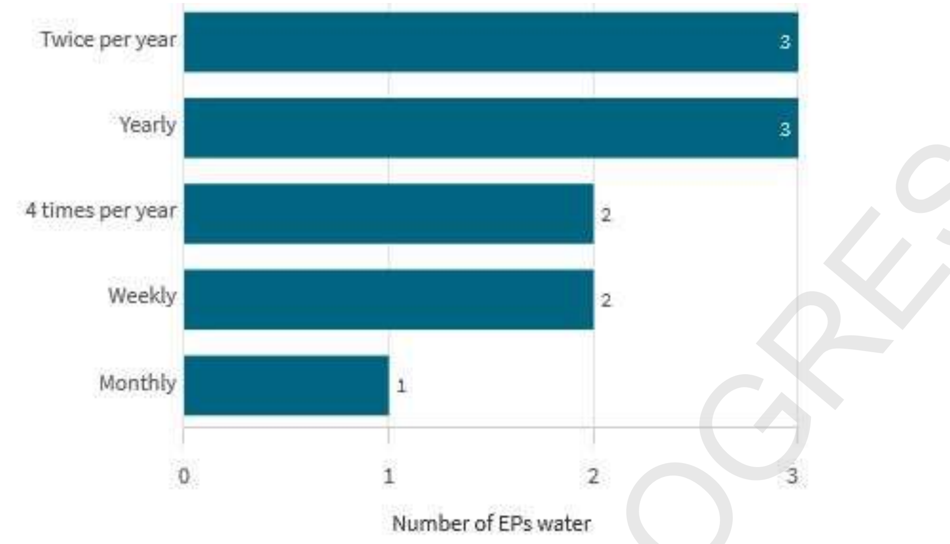
[Note to the TWG: please provide further information on origin of the pollutant.]

Metal emissions to water may originate from glazing and decoration steps. The reported levels for Pb emissions are presented in Section 3.3.7.7. Table 3-35 presents a summary of reported data for Pb emissions.

Table 3-35: Summary of data for Pb emissions to water

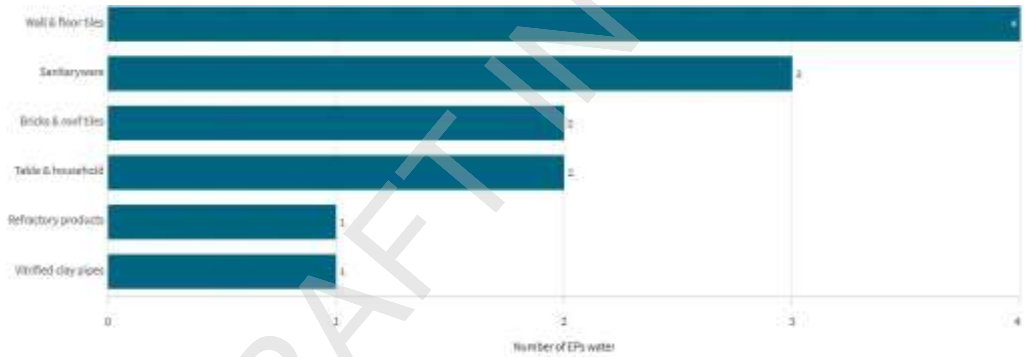
Pb emissions	
Number of plants	12
Number of EPs Water	13
Direct discharge	6
Indirect discharge	6
Source: [35, TWG 2023]	

Figure 3-190, Figure 3-191, Figure 3-192 and Figure 3-193 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



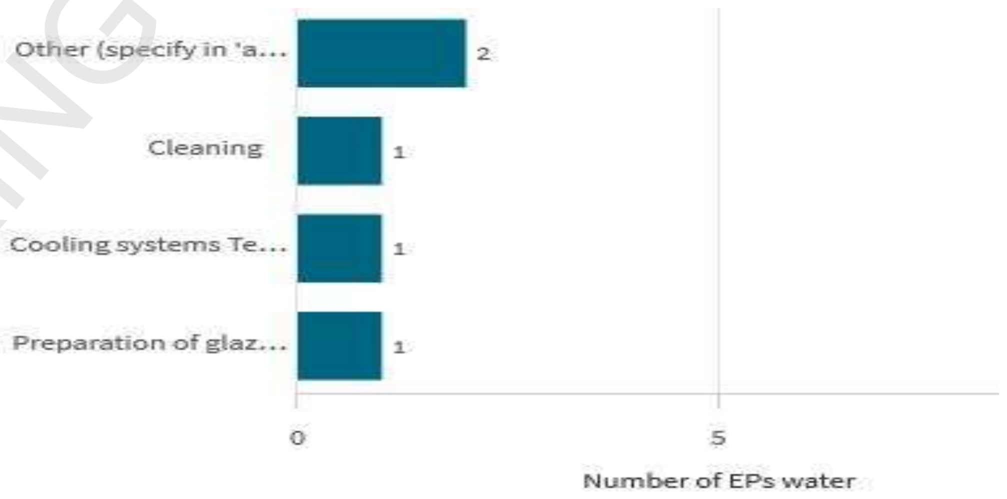
Source: [35, TWG 2023]

Figure 3-190: Monitoring frequency for Pb emissions to water



Source: [35, TWG 2023]

Figure 3-191: Number of emission points for Pb emissions to water by main sector



Source: [35, TWG 2023]

Figure 3-192: Number of emission points for Pb emissions to water by associated process(es)

Source: [35, TWG 2023]

Figure 3-193: Distribution of maximum concentrations for Pb emissions to water

3.3.6.10 Nickel (Ni)

[Note to the TWG: please provide further information on origin of the pollutant.]

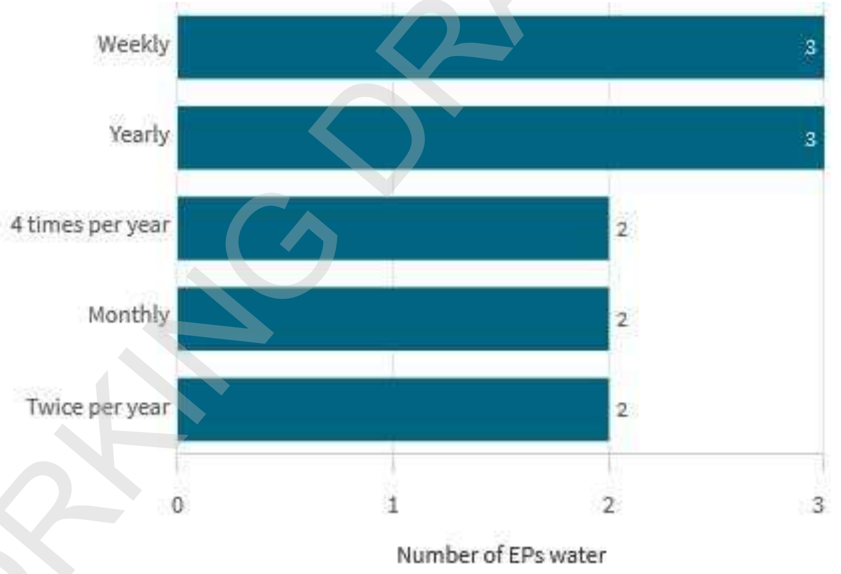
Metal emissions to water may originate from glazing and decoration steps. Table 3-36 presents a summary of reported data for Ni emissions.

Table 3-36: Summary of data for Ni emissions

Ni emissions	
Number of plants	13
Number of EPs Water	14
Direct discharge	6
Indirect discharge	7

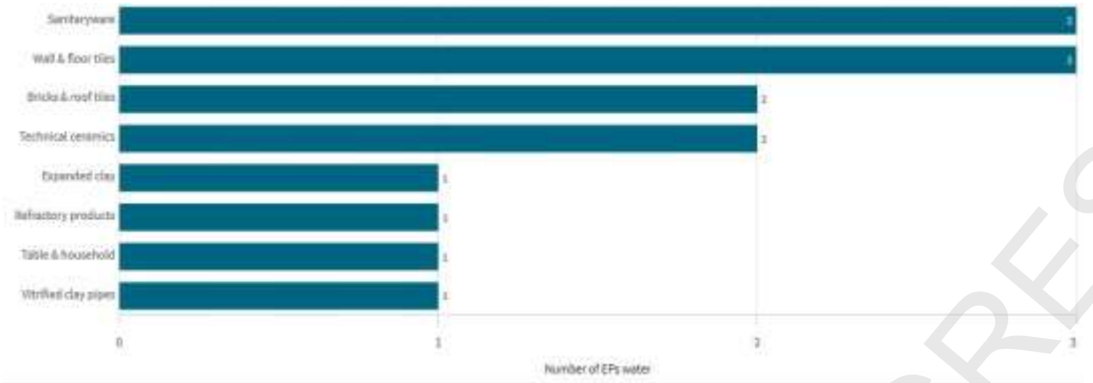
Source: [35, TWG 2023]

Figure 3-194, Figure 3-195, Figure 3-196 and Figure 3-197 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



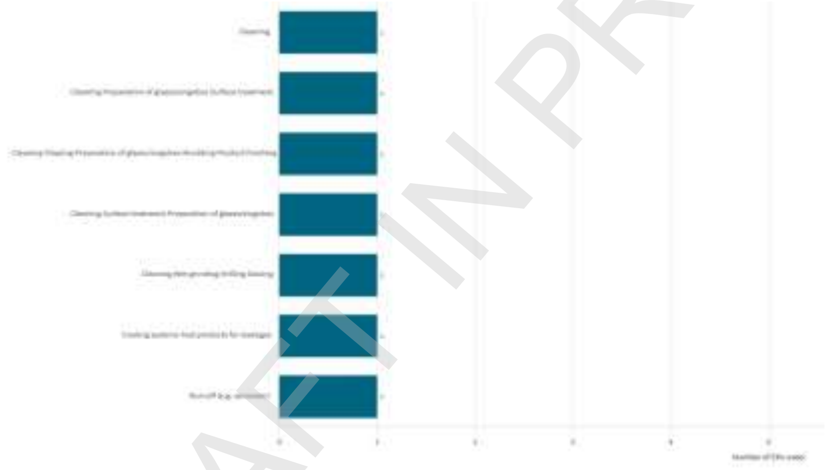
Source: [35, TWG 2023]

Figure 3-194: Monitoring frequency for Ni emissions to water



Source: [35, TWG 2023]

Figure 3-195: Number of emission points for Ni emissions to water by main sector



Source: [35, TWG 2023]

Figure 3-196: Number of emission points for Ni emissions to water by associated process(es)

Source: [35, TWG 2023]

Figure 3-197: Distribution of maximum concentrations for Ni emissions to water

3.3.6.11 Zinc (Zn)

[Note to the TWG: please provide further information on origin of the pollutant.]

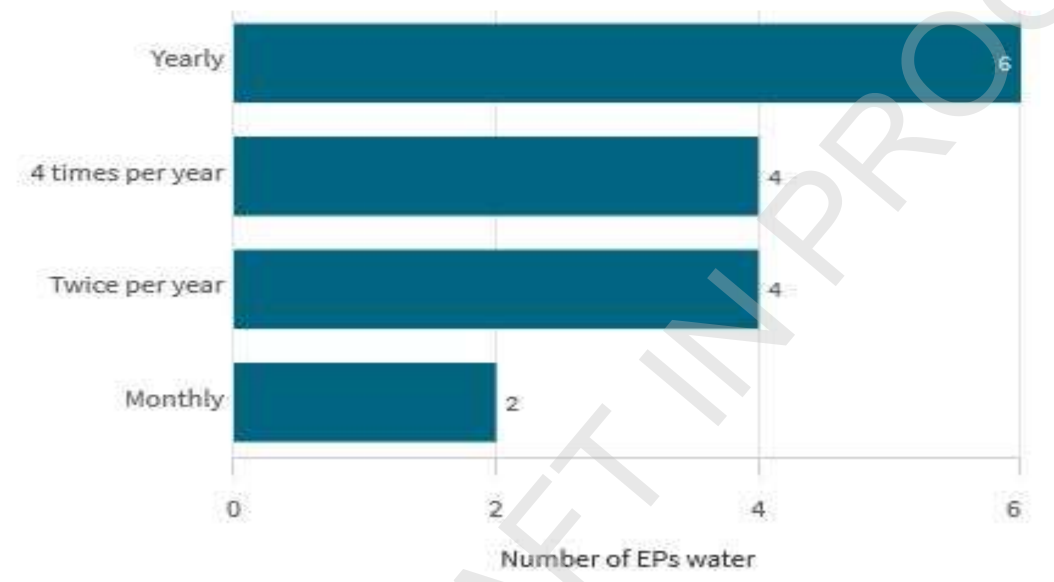
Metal emissions to water may originate from glazing and decoration steps. The reported levels for Zn emissions are presented in Section 3.3.7.9. Table 3-37 presents a summary of reported data for Zn emissions.

Table 3-37: Summary of data for Zn emissions

Zn emissions	
Number of plants	20
Number of EPs Water	21
Direct discharge	9
Indirect discharge	10

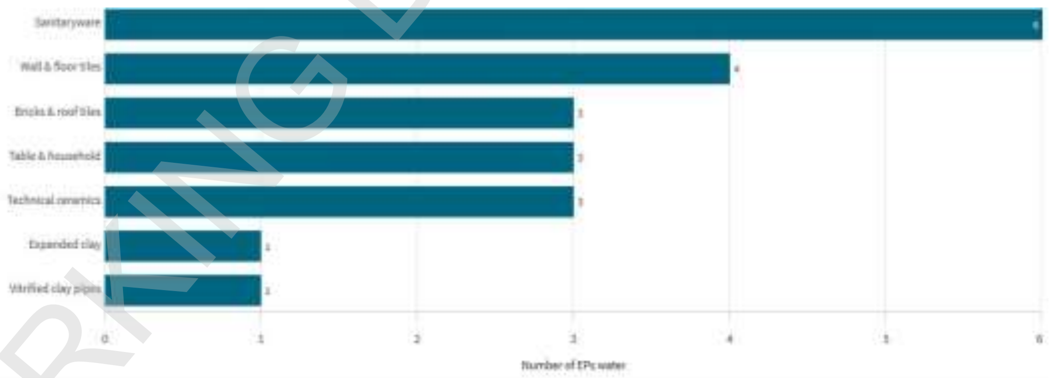
Source: [35, TWG 2023]

Figure 3-198, Figure 3-199, Figure 3-200 and Figure 3-201 below present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.



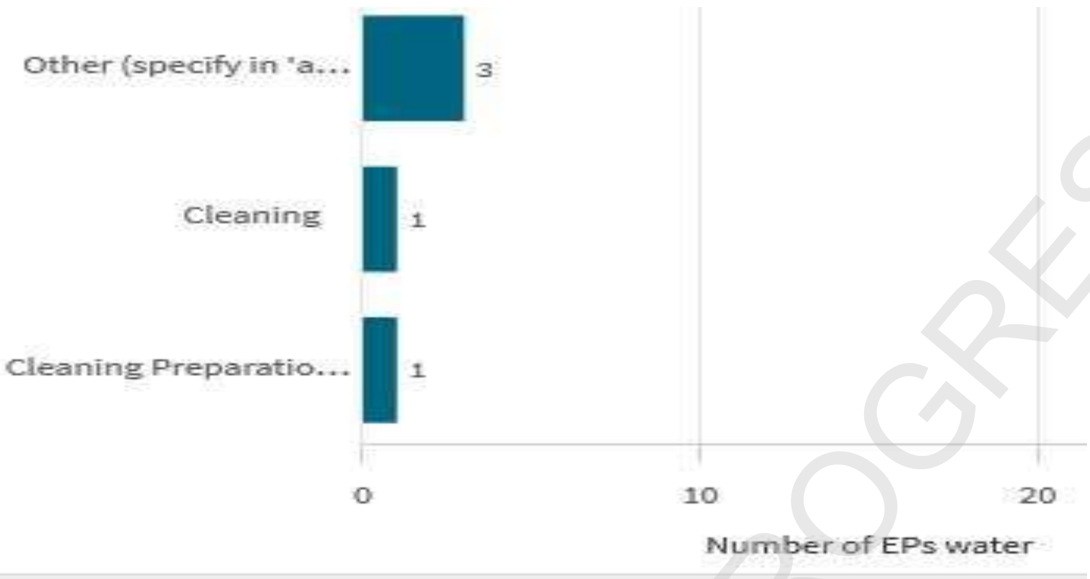
Source: [35, TWG 2023]

Figure 3-198: Monitoring frequency for Zn emissions to water



Source: [35, TWG 2023]

Figure 3-199: Number of emission points for Zn emissions to water by main sector



Source: [35, TWG 2023]

Figure 3-200: Number of emission points for Zn emissions to water by associated process(es)

Source: [35, TWG 2023]

Figure 3-201: Distribution of maximum concentration for Zn emissions to water

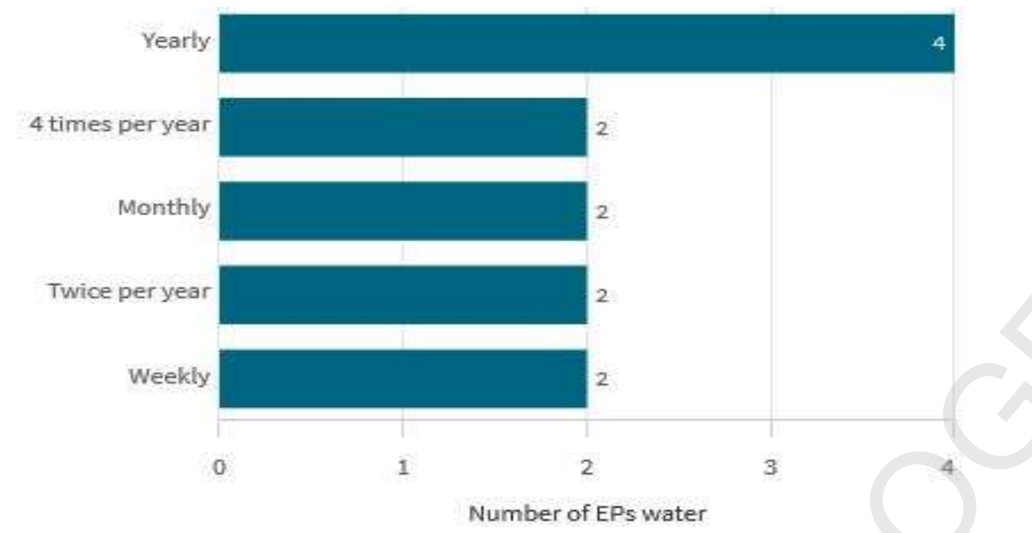
3.3.6.12 Other metals and metalloids

Table 3-38 presents a summary of reported data for other metals and metalloids (more specifically for Al, Ba and Co) emissions.

Table 3-38: Summary of data for other metals and metalloids emissions

Other metals and metalloids emissions	
Number of plants	13
Number of EPs Water	14*
Direct discharge	5
Indirect discharge	8
NB: Summary of data for other metals and metalloids includes reported data for Al, Ba, and Co emissions. *Source:* [35, TWG 2023]	

Figure 3-202, Figure 3-203, Figure 3-204 and Figure 3-205 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es), and distribution of maximum reported concentrations.

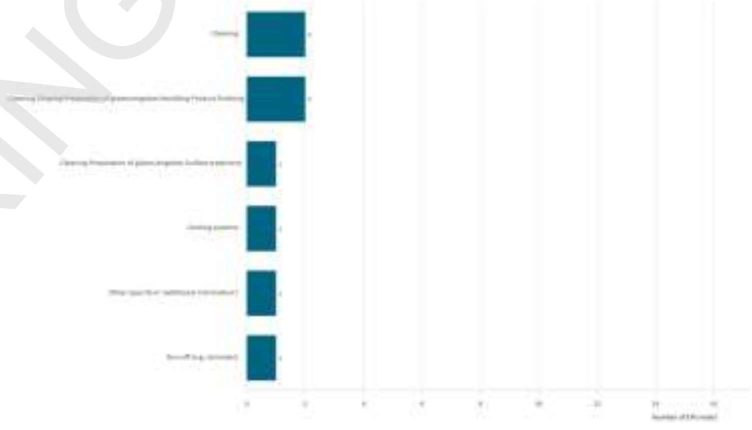


Source: [35, TWG 2023]

Figure 3-202: Monitoring frequency for other metals and metalloids emissions to water

Source: [35, TWG 2023]

Figure 3-203: Number of other metals and metalloids emissions to water by main sector



Source: [35, TWG 2023]

Figure 3-204: Number of other metals and metalloids emissions to water by associated process(es)

Source: [35, TWG 2023]

Figure 3-205: Distribution of maximum concentrations from other metals and metalloids emissions to water

3.3.7 Figures for emissions to water

This section reports on the ranges of reported emissions to water data with concentration values (in mg/l).

Each graph shows the minimum, average and maximum emission concentrations over the 3-year reference period, the emission limit value (ELV), the abatement techniques applied, associated process(es) and other relevant information at emission point level. Below the graph, the contextual information is given as follows: EPs Water, type of discharge and the monitoring frequency.

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.

The meanings of the acronyms used in the figures are as follows:

Table 3-39: Description of acronyms for monitoring frequency

Monitoring frequency	Abbreviation
Daily	D
Weekly	W
Monthly	M
4 times per year	4Y
Twice per year	2Y
Yearly	Y
Once every 2 years	1/2y
Once every 3 years	1/3y
Other	Oth.
No information	-
Source: [35, TWG 2023]	

Table 3-40: Other Acronyms

Type of Discharge	Abbreviation
Direct discharge to environment	D
Indirect discharge to a downstream (off-site) industrial WWTP	IND.
Indirect discharge to a downstream (off-site) urban WWTP	IND.
No discharge	-
Source: [35, TWG 2023]	

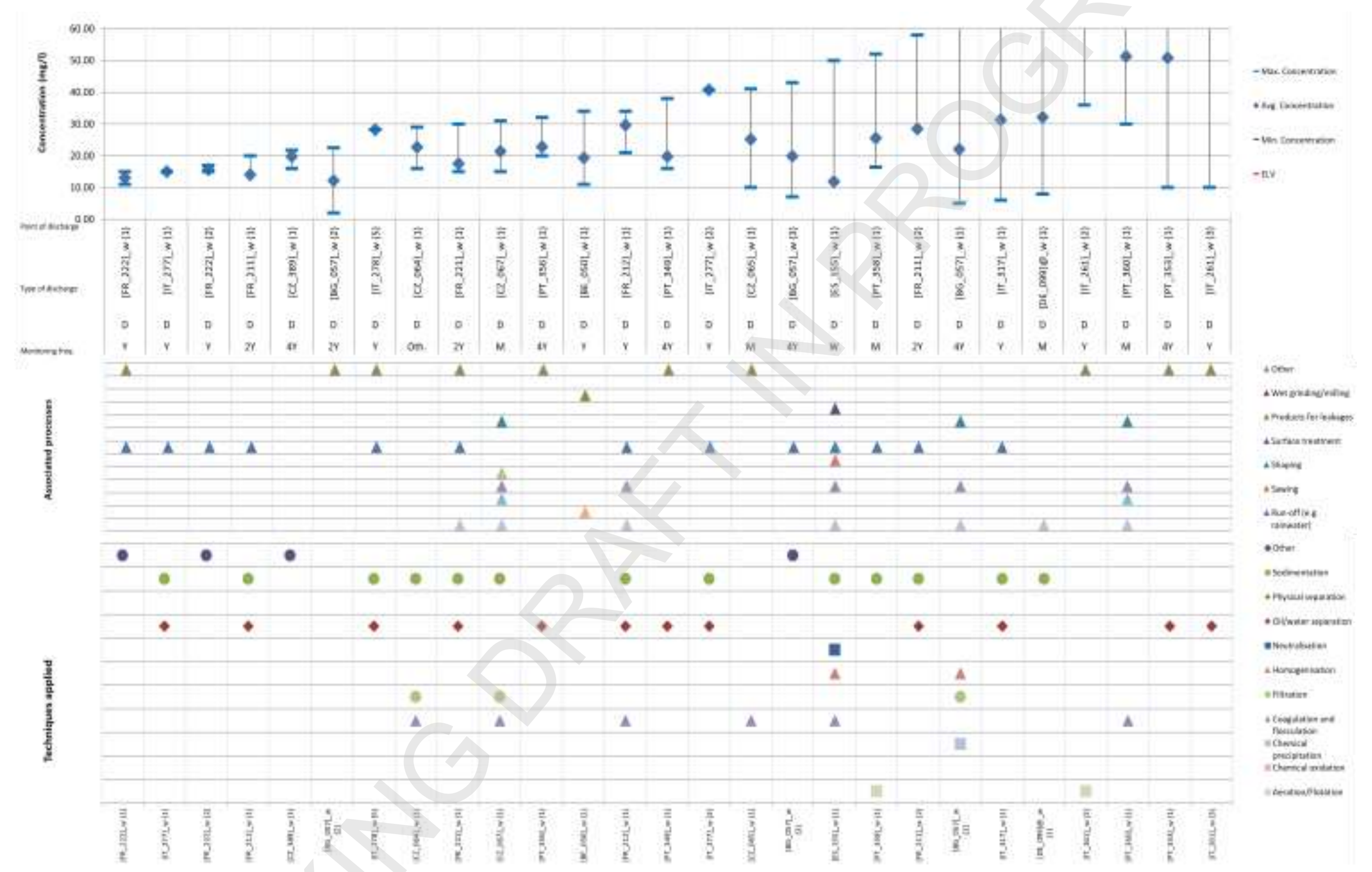
[Note to the TWG: figures for emissions to air by pollutants/parameters could be extended and updated when relevant information and data on emission levels is provided.]

3.3.7.1 AOX emissions to water for direct and indirect discharges

Source: [35, TWG 2023]

Figure 3-206: AOX emissions to water for direct and indirect discharges

3.3.7.2 COD emissions to water for direct discharges



Source: [35, TWG 2023]

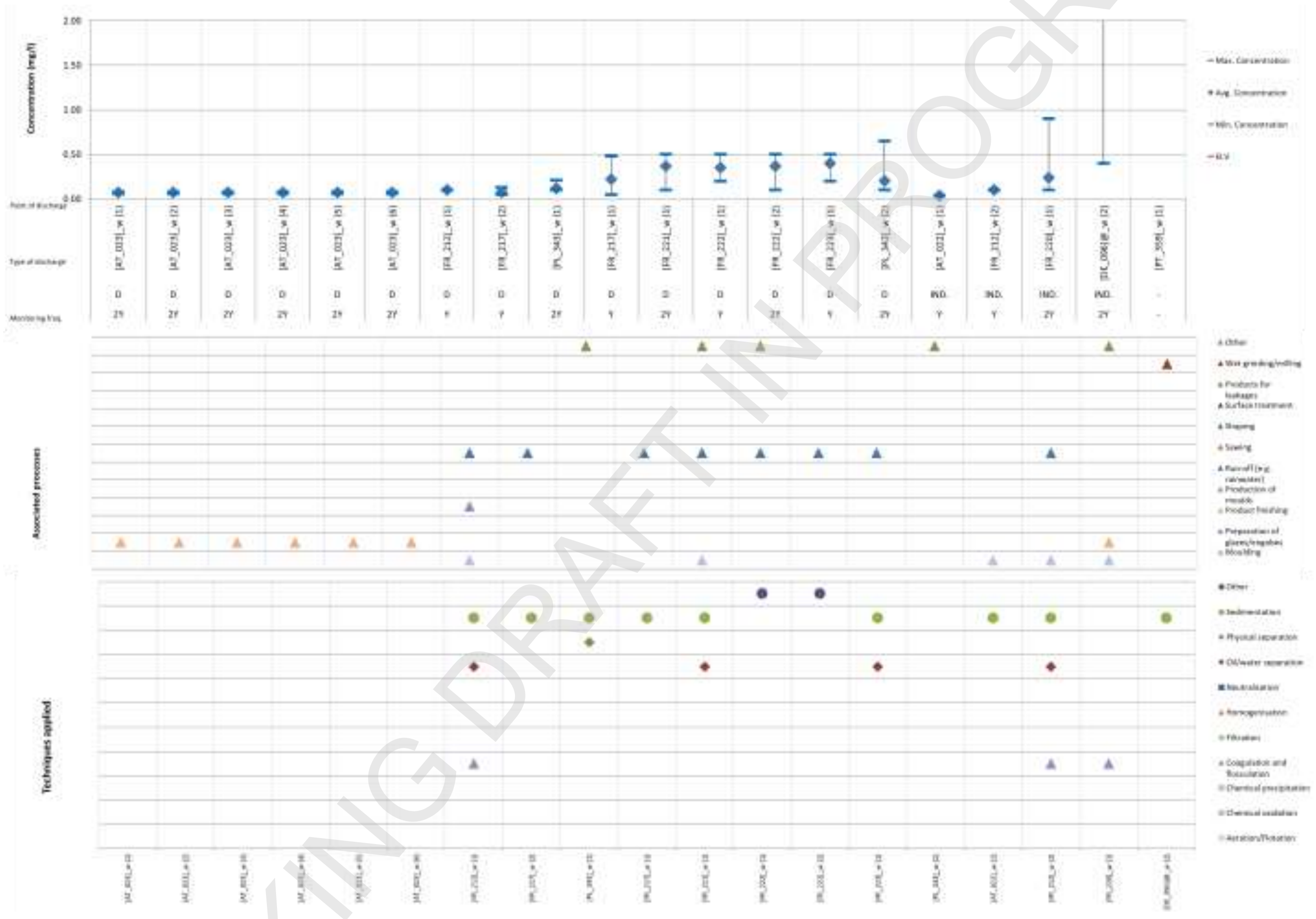
Figure 3-207: COD emissions to water for direct discharges

3.3.7.3 TOC emissions to water for direct discharges

Source: [35, TWG 2023]

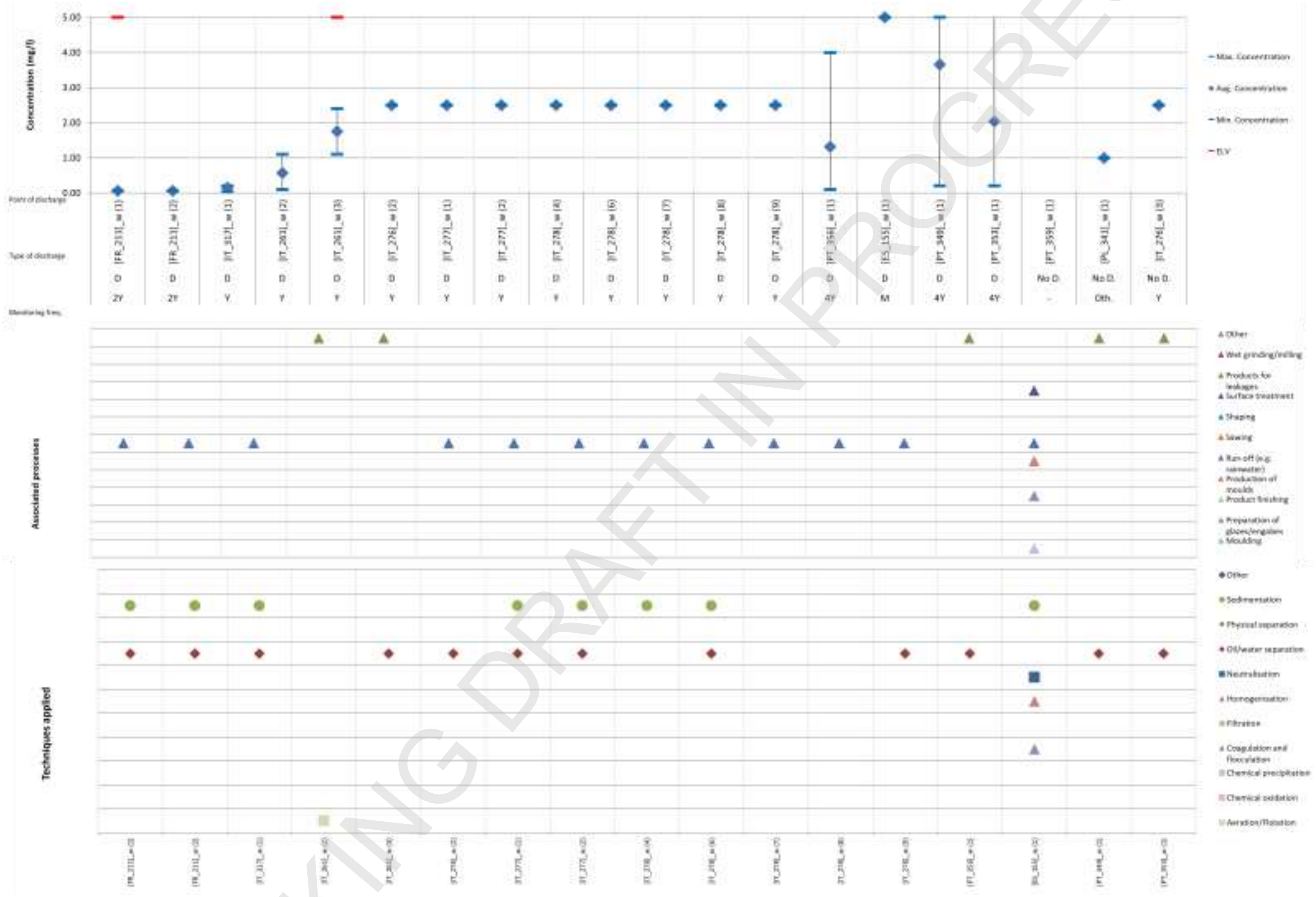
Figure 3-208: TOC emissions to water for direct discharges

3.3.7.4 HOI and Oils/Total hydrocarbons emissions to water for direct and indirect discharges



Source: [35, TWG 2023]

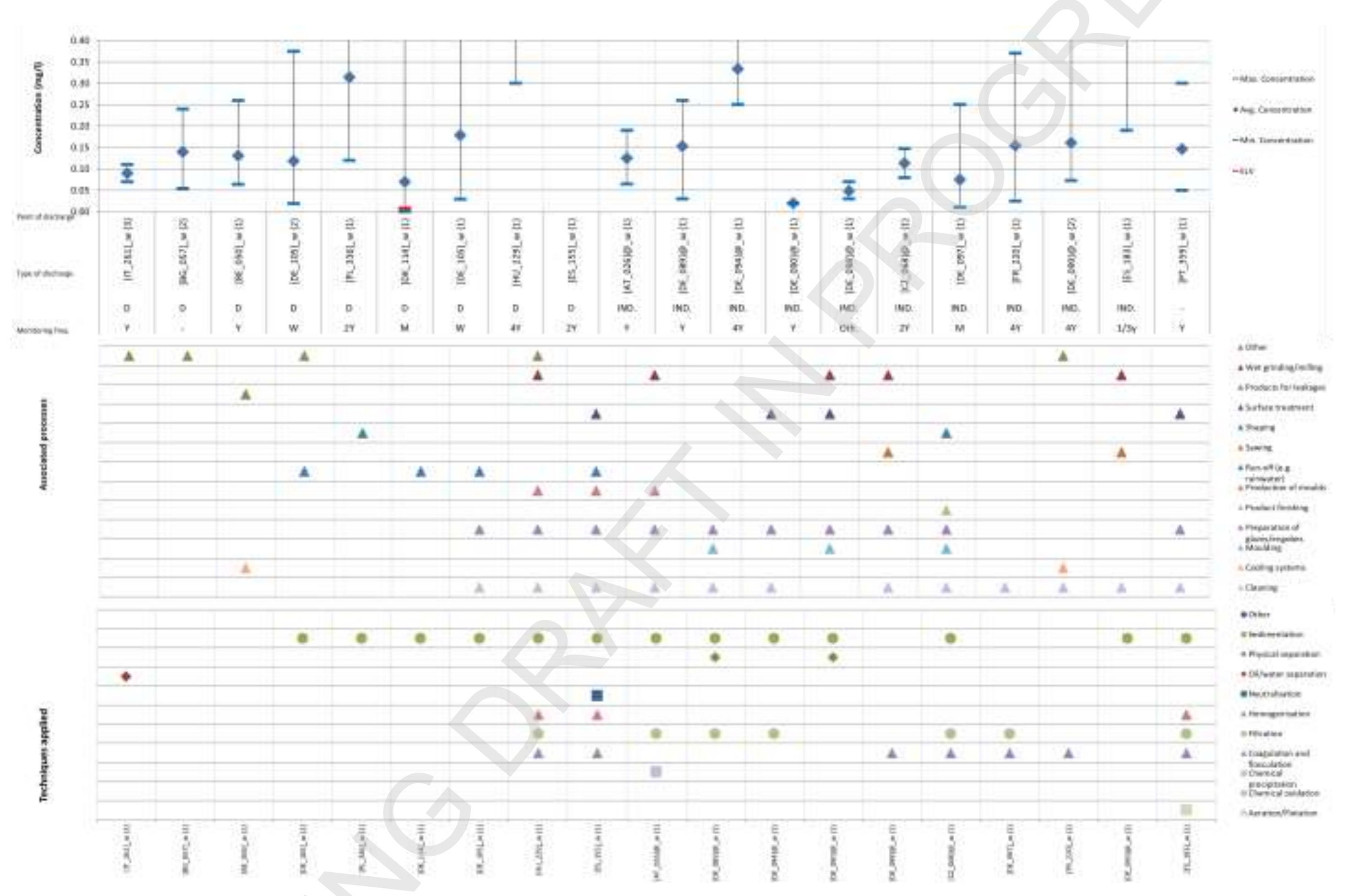
Figure 3-209: HOI emissions to water for direct and indirect discharges



Source: [35, TWG 2023]

Figure 3-210: Oils/Total hydrocarbons emissions to water for direct discharges

3.3.7.5 TSS emissions to water for direct and indirect discharges



Source: [35, TWG 2023]

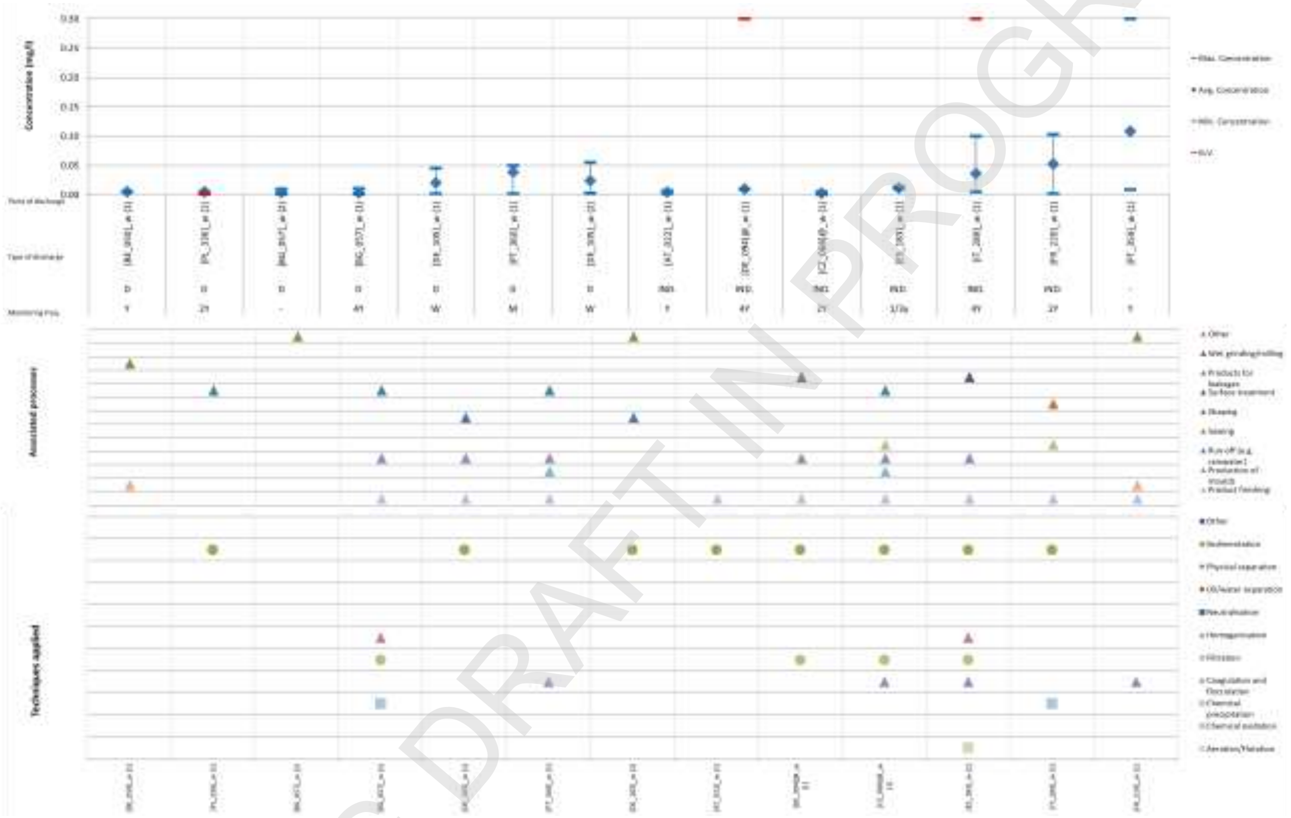
Figure 3-211: TSS emissions to water for direct and indirect discharges

3.3.7.6 Cd emissions to water for direct and indirect discharges

Source: [35, TWG 2023]

Figure 3-212: Cd emissions to water for direct and indirect discharges

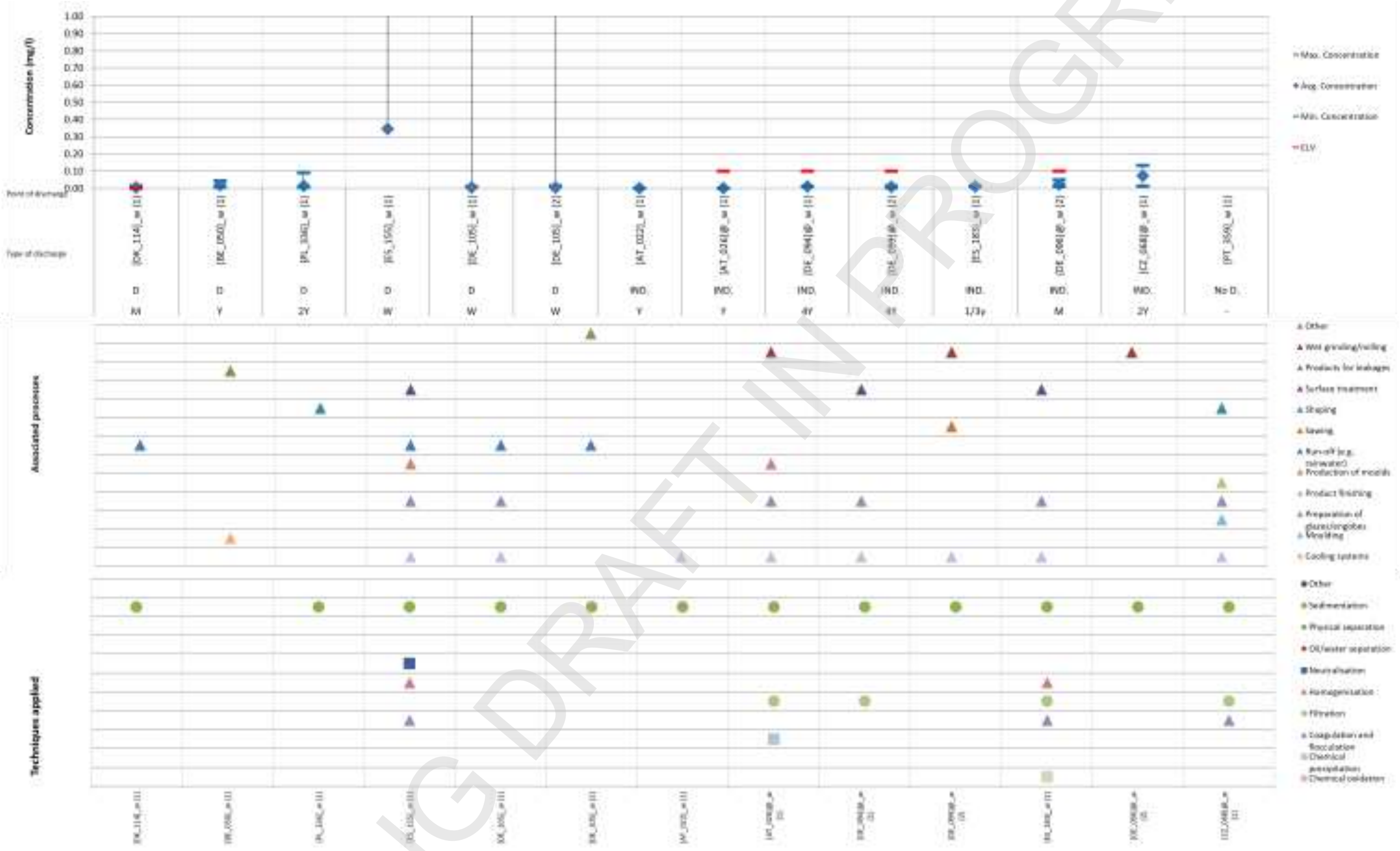
3.3.7.7 Pb emissions to water for direct and indirect discharges



Source: [35, TWG 2023]

Figure 3-213: Pb emissions to water for direct and indirect discharges

3.3.7.8 Ni emissions to water for direct and indirect discharges



Source: [35, TWG 2023]

Figure 3-214: Ni emissions to water for direct and indirect discharges

3.3.7.9 Zn emissions to water for direct and indirect discharges

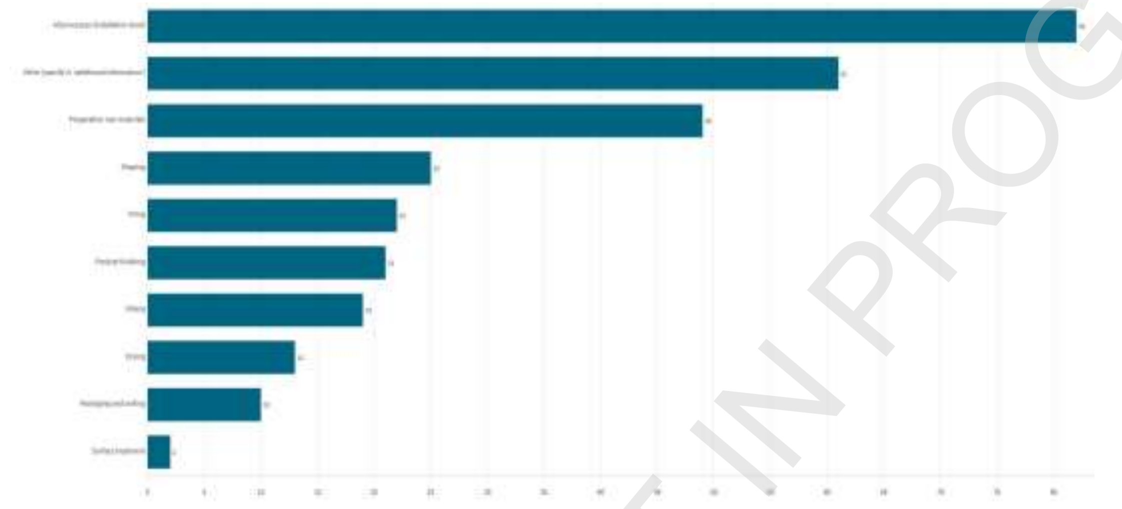
Source: [35, TWG 2023]

Figure 3-215: Zn emissions to water for direct and indirect charge

3.4 Noise

Noise occurs in the several steps during the manufacturing process of ceramic products, mainly generated by operating machinery and by carrying out noisy working procedures. Preparation of raw material, shaping and firing are some of the process steps reported by the majority of plants. However in reality, all rocesses at plant/installation level are sources of noise [35, TWG 2023], [44, COM 2020].

Figure 3-216 shows main sources that generate noise.



Source: [35, TWG 2023]

Figure 3-216: Main sources of noise in ceramic manufacturing

3.5 Odour

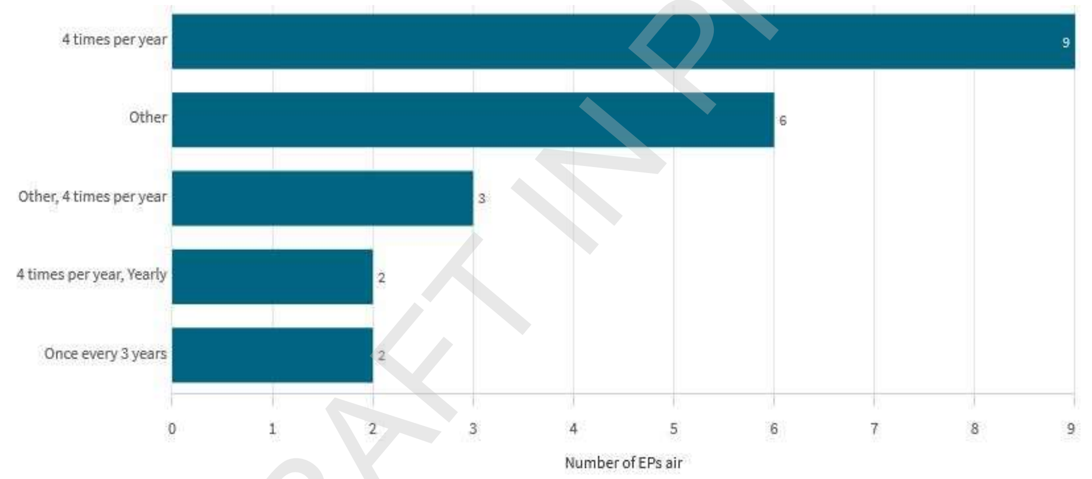
Odour emissions occur mainly due to the use of organic additives.

Table 3-41 presents a summary of reported data for odour emissions.

Table 3-41: Summary of data collected for odour emissions

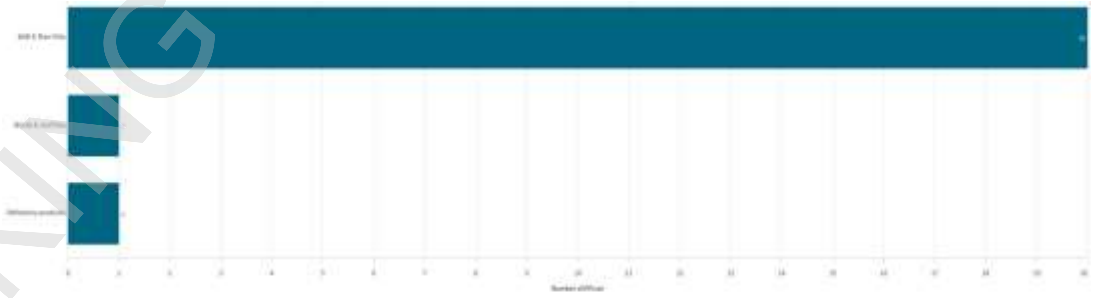
Odour emissions	
Number of plants	8
Number of EPs Air	23
Source: [35, TWG 2023]	

Figure 3-217, Figure 3-218 and Figure 3-219 present the reported data on monitoring frequency, distribution of the number of emission points by main sector and associated process(es) and distribution of maximum reported concentrations.



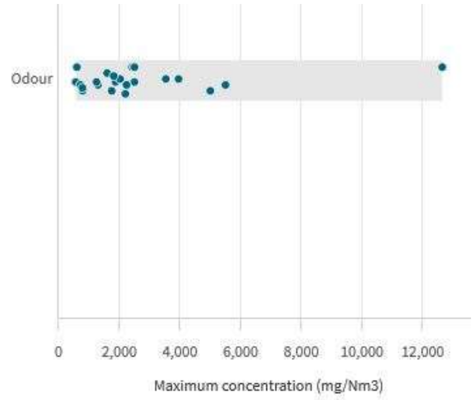
Source: [35, TWG 2023]

Figure 3-217: Monitoring frequency for odour emissions



Source: [35, TWG 2023]

Figure 3-218: Number of odour emission points by main sector



Source: [35, TWG 2023]

Figure 3-219: Distribution of the maximum concentrations for odour emissions

3.6 Energy consumption

The primary energy use in ceramic manufacturing is for kiln firing and, in many processes, drying of intermediates or shaped ware is also energy-intensive. Natural gas, LPG and fuel oil are employed for most drying and firing operations, but solid fuels, electricity, LNG and biogas/biomass are also used.

Plant and machinery used for the comminution and mixing of raw materials, and the forming of ware, require electrical energy. Diesel fuel is required for on-site transportation, which may include haulage of raw materials from a quarry, and internal transport with lorries. Additionally, electricity (battery-powered) and LPG bottles (butane, propane) are also used for on-site transportation, for instance with forklifts.

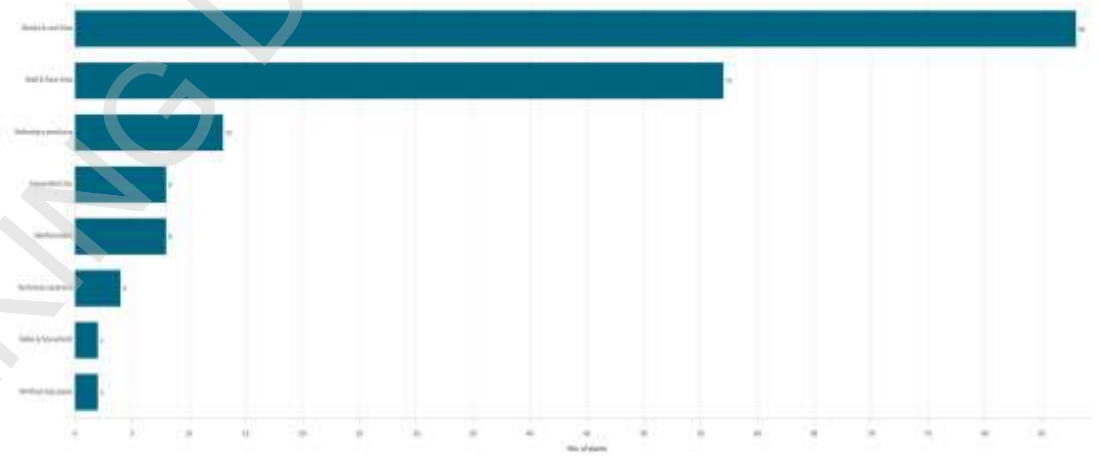
The brick and roof tile and the wall and floor tile sectors are the biggest energy consumers, but this is related to their larger tonnage outputs. In terms of specific energy consumption, the brick and roof tile sector shows the highest efficiency [3, Ceram-Unie 2003].

It should be noted that electrical heating of kilns is nevertheless employed for certain tableware and technical ceramics [14, UBA 2004], [17, Burkart, M. 2004]. This is necessary to achieve the required quality.

To facilitate better visualisation, the data in the form of examples and ranges of current consumption levels are summarised at plant and process levels and, when relevant, the data are presented by sector. Based on reported data, 182 plants reported data on total energy consumption at plant level and 66 plants reported specific energy consumption by associated process(es) [35, TWG 2023].

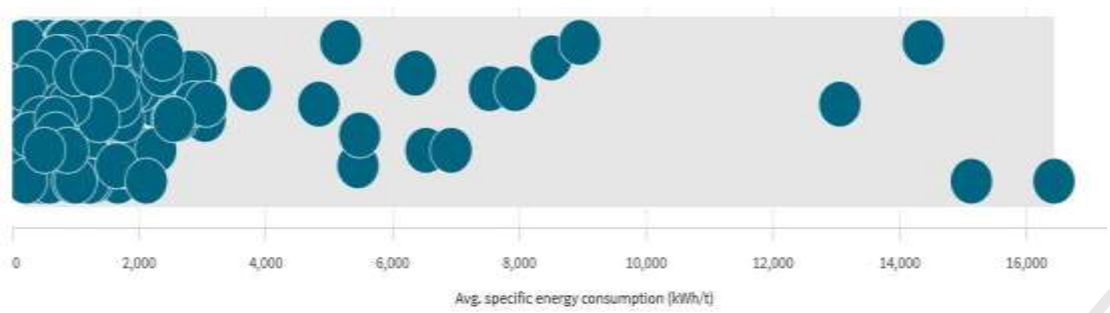
3.6.1 Specific energy consumption at plant level

Figure 3-220, Figure 3-221, Figure 3-222 and Figure 3-223 present the reported data for specific energy consumption at plant level. The figures present key reported information such as number of plants reporting specific energy consumption by various main sectors, average specific energy consumption, energy sources and techniques to reduce energy consumption.



Source: [35, TWG 2023]

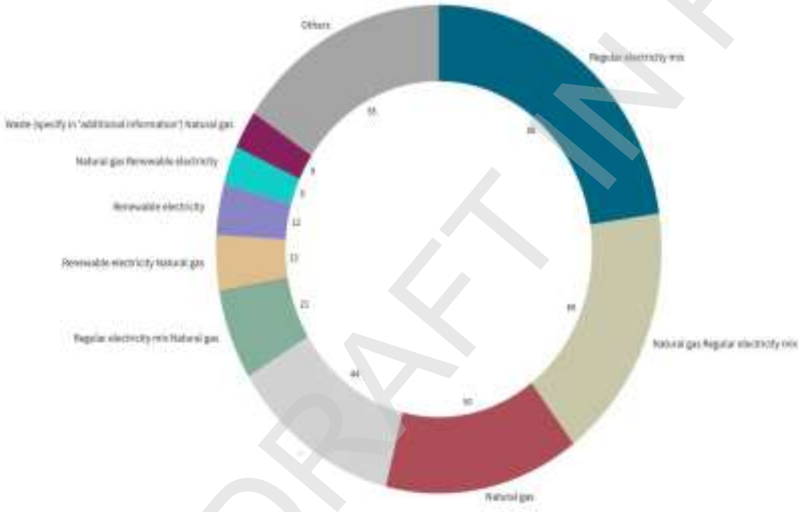
Figure 3-220: Number of plants reporting specific energy consumption by main sector



Source: [35, TWG 2023]

Figure 3-221: Distribution of the average specific energy consumption at plant level

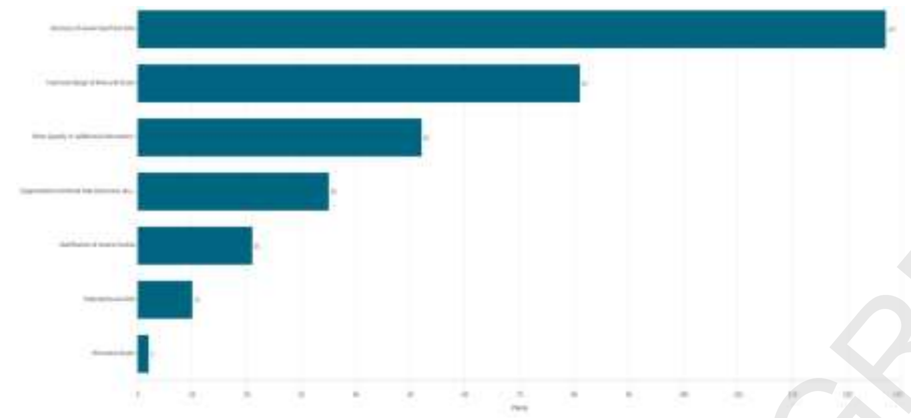
The majority of plants reported the type of energy sources as electricity mix and natural gas.



Source: [35, TWG 2023]

Figure 3-222: Numbers of plants reporting various energy sources

Techniques such as recovery of excess heat from kilns and improved design of kilns and dryers are reported by plants as the most commonly applied techniques to reduce energy consumption.

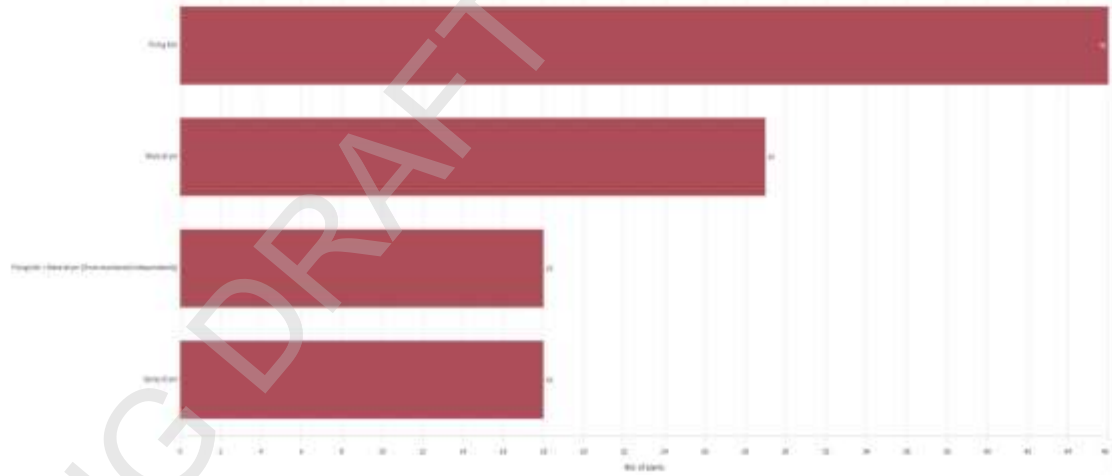


Source: [35, TWG 2023]

Figure 3-223: Number of plants reporting techniques to reduce energy consumption

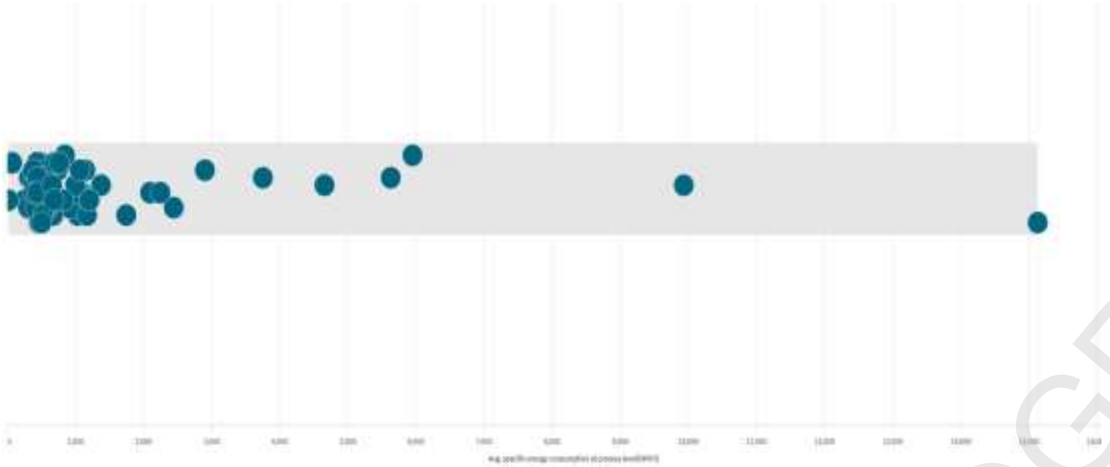
3.6.2 Specific energy consumption at process level

Figure 3-224, Figure 3-225, Figure 3-226 and Figure 3-237 present the reported data for specific energy consumption at process level. The figures present key reported information such as number of plants by specific energy consumption at process level, and distribution of the average specific energy consumption at process level.



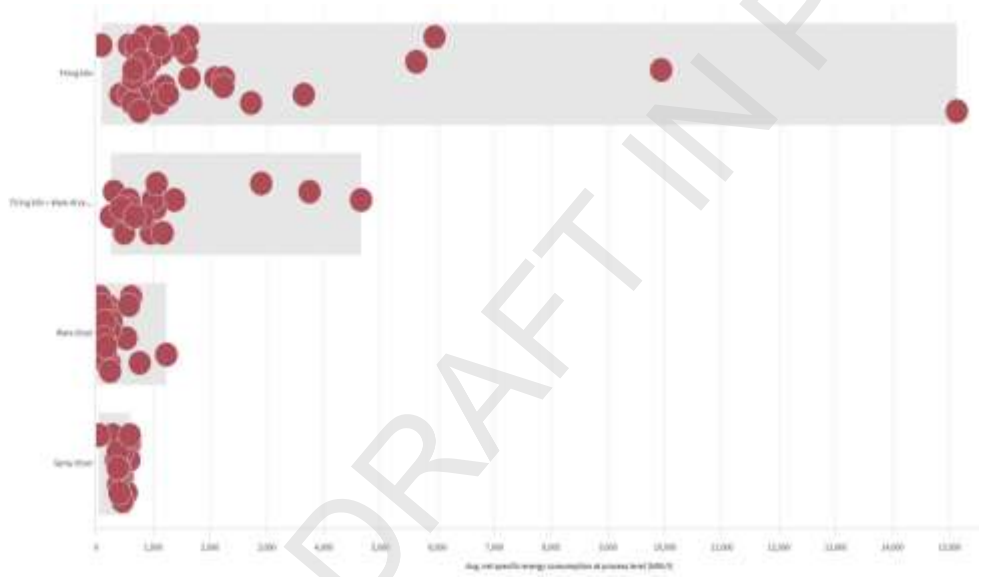
Source: [35, TWG 2023]

Figure 3-224: Number of plants reporting specific energy consumption at process level



Source: [35, TWG 2023]

Figure 3-225: Distribution of the average specific energy consumption at process level



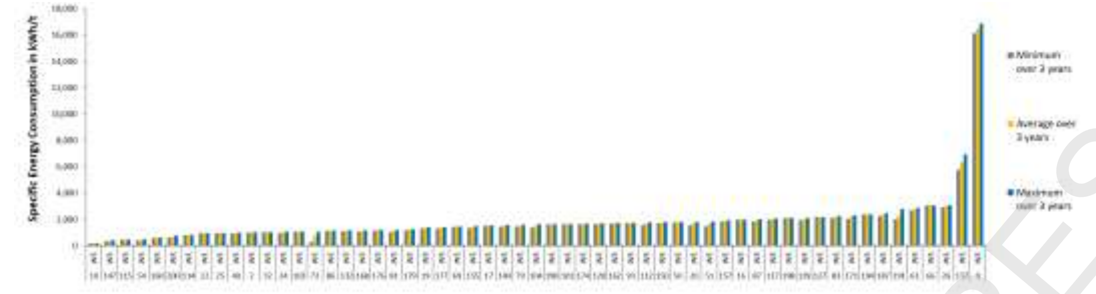
Source: [35, TWG 2023]

Figure 3-226: Distribution of the average specific energy consumption at process level

3.6.3 Figures for specific energy consumption

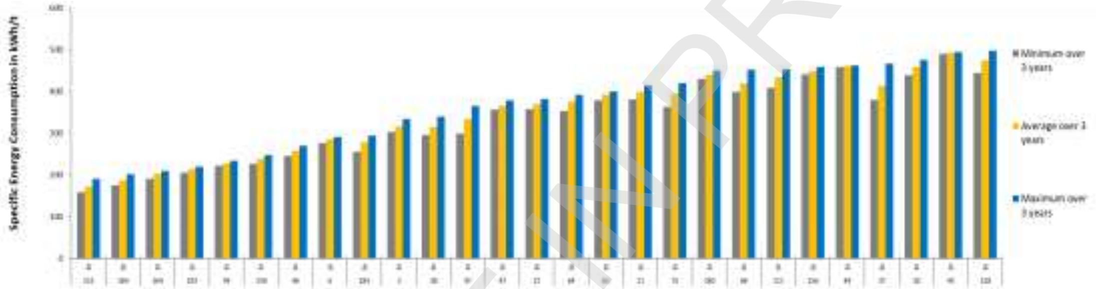
3.6.3.1 Specific energy consumption at plant level

The reported levels for specific energy consumption at plant level are presented in Figure 3-227, Figure 3-228, Figure 3-229, Figure 3-230, Figure 3-231 and Figure 3-232. Energy consumption data were reported for the 3 years, [35, TWG 2023]. The figures contain information on reported sector and plants are indicated by plant CBI codes.



Source: [35, TWG 2023]

Figure 3-227: Specific net energy consumption reported at plant level by wall and floor tiles plants

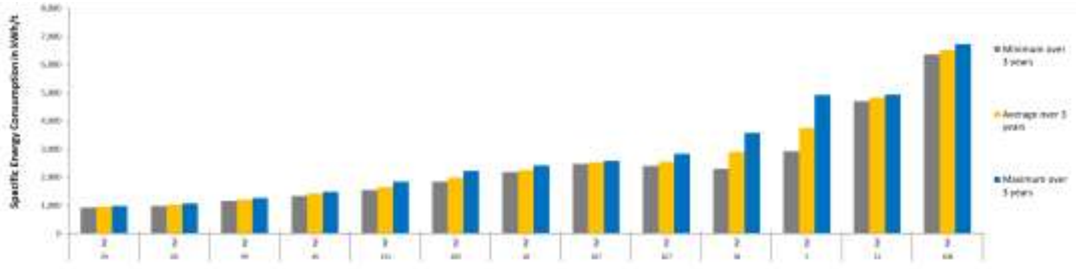


Source: [35, TWG 2023]

Figure 3-228: Specific net energy consumption reported at plant level by bricks and roof tiles plants

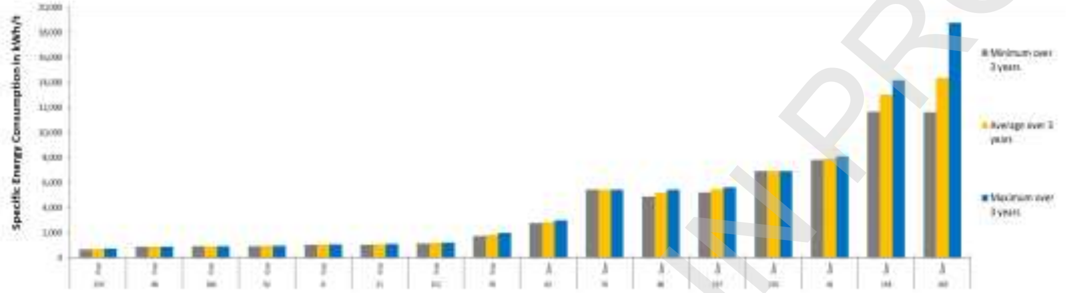
Source: [35, TWG 2023]

Figure 3-229: Specific net energy consumption reported at plant level by bricks and roof tiles plants



Source: [35, TWG 2023]

Figure 3-230: Specific net energy consumption reported at plant level by refractory plants



Source: [35, TWG 2023]

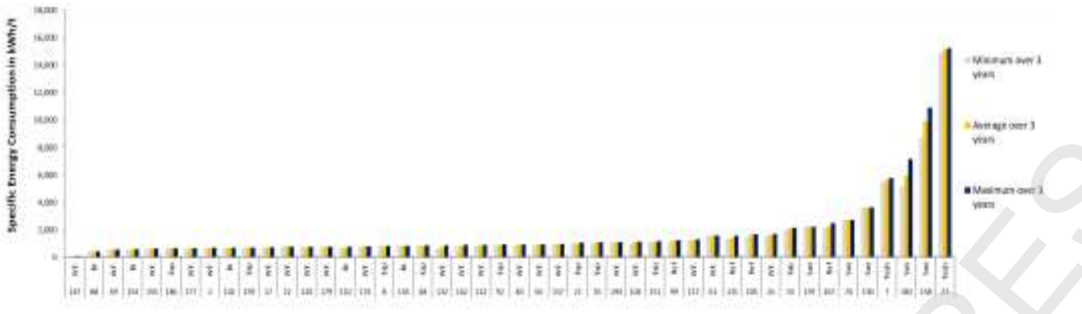
Figure 3-231: Specific net energy consumption reported at plant level by expanded clay and sanitaryware plants

Source: [35, TWG 2023]

Figure 3-232: Specific net energy consumption reported at plant level by other sector plants

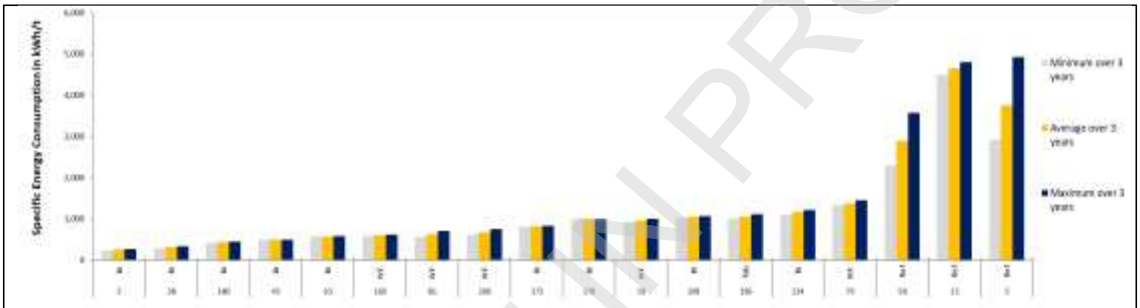
3.6.3.2 Specific energy consumption at process level

The reported specific energy consumption at process level by plants is reported in Figure 3-233, Figure 3-234, Figure 3-235 and Figure 3-236. On process level, the specific energy consumption is reported for: firing kiln, firing kiln and ware dryer, spray dryer and ware dryer. The figures also contain information on reported sector and plants are indicated by plant CBI codes.



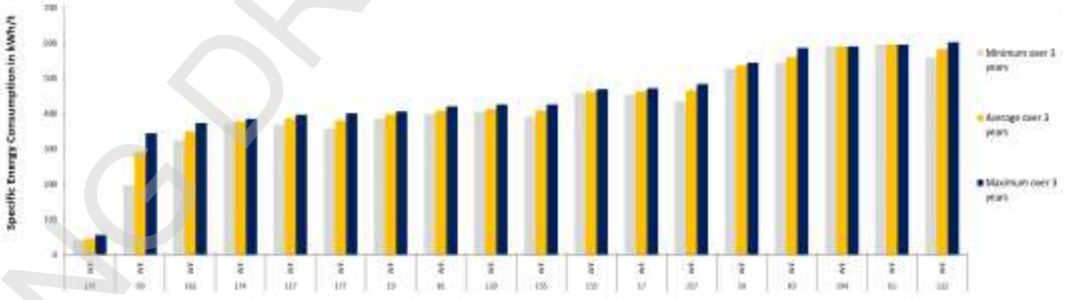
Source: [35, TWG 2023]

Figure 3-233: Specific net energy consumption reported at firing kiln process level



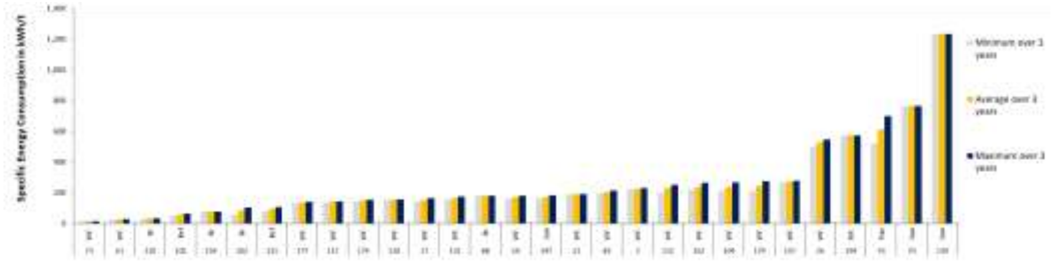
Source: [35, TWG 2023]

Figure 3-234: Specific net energy consumption reported at firing kiln and ware dryer process level



Source: [35, TWG 2023]

Figure 3-235: Specific net energy consumption reported at spray dryer process level



Source: [35, TWG 2023]

Figure 3-236: Specific net energy consumption reported at ware dryer process level

3.7 Waste and residue

Process losses/waste/residues originating from the manufacture of ceramic products~~,~~ mainly consist of the following materials:

- ~~d~~Different kinds of sludge originate from the process waste water treatment facilities of water arising in the associated processes in cleaning body preparation, glaze preparation and application equipment, and also from wet grinding. The quantity and composition of sludge varies considerably as, besides arising in the different production processes, a great variety of raw materials tends to be used (different glazes, frits, clays, etc.), even in the same facility, which produces significant fluctuations in sludge composition.
- ~~b~~Broken material/ware arises from mixing and shaping, drying, spray drying, firing, subsequent treatment and broken refractory material.
- ~~d~~Dust arises from off-gas cleaning units.
- ~~u~~Used plaster moulds arise from shaping processes.
- ~~u~~Used sorption agents (granular limestone, limestone dust) arise from flue-gas cleaning systems.
- ~~p~~Packaging waste (plastic, wood, metal, paper, etc.) arises in the packaging step.
- ~~s~~Solid residues, e.g. ashes arise from firing with solid fuels.

Parts of the accumulated process losses mentioned above~~,~~ can be recycled and reused within the plant due to product specifications or process requirements. Materials~~,~~ which cannot be recycled internally~~,~~ leave the plant to be used in other industries or to be supplied to external waste recycling or waste disposal facilities.

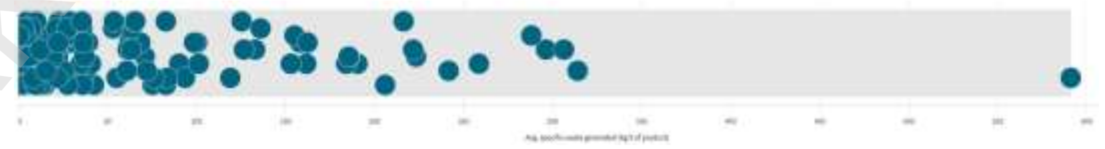
Out of 199 plants, 135 plants reported data for the amount of waste/residues generated. The reported data contain various types of waste/residues such as broken ware, waste/residues from flue-gas cleaning, other used materials, sludge and other waste/residues.

The data for broken ware were collected as follows:

- fired broken ware;
- unfired broken ware;
- total broken ware (if information for fired and unfired broken ware was not given).

A total of 165 plants reported information on generation of fired broken ware and, of these, 129 plants reported the amount of waste generated. In total, 144 plants reported information on the generation of unfired broken ware and 94 plants reported the amount of waste generated. There are 14 plants that reported data for broken ware and 6 plants reported the amount of broken waste generated.

Figure 3-237, Figure 3-238 and Figure 3-239 show the specific amount of waste/residues generated by plants from broken ware.



Source: [35, TWG 2023]

Figure 3-237: Distribution of average specific amount of waste/residues generated from fired broken ware by plant

Source: [35, TWG 2023]

Figure 3-238: Distribution of average specific amount of waste/residues generated from unfired broken ware by plant

Source: [35, TWG 2023]

Figure 3-239: Distribution of average specific amount of waste/residues generated from broken ware

Table 3-42, Table 3-43 and Table 3-44 present the number of plants which reported data on reuse, recycling, recovery and disposal for fired broken ware, unfired broken ware and broken ware (if there was no information about fired or unfired given).

Table 3-42: Number of plants reporting data for use and disposal for fired broken ware

On-site				Off-site			
Reuse	Recycling	Recovery	Disposal	Reuse	Recycling	Recovery	Disposal
47	21	18	15	19	34	21	14
Source: [35, TWG 2023]							

Table 3-43: Number of plants reporting data for use and disposal for unfired broken ware

On-site				Off-site			
Reuse	Recycling	Recovery	Disposal	Reuse	Recycling	Recovery	Disposal
59	23	1	4	13	21	2	9
Source: [35, TWG 2023]							

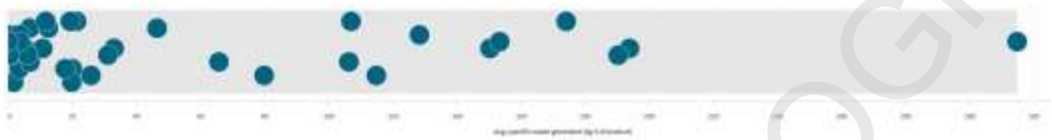
Table 3-44: Number of plants reporting data for use and disposal for broken ware

On-site				Off-site			
Reuse	Recycling	Recovery	Disposal	Reuse	Recycling	Recovery	Disposal
3	1	-	1	-	1	1	2
Source: [35, TWG 2023]							

The plants also reported specific generated waste/residues amounts for other type of waste/residues (e.g. off-gas cleaning waste, sludge, other waste/used materials).

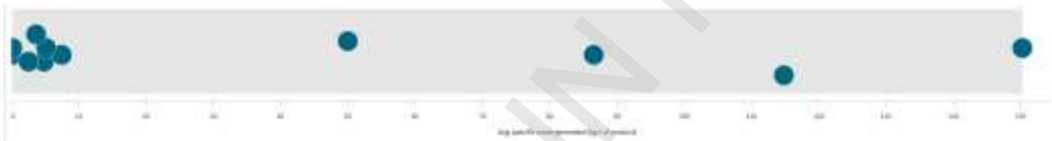
Source: [35, TWG 2023]

Figure 3-240: Distribution of average specific amount of waste/residues generated from off-gas cleaning



Source: [35, TWG 2023]

Figure 3-241: Distribution of average specific amount of waste/residues generated of sludge



Source: [35, TWG 2023]

Figure 3-242: Distribution of average specific amounts of waste/residue generated of other waste/used materials

The data reported for use and disposal for flue-gas cleaning, sludge and other waste/used materials are presented in Figures 3-164, 3-165 and 3-166.

For reducing waste/residues from flue-gas cleaning, the most commonly reported techniques are electronic controlling of firing, use of solid process losses, optimised setting of ware and other techniques.

Table 3-45: Number of plants reporting data for use and disposal of waste/residues from flue-gas cleaning

On-site				Off-site			
Reuse	Recycling	Recovery	Disposal	Re-use	Recycling	Recovery	Disposal
5	3	-	1	4	3	1	1
Source: [35, TWG 2023]							

The plants reported techniques to reduce sludge waste such as sludge reuse, sludge recycling, use of unmixed raw materials and other techniques.

Table 3-46: Number of plants reporting data for use and disposal for sludge

On-site				Off-site			
Reuse	Recycling	Recovery	Disposal	Re-use	Recycling	Recovery	Disposal
24	10	2	1	12	18	8	1
Source: [35, TWG 2023]							

For other waste and used materials waste, the plants reported techniques to reduce waste as follows: frequent feedback of unmixed materials, use of solid process losses and other techniques.

Table 3-47: Number of plants reporting data for use and disposal for other waste/used materials

On-site				Off-site			
Reuse	Recycling	Recovery	Disposal	Re-use	Recycling	Recovery	Disposal
6	6	2	2	-	3	5	3

Source: [35, TWG 2023]

3.8 Water consumption and discharge

Water is used in virtually all ceramic processes, and good quality water is essential for the preparation of clays and glaze slips; clay bodies for extrusion and ‘muds’ for moulding; preparation of spray-dried powders; wet grinding/milling; washing operations.

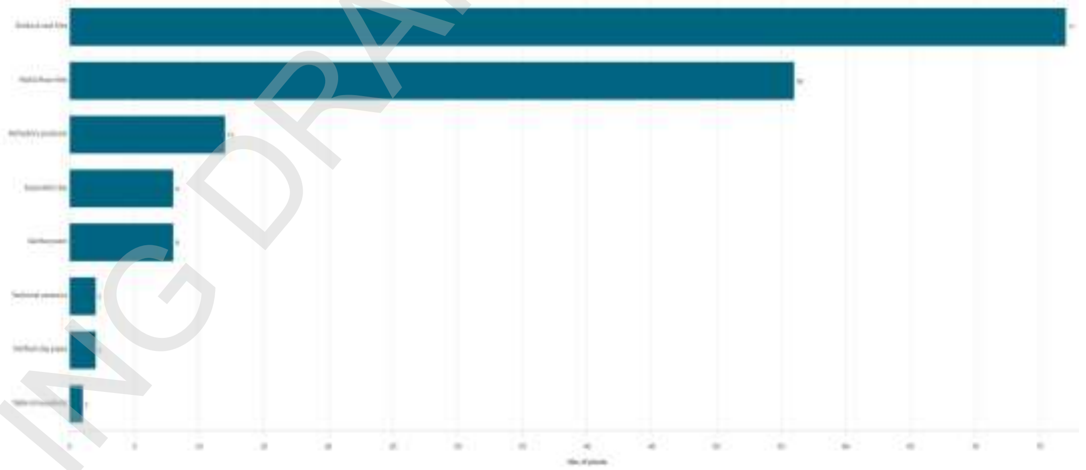
Water is used for different purposes, basically, as a raw material for the body and its preparation, as a raw material for glazes, as a washing fluid and as a cooling medium. Good quality water is required for glazes, washing and cooling purposes. Low quality water like untreated process waste water from washing operations in the glaze section can be suitable for the body. Process waste water reuse techniques take these different qualities into account.

In the data collection, total specific water consumption and waste water discharge are reported at plant level and process level. Out of 199 participating plants, 166 plants reported data on total water consumption at plant level and 55 plants reported specific water consumption by associated process [35, TWG 2023].

The specific water consumption data are considered confidential business information (CBI) by the TWG. Therefore, plant names are systematically replaced by randomly attributed CBI codes for each individual plant.

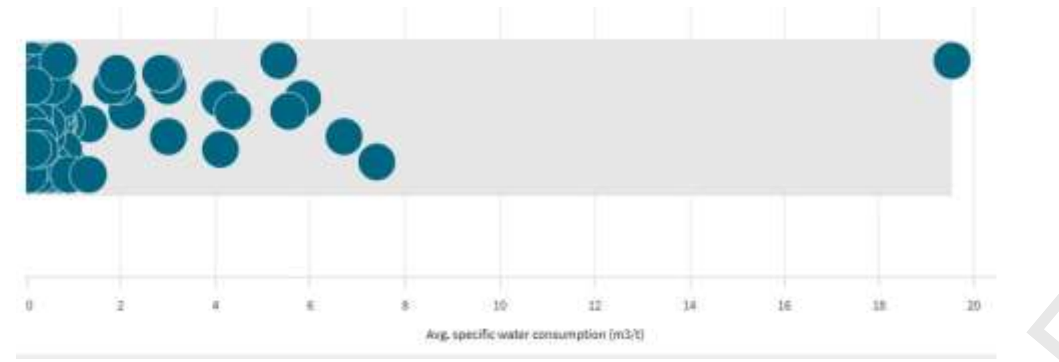
3.8.1 Specific water consumption and waste water discharge at plant level

Figure 3-243, Figure 3-244, Figure 3-245 and Figure 3-246 present the reported data for specific water consumption and waste water discharge at plant level. The figures show information on the number of plants that reported specific water consumption by main sector, distribution of average specific water consumption, waste water recycling level and specific waste water discharge.



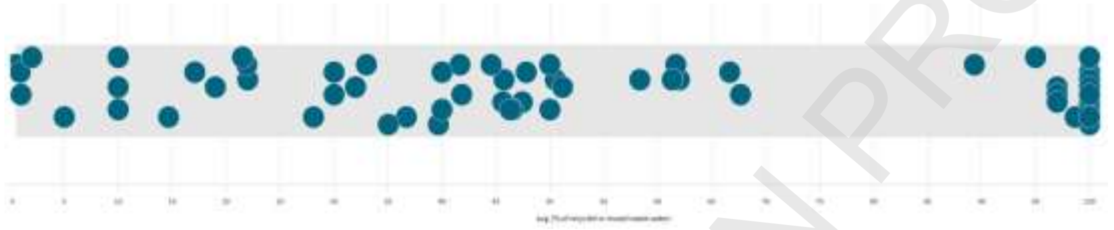
Source: [35, TWG 2023]

Figure 3-243: Number of plants reporting specific water consumption by main sector



Source: [35, TWG 2023]

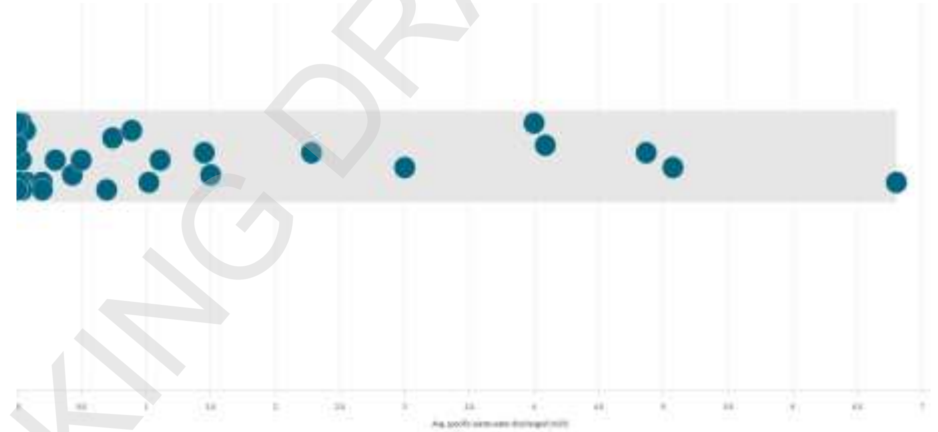
Figure 3-244: Distribution of the average specific water consumption at plant level



Source: [35, TWG 2023]

Figure 3-245: Distribution of the average waste water recycling or reuse level (%)

Out of 166 plants, 33 reported information on the waste water discharge and the distribution of the average value of total specific waste water discharged. Figure 3-138 presents the distribution of waste water discharged by plants at plant level.



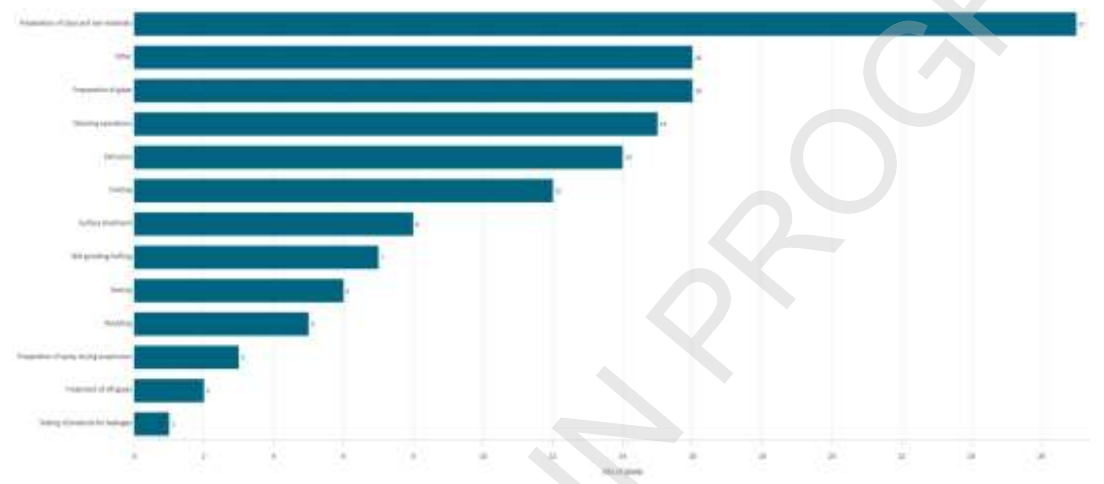
Source: [35, TWG 2023]

Figure 3-246: Distribution of the average values of specific waste water discharge at plant level

For better visualisation, reported data for total specific water consumption by plant level is presented in Section 3.8.3. The figure related to specific water consumption shows the upper part of the maximum, average and minimum reported values of specific water consumption for the 3-year reporting period.

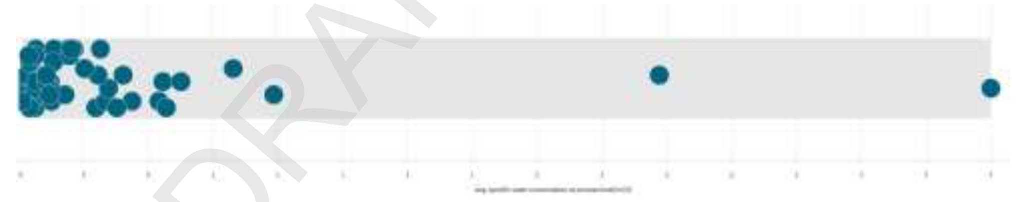
3.8.2 Specific water consumption and waste water discharge at process level

Figure 3-247, Figure 3-248, Figure 3-249 and Figure 3-250 present the reported data for specific water consumption and waste water discharge at process level. The figures present key reported information such as the number of plants reporting specific water consumption at process level, distribution of average specific water consumption at process level, and specific waste water discharge at process level.



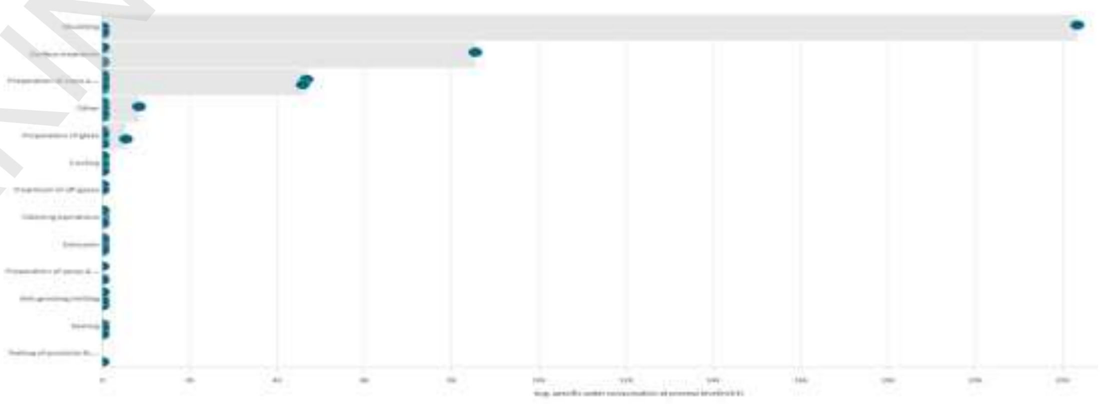
Source: [35, TWG 2023]

Figure 3-247: Number of plants reporting specific water consumption at process level



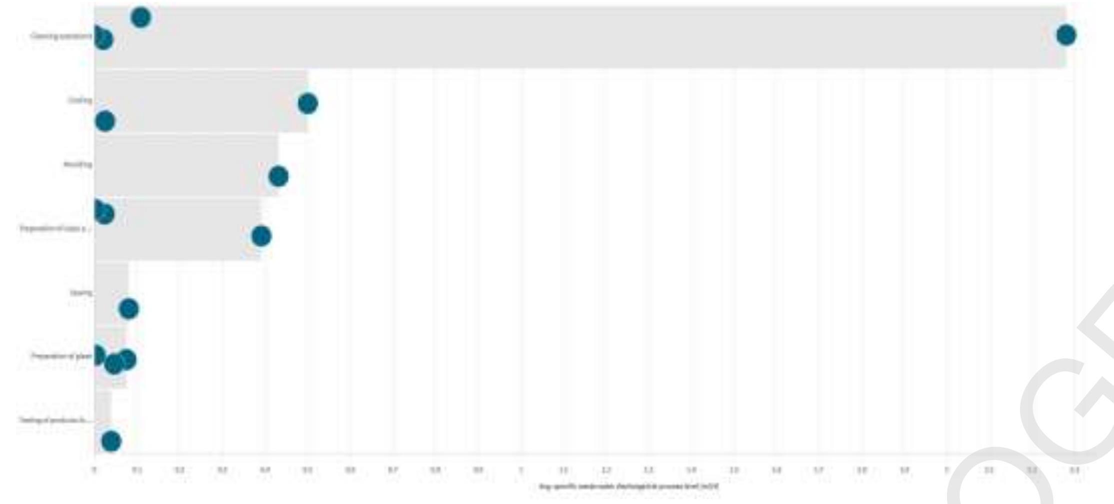
Source: [35, TWG 2023]

Figure 3-248: Distribution of the average specific water consumption at process level



Source: [35, TWG 2023]

Figure 3-249: Distribution of the average specific water consumption by associated process(es)



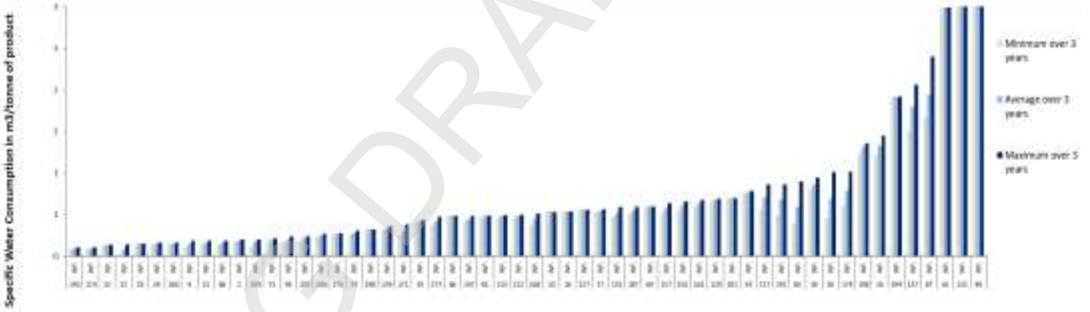
Source: [35, TWG 2023]

Figure 3-250: Distribution of the average values of total specific waste water discharge at process level

3.8.3 Figures for specific water consumption and waste water discharge

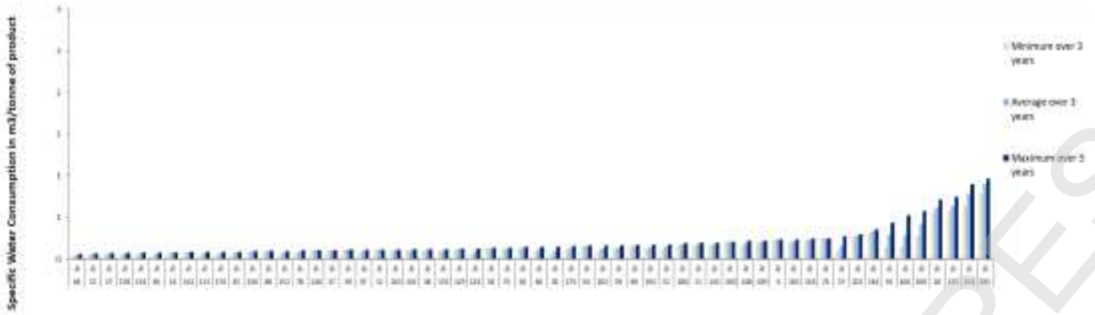
3.8.3.1 Specific water consumption at plant level

The reported levels for specific water consumption at plant level are presented in the figures below. The figures also contain information on the reported sector and plants are indicated by plant CBI codes.



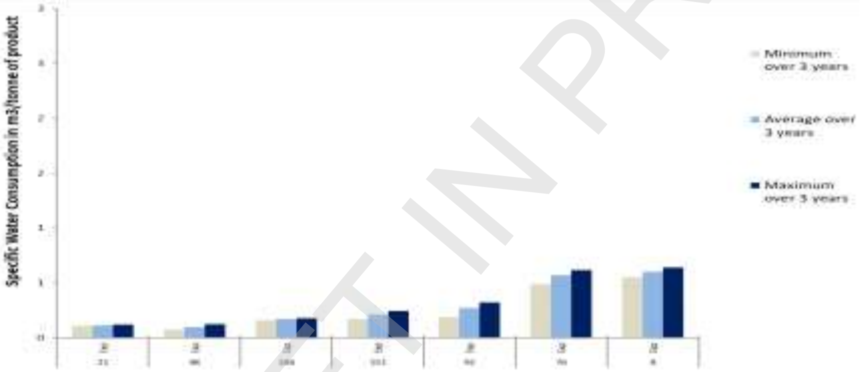
Source: [35, TWG 2023]

Figure 3-251: Specific net water consumption reported at plant level by wall and floor tiles plants



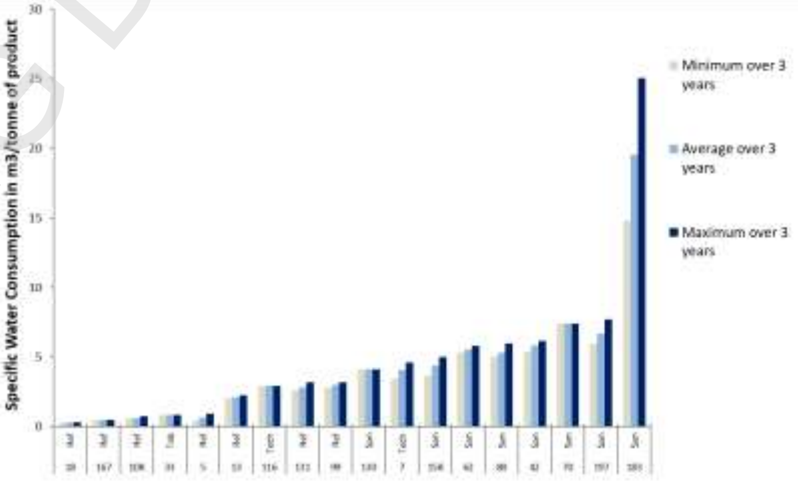
Source: [35, TWG 2023]

Figure 3-252: Specific net water consumption reported at plant level by bricks and roof tiles plants



Source: [35, TWG 2023]

Figure 3-253: Specific net water consumption reported at plant level by expanded clay plants

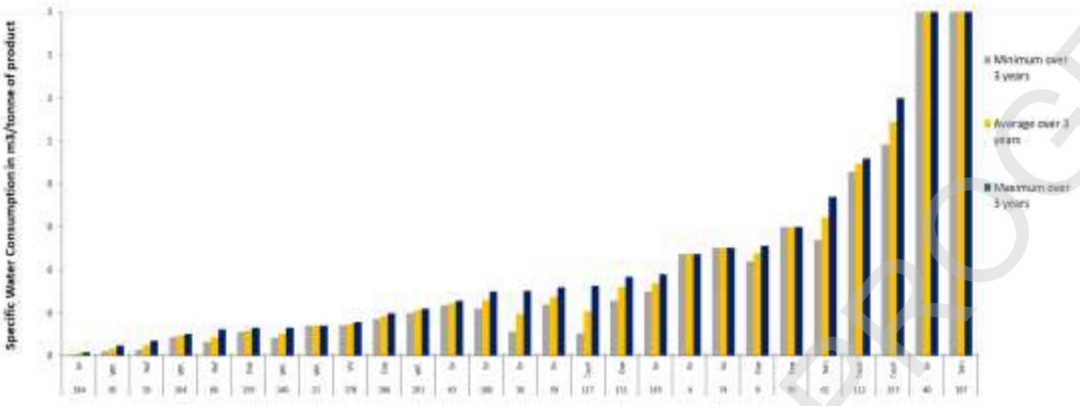


Source: [35, TWG 2023]

Figure 3-254: Specific net water consumption reported at plant level by plants of other sectors

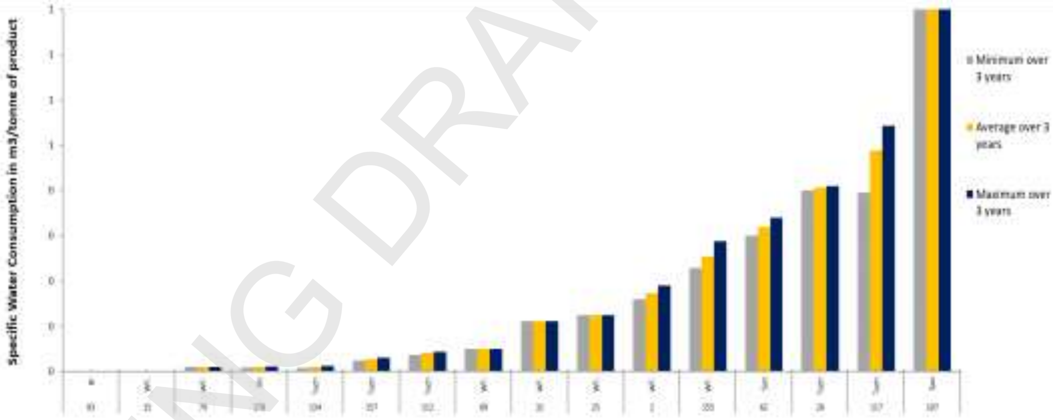
3.8.3.2 Specific water consumption at process level

The reported levels for specific water consumption at process level are presented in the figures below. The figures also contain information on the reported sector and plants are indicated by plant CBI codes. The following figures only present specific water consumption at process levels based on the data which were mostly reported by specific process(es).



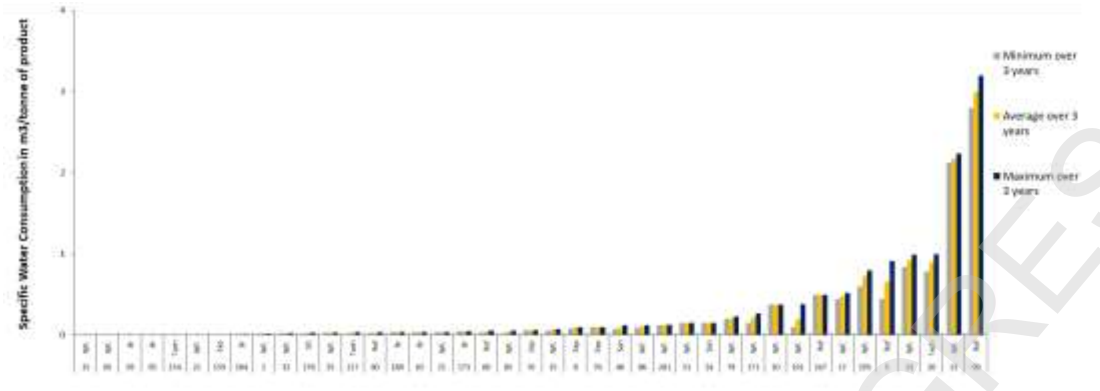
Source: [35, TWG 2023]

Figure 3-255: Specific net water consumption reported for the preparation of clays and raw material process



Source: [35, TWG 2023]

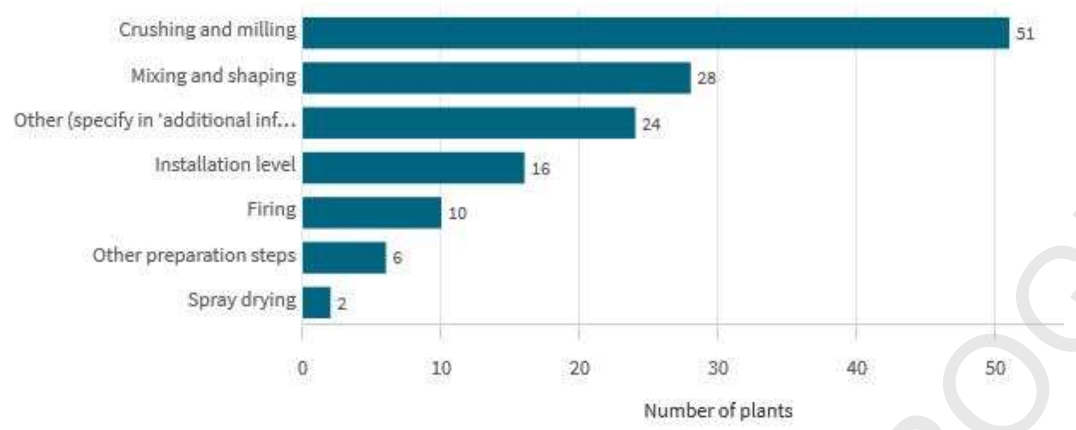
Figure 3-256: Specific net water consumption reported for the preparation of glaze process



Source: [35, TWG 2023]

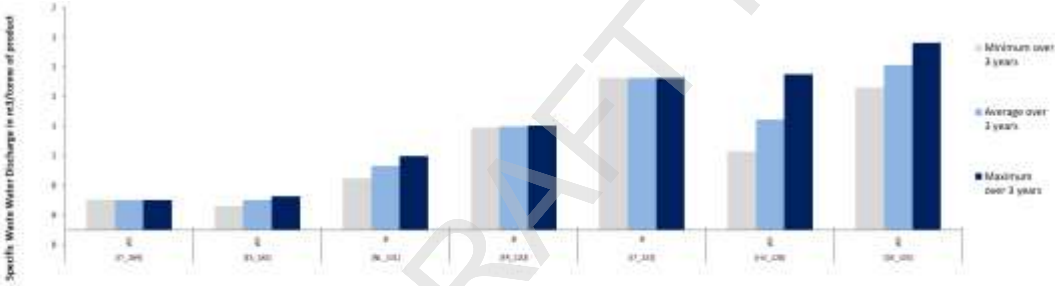
Figure 3-257: Specific net water consumption reported for the preparation of cleaning operations, extrusion and cooling process(es)

3.8.3.3 Specific waste water discharge at plant level



NB: For better visualisation, waste water discharge reported above 0.1 m^3/tonne of product are shown in this figure.
Source: [35, TWG 2023]

Figure 3-258: Specific waste water discharge reported at plant level by walls and floor tiles and bricks and roof tiles plants



NB: For better visualisation, waste water discharge reported above 0.1 m^3/tonne of product are shown in this figure.
Source: [35, TWG 2023]

Figure 3-259: Specific waste water discharge reported at plant level by other sectors

3.8.3.4 Specific waste water discharge at process level

[Note to the TWG: please provide information to update the information on waste water discharge at process level. Figures can be updated after the updated data collection.]

3.9 Material and chemical consumption

3.9.1 Raw material

A vast range of raw materials is consumed by the ceramic industry, as indicated in Chapter 2. These include the main body-forming materials, involving high tonnages, and various additives, binders and decorative surface-applied materials, which are used on a lesser scale.

Based on the data collection, the main raw materials consumed by the ceramic manufacturing industry can be classed in three main groups: clay, spray-dried powder and others (e.g. aluminium oxide, feldspar, magnesia, refractory clays).

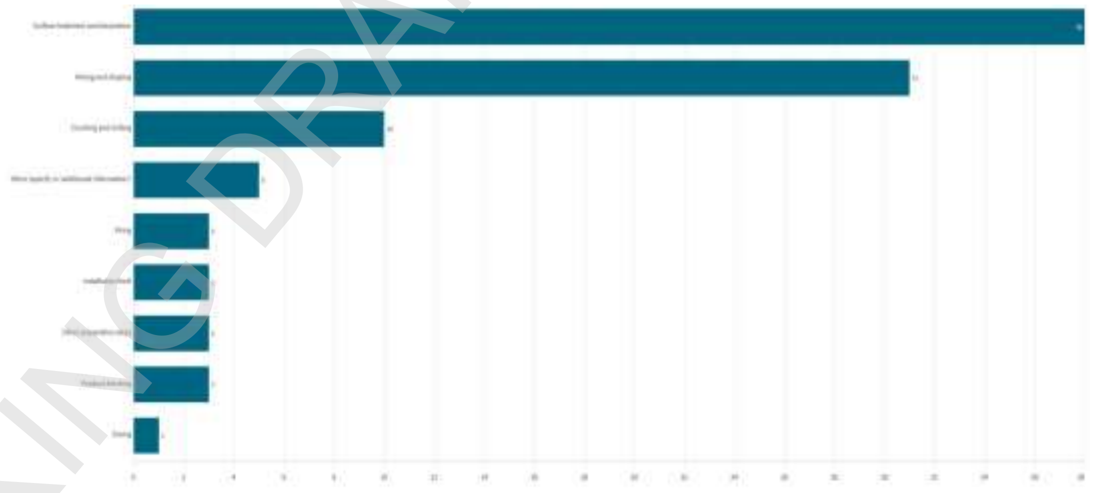
Out of 199 participating plants, the main raw materials reported by plants in the data collection were the following:

- 121 plants reported the use of clay as a main raw material;
- 18 plants reported the use of spray-dried powder;
- 13 plants, which reported the use of other raw materials, are mainly from the refractory industry.

3.9.2 Chemical substances and/or mixtures

A manageable list of chemicals was defined for the data collection with the support of ECHA. A total of 77 plants in the data collection reported some information on the use of hazardous chemicals.

Figure 3-260 presents the number of plants that reported data on hazardous chemicals use by associated process(es).



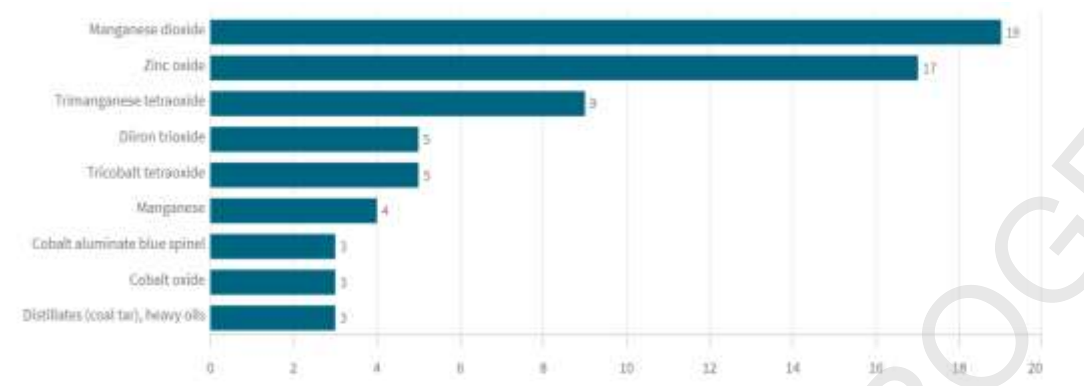
Source: [35, TWG 2023]

Figure 3-260: Number of plants reporting data on hazardous chemicals by associated process(es)

The consumption data of hazardous chemicals are considered CBI data. According to the reported data, there is no information on consumption of hazardous chemicals.

[Note to the TWG: please provide information to update the information on consumption of chemicals.]

Figure 3-261 shows the number of plants that reported the use of the substances included in the list designed for the data collection. Only those substances reported by more than three plants have been included.



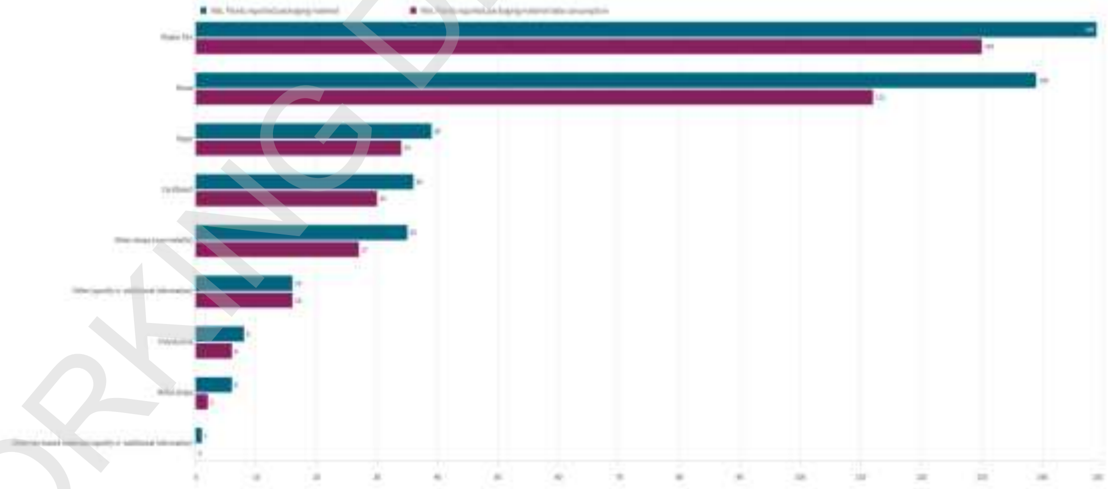
Source: [35, TWG 2023]

Figure 3-261: Number of plants reporting the use of hazardous substances included in the data collection

3.9.3 Packaging material

The questionnaires require information on the consumption of packaging materials such as cardboard, metal straps, bio-based materials, paper, plastic film, polystyrene, wood and other straps and other materials (e.g. big plastic bags, plastic trays).

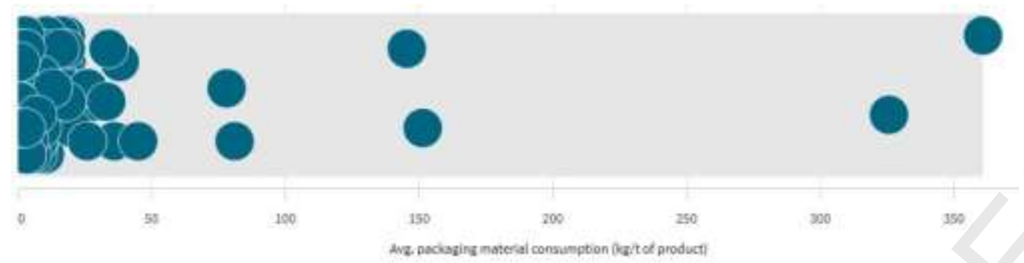
Figure 3-262 shows the distribution of plants that reported data on packaging material and consumption data for packaging material. The blue bar corresponds to the number of plants that reported the consumption of a given packaging material while the purple bar corresponds to the number of plants that reported specific consumption values for a given packaging material.



Source: [35, TWG 2023]

Figure 3-262: Number of plants that reported data on packaging material and consumption data

Figure 3-263 presents the distribution of average packaging material consumption levels reported by the plants.



Source: [35, TWG 2023]

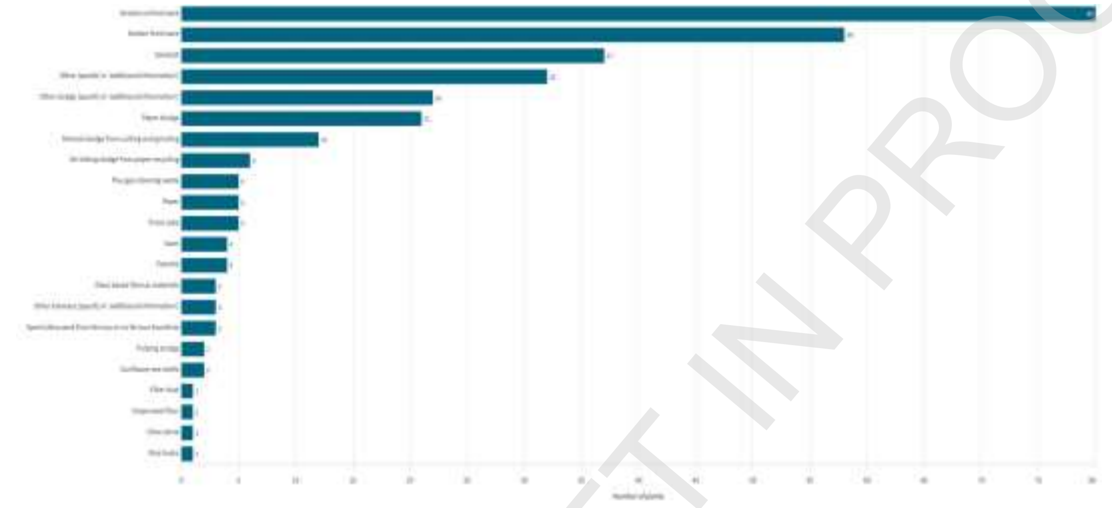
Figure 3-263: Average packaging material consumption levels by plants

3.10 Circular economy and decarbonisation

This section covers reported data and information of participating plants for circular economy and decarbonisation. The plants reported data on the use of secondary raw materials, supply of secondary raw material to other industries, energy recovery, and recycled products, innovative solutions for production and process steps, techniques applied for decarbonisation and to reduce carbon dioxide (CO_2) emissions.

Broken unfired and fired ware and sawdust are commonly used as secondary raw material.

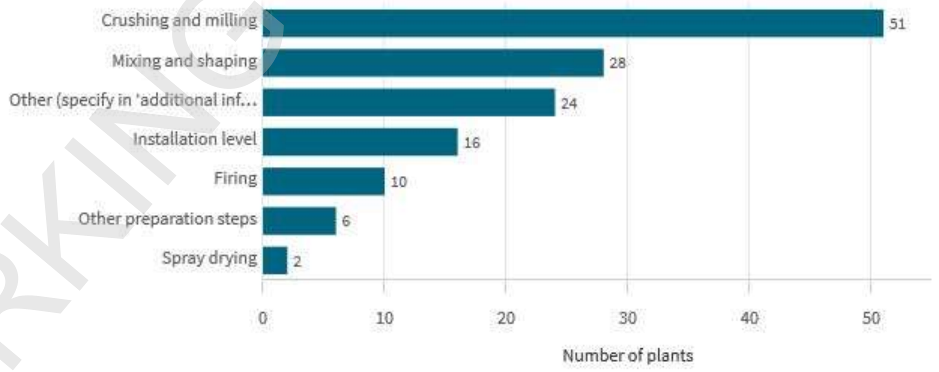
Figure 3-264 shows the reported data on secondary raw material by number of plants.



Source: [35, TWG 2023]

Figure 3-264: Number of plants that reported data on secondary raw material

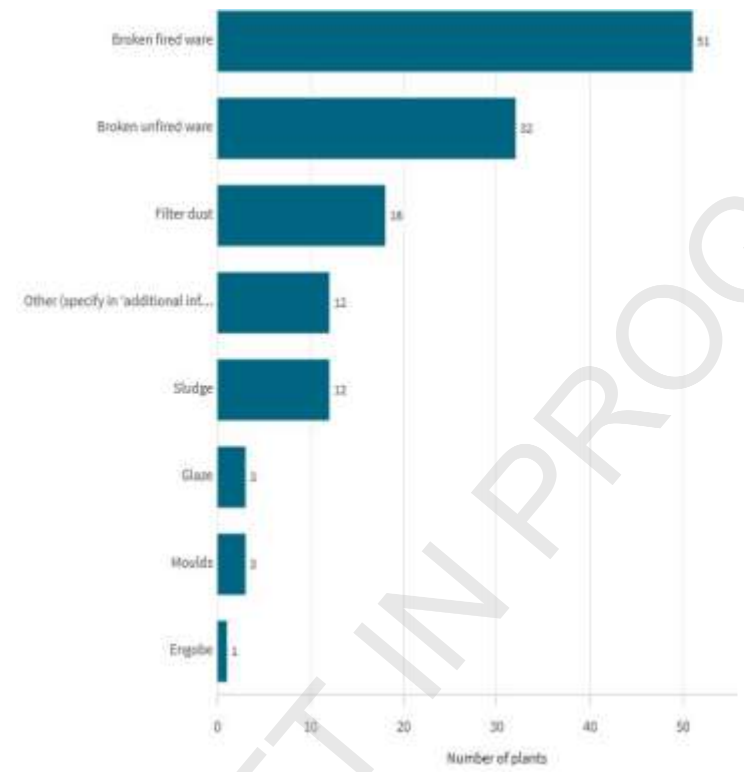
Figure 3-265 shows the associated process(es) using the secondary raw material. Crushing and milling is the most commonly reported process step using secondary raw material.



Source: [35, TWG 2023]

Figure 3-265: Share of associated process(es) using the secondary raw material

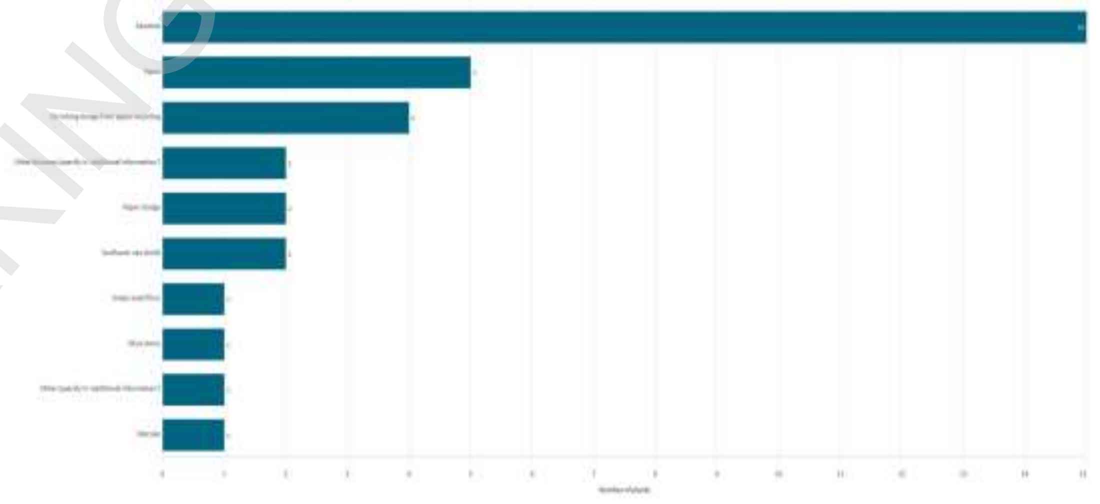
According to the reported data, plants generate and supply secondary raw material to other industries (e.g. cement manufacturing, forestry and agriculture and mainly to other ceramic manufacturing plants). The crushing and grinding process is the most commonly reported process step that generates secondary raw material. Figure 3-266 presents the number of plants reporting secondary raw material generation.



Source: [35, TWG 2023]

Figure 3-266: Number of plants reporting generation of secondary raw material

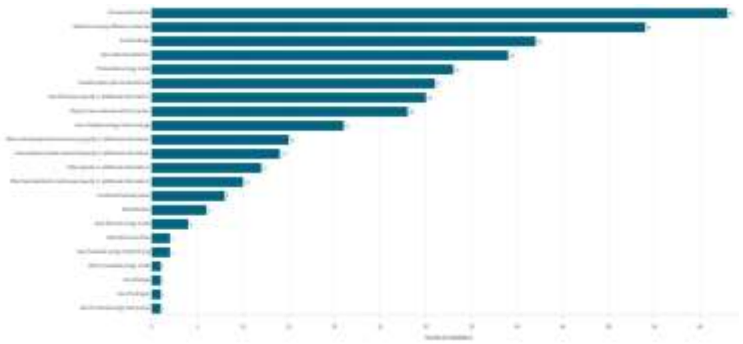
Plants reported data on energy recovery from waste/residues. Figure 3-267 shows the number of plants that reported energy recovery from various waste/residues and the share of fuel replaced from the recovery (e.g. natural gas, coke).



Source: [35, TWG 2023]

Figure 3-267: Number of plants that reported data on energy recovery from waste/residues

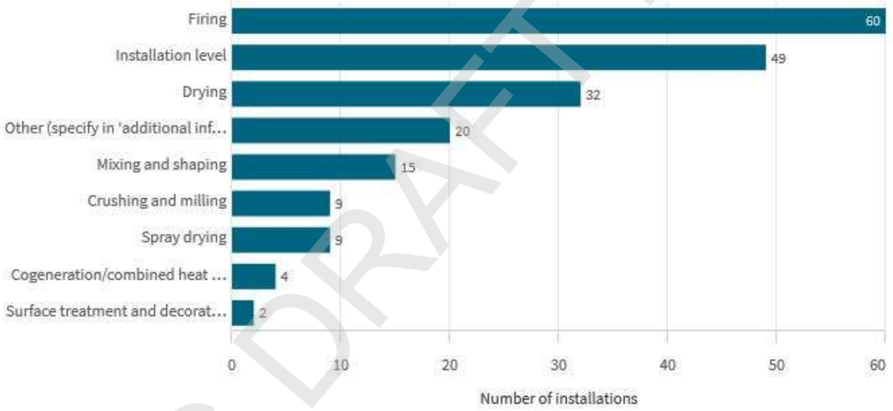
Plants also reported data on applied techniques for decarbonisation. Figure 3-268 shows the techniques applied for decarbonisation by number of plants.



Source: [35, TWG 2023]

Figure 3-268: Techniques applied for decarbonisation

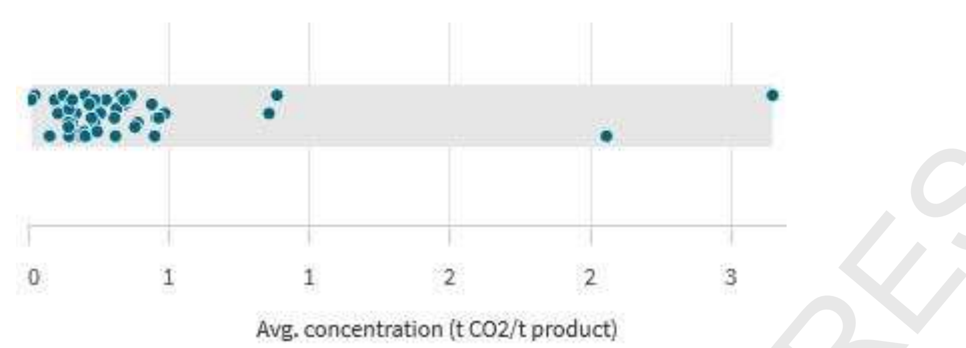
Techniques for decarbonisation are applied for various process(es). Figure 3-269 shows the number of plants that reported applying techniques during associated process(es). Material or energy efficiency measures are mostly applied in firing process and at plant/installation level. The use of residual energy and the heat exchange technique is applied commonly in drying process.



Source: [35, TWG 2023]

Figure 3-269: Techniques applied during associated process(es)

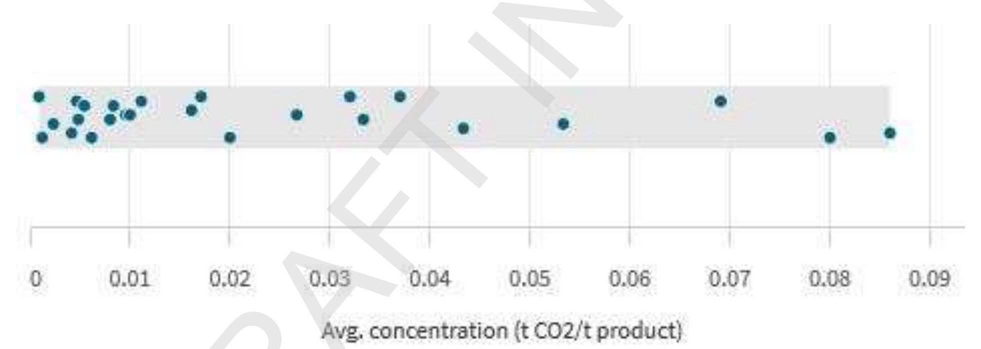
With regards to the carbon dioxide (CO_2) emission levels of plants, out of 199 plants, 145 reported data on CO_2 emissions. Figure 3-270 shows the distribution of average CO_2 emissions by plant.



Source: [35, TWG 2023]

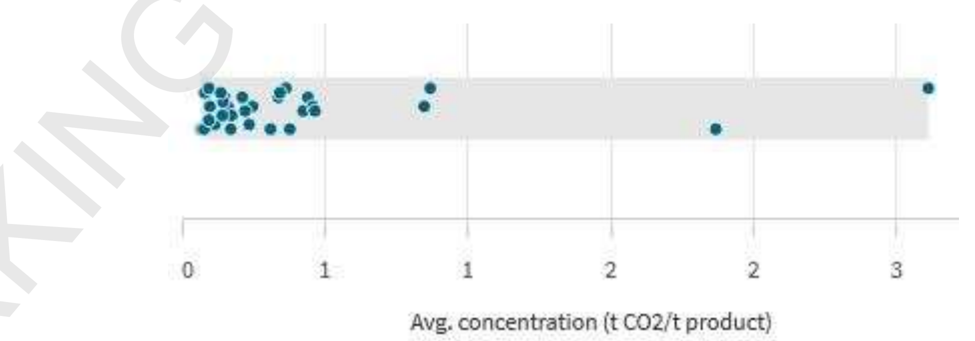
Figure 3-270: Distribution of average CO_2 emissions by plant

The CO_2 emissions are mainly released from the calcination process (from calcination of carbonates and other carbon contained naturally in the clay) and caused by various types of fuel use (i.e. process to which fuel emissions relate, e.g. kiln, kiln and spray dryer, kiln and ware dryer, other). Figure 3-271 and Figure 3-272 show the average CO_2 emissions from calcination and fuel use.



Source: [35, TWG 2023]

Figure 3-271: Distribution of average CO_2 emissions from calcination



Source: [35, TWG 2023]

Figure 3-272: Distribution of average CO_2 emissions from fuel use

4 TECHNIQUES TO CONSIDER IN THE DETERMINATION OF BAT ~~FOR CERAMIC MANUFACTURING~~

4.1 Introduction

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

This section 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 measures used to prevent or to limit the environmental consequences of accidents and incidents, as well as site remediation measures. 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 section does not necessarily provide an exhaustive list of techniques that could be applied in the ceramic manufacturing industry. Other techniques may exist, or may be developed, which could be considered in the determination of BAT for an individual installations.

Table 4-1: Information for each techniques to consider in the determination of BAT

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 main 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.).

Heading within the sections	Type of information included
Environmental performance and operational data	Actual and plant-specific 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. Any other useful information on the following items: • how to design, operate, maintain, control and decommission the technique; • emission monitoring issues related to the use of the technique; • sensitivity and durability of the technique; • issues regarding accident prevention. 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 environmental performance levels cannot be achieved at the same time. 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). 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.
Cross-media effects	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: • consumption and nature of raw materials and water; • energy consumption and contribution to climate change; • stratospheric ozone depletion potential; • photochemical ozone creation potential; • acidification resulting from emissions to air; • presence of particulate matter in ambient air (including microparticles and metals); • eutrophication of land and waters resulting from emissions to air or water; • oxygen depletion potential in water; • persistent/toxic/bioaccumulable components (including metals); • generation of residues/waste; • limitation of the ability to reuse or recycle residues/waste; • generation of noise and/or odour; • increased risk of accidents. The Reference Document on Economics and Cross-media Effects (ECM) should be taken into account.

Heading within the sections	Type of information included
Technical considerations relevant to applicability	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: • an indication of the type of plants or processes within the sector to which the technique cannot be applied; • constraints to implementation in certain generic cases, considering, e.g.: - 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; - plant size, capacity or load factor; - quantity, type or quality of product manufactured; - type of fuel or raw material used; - animal welfare; - climatic conditions. These restrictions are indicated together with the reasons for them. 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.
Economics	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. 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. Information on the market for the sector is given in order to put costs of techniques into context. 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 and possible economic limitations to its application. 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. 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.
Driving force for implementation	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. This subsection should be very short and use a list of bullet points.
Example plants	Reference(s) 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 may be provided of the degree to which the technique is in use in the EU or worldwide.
Reference literature	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).

~~This chapter sets out techniques considered generally to have potential for achieving a high level of environmental protection in the industries within the scope of this document. Management systems, process-integrated techniques and end-of-pipe measures are included, but a certain amount of overlap exists between these three when seeking the optimum results.~~

~~Prevention, control, minimisation and recycling procedures are considered as well as the re-use of materials and energy.~~

~~Techniques may be presented singly or as combinations to achieve the objectives of IPPC. Annex IV to the Directive lists a number of general considerations to be taken into account when determining BAT and techniques within this chapter will address one or more of these considerations. As far as possible a standard structure is used to outline each technique, to enable comparison of techniques and an objective assessment against the definition of BAT given in the Directive.~~

~~The content of this chapter is not an exhaustive list of techniques and others may exist or be developed which may be equally valid within the framework of BAT.~~

~~Generally, a standard structure is used to outline each technique, as shown in Table 4.1:~~

~~**Type of information considered**~~	~~**Type of information included**~~
~~Description~~	~~Technical description of the technique~~
~~Achieved environmental benefits~~	~~Main environmental impact(s) to be addressed by the technique (process or abatement), including emission values achieved and efficiency performance. Environmental benefits of the technique in comparison with others~~
~~Cross-media effects~~	~~Any side-effects and disadvantages caused by implementation of the technique. Details on the environmental problems of the technique in comparison with others~~
~~Operational data~~	~~Performance data on emissions/wastes and consumption (raw materials, water and energy). Any other useful information on how to operate, maintain and control the technique, including safety aspects, operability constraints of the technique, output quality, etc.~~
~~Applicability~~	~~Consideration of the factors involved in applying and retrofitting the technique (e.g. space availability, process specific)~~
~~Economics~~	~~Information on costs (investment and operation) and any possible savings (e.g. reduced raw material consumption, waste charges) also as related to the capacity of the technique~~
~~Driving force for implementation~~	~~Reasons for implementation of the technique (e.g. other legislation, improvement in production quality)~~
~~Example plants~~	~~Reference to plants where the technique is reported to be used~~
~~Reference literature~~	~~Literature for more detailed information on the technique~~

~~As the boundaries between the elements mentioned above may overlap to a certain extent, the structure is kept flexible, reflecting the particular individual case.~~

~~The costs for abatement techniques have to be evaluated in relation to the size of the installations, the effectiveness of the techniques and the circumstances of the individual application. In this context, Table 4-8 gives examples about investment costs, maintenance costs, costs for sorbents and operational costs for the abatement of dust, inorganic gaseous compounds and organic gaseous compounds by using different abatement techniques [32, TWG 2006].~~

~~Regarding the standard conditions for measurements of volume flows and concentrations, see the following definitions, which are also stated in the Glossary:~~

~~m^3/h~~	~~volume flow: if not otherwise mentioned in this document, the volume flows refer to 18 vol-% oxygen and standard state.~~
~~mg/m^3~~	~~concentration: if not otherwise mentioned in this document, the concentrations of gaseous substances or mixtures of substances refer to dry flue-gas at 18 vol-% oxygen and standard state, and benzene concentrations refer to 15 vol-% oxygen and standard state.~~
~~standard state~~	~~refers to a temperature of 273 K and a pressure of 1013 hPa.~~

4.2 General techniques

[Note to the TWG: the techniques in this section are in general widely used. Please provide further example plants from the data collection.]

4.2.1 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).

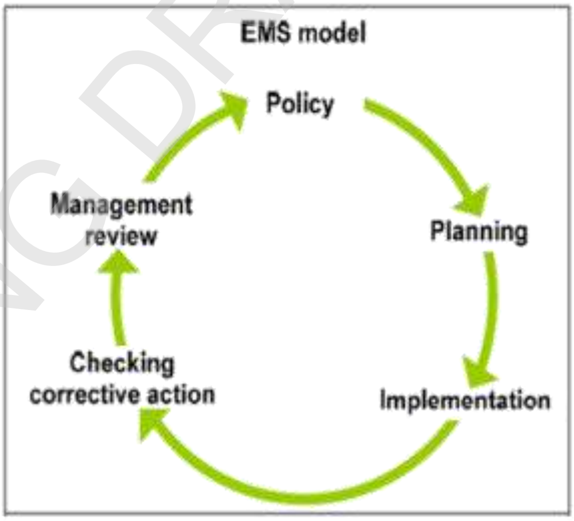


Figure 4-1: Continuous improvement in an EMS model

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 Directive 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;
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 ceramic manufacturing industry, the following features are included in the EMS:

xxi. an inventory of inputs and outputs (see Section 4.2.2);
xxii. a chemicals management system (see Section 4.2.3);
xxiii. a plan for the prevention and control of leaks and spillages (see Section 4.2.4.1);
xxiv. an OTNOC management plan (see Section 4.2.4);
xxv. an energy efficiency plan and audits (see Section 4.3.2);
xxvi. a residues management plan (see Section 4.4.1);
xxvii. a water management plan and audits (see Section 4.5.1);
xxviii. a noise management plan (see Section 4.9.1);
xxix. an odour management plan (see Section 4.10.1).

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
[Note to the TWG: please provide information]

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

[Note to the TWG: please provide information]

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

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

Example plants
EMSs are applied in a number of installations throughout the EU. A total of 90 installations in the data collection reported applying an environmental management system according to the EMAS Regulation or ISO 14000.

Reference literature
[53, EU 2009], [54, COM 2023], [55, CEN 2015]

~~4.8 Environmental management tools~~

~~Description~~

~~The best environmental performance is usually achieved by the installation of the best technology and its operation in the most effective and efficient manner. This is recognised by the IPPC Directive definition of 'techniques' as *"both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned"*.~~

~~For IPPC installations an Environmental Management System (EMS) is a tool that operators can use to address these design, construction, maintenance, operation and decommissioning issues in a systematic, demonstrable way. An EMS includes the organisational structure, responsibilities, practices, procedures, processes and resources for developing, implementing, maintaining, reviewing and monitoring the environmental policy. Environmental Management Systems are most effective and efficient where they form an inherent part of the overall management and operation of an installation.~~

~~Within the European Union, many organisations have decided on a voluntary basis to implement environmental management systems based on EN ISO 14001:2004 or the EU Eco-management and audit scheme EMAS. EMAS includes the management system requirements of EN ISO 14001, but places additional emphasis on legal compliance, environmental performance and employee involvement; it also requires external verification of the management system and validation of a public environmental statement (in EN ISO 14001 self-declaration is an alternative to external verification). There are also many organisations that have decided to put in place non-standardised EMSs.~~

~~While both standardised systems (EN ISO 14001:2004 and EMAS) and non-standardised ("customised") systems in principle take the *organisation* as the entity, this document takes a more narrow approach, not including all activities of the organisation e.g. with regard to their products and services, due to the fact that the regulated entity under the IPPC Directive is the *installation* (as defined in Article 2).~~

~~An environmental management system (EMS) for an IPPC installation can contain the following components:~~

~~(a) definition of an environmental policy~~
~~(b) planning and establishing objectives and targets~~
~~(c) implementation and operation of procedures~~
~~(d) checking and corrective action~~
~~(e) management review~~
~~(f) preparation of a regular environmental statement~~
~~(g) validation by certification body or external EMS verifier~~
~~(h) design considerations for end-of-life plant decommissioning~~
~~(i) development of cleaner technologies~~
~~(j) benchmarking.~~

~~These features are explained in somewhat greater detail below. For detailed information on components (a) to (g), which are all included in EMAS, the reader is referred to the reference literature indicated below.~~

~~(a) Definition of an environmental policy~~

~~Top management are responsible for defining an environmental policy for an installation and ensuring that it:~~

- ~~is appropriate to the nature, scale and environmental impacts of the activities~~
- ~~includes a commitment to pollution prevention and control~~
- ~~includes a commitment to comply with all relevant applicable environmental legislation and regulations, and with other requirements to which the organisation subscribes~~
- ~~provides the framework for setting and reviewing environmental objectives and targets~~
- ~~is documented and communicated to all employees~~
- ~~is available to the public and all interested parties.~~

~~(b) Planning, i.e.:~~

- ~~procedures to identify the environmental aspects of the installation, in order to determine those activities which have or can have significant impacts on the environment, and to keep this information up-to-date~~
- ~~procedures to identify and have access to legal and other requirements to which the organisation subscribes and that are applicable to the environmental aspects of its activities~~
- ~~establishing and reviewing documented environmental objectives and targets, taking into consideration the legal and other requirements and the views of interested parties~~
- ~~establishing and regularly updating an environmental management programme, including designation of responsibility for achieving objectives and targets at each relevant function and level as well as the means and timeframe by which they are to be achieved.~~

~~(c) Implementation and operation of procedures~~

~~It is important to have systems in place to ensure that procedures are known, understood and complied with, therefore effective environmental management includes:~~

~~(i) Structure and responsibility~~
- ~~defining, documenting and communicating roles, responsibilities and authorities, which includes appointing one specific management representative~~
- ~~providing resources essential to the implementation and control of the environmental management system, including human resources and specialised skills, technology and financial resources.~~

~~(ii) Training, awareness and competence~~

- ~~identifying training needs to ensure that all personnel whose work may significantly affect the environmental impacts of the activity have received appropriate training.~~

~~(iii) Communication~~
- ~~establishing and maintaining procedures for internal communication between the various levels and functions of the installation, as well as procedures that foster a dialogue with external interested parties and procedures for receiving, documenting and, where reasonable, responding to relevant communication from external interested parties.~~

~~(iv) Employee involvement~~
- ~~involving employees in the process aimed at achieving a high level of environmental performance by applying appropriate forms of participation such as the suggestion-book system or project-based group works or environmental committees.~~

~~(v) Documentation~~

- ~~establishing and maintaining up-to-date information, in paper or electronic form, to describe the core elements of the management system and their interaction and to provide direction to related documentation.~~

~~(vi) Efficient process control~~

- ~~adequate control of processes under all modes of operation, i.e. preparation, start-up, routine operation, shutdown and abnormal conditions~~
- ~~identifying the key performance indicators and methods for measuring and controlling these parameters (e.g. flow, pressure, temperature, composition and quantity)~~
- ~~documenting and analysing abnormal operating conditions to identify the root causes and then addressing these to ensure that events do not recur (this can be facilitated by a 'no-blame' culture where the identification of causes is more important than apportioning blame to individuals).~~

~~(vii) Maintenance programme~~

- ~~establishing a structured programme for maintenance based on technical descriptions of the equipment, norms etc. as well as any equipment failures and consequences~~
- ~~supporting the maintenance programme by appropriate record keeping systems and diagnostic testing~~
- ~~clearly allocating responsibility for the planning and execution of maintenance.~~

~~(viii) Emergency preparedness and response~~

- ~~establishing and maintaining procedures to identify the potential for and response to accidents and emergency situations, and for preventing and mitigating the environmental impacts that may be associated with them.~~

~~(d) Checking and corrective action, i.e.:~~

~~(i) Monitoring and measurement~~

- ~~establishing and maintaining documented procedures to monitor and measure, on a regular basis, the key characteristics of operations and activities that can have a significant impact on the environment, including the recording of information for tracking performance, relevant operational controls and conformance with the installation's environmental objectives and targets *(see also the Reference document on Monitoring of Emissions)*~~
- ~~establishing and maintaining a documented procedure for periodically evaluating compliance with relevant environmental legislation and regulations.~~

~~(ii) Corrective and preventive action~~

- ~~establishing and maintaining procedures for defining responsibility and authority for handling and investigating non-conformance with permit conditions, other legal requirements as well as objectives and targets, taking action to mitigate any impacts caused and for initiating and completing corrective and preventive action that are appropriate to the magnitude of the problem and commensurate with the environmental impact encountered.~~

~~(iii) Records~~

- ~~establishing and maintaining procedures for the identification, maintenance and disposition of legible, identifiable and traceable environmental records, including training records and the results of audits and reviews.~~

~~(iv) Audit~~

- ~~establishing and maintaining (a) programme(s) and procedures for periodic environmental management system audits that include discussions with personnel, inspection of operating conditions and equipment and reviewing of records and documentation and that results in a written report, to be carried out impartially and objectively by employees (internal audits) or external parties (external audits),~~

~~covering the audit scope, frequency and methodologies, as well as the responsibilities and requirements for conducting audits and reporting results, in order to determine whether or not the environmental management system conforms to planned arrangements and has been properly implemented and maintained~~

- ~~completing the audit or audit cycle, as appropriate, at intervals of no longer than three years, depending on the nature, scale and complexity of the activities, the significance of associated environmental impacts, the importance and urgency of the problems detected by previous audits and the history of environmental problems – more complex activities with a more significant environmental impact are audited more frequently~~
- ~~having appropriate mechanisms in place to ensure that the audit results are followed up.~~

~~(v) Periodic evaluation of legal compliance~~

- ~~reviewing compliance with the applicable environmental legislation and the conditions of the environmental permit(s) held by the installation~~
- ~~documentation of the evaluation.~~

~~(e) Management review, i.e.:~~

- ~~reviewing, by top management, at intervals that it determines, the environmental management system, to ensure its continuing suitability, adequacy and effectiveness~~
- ~~ensuring that the necessary information is collected to allow management to carry out this evaluation~~
- ~~documentation of the review.~~

~~(f) Preparation of a regular environmental statement:~~

- ~~preparing an environmental statement that pays particular attention to the results achieved by the installation against its environmental objectives and targets. It is regularly produced – from once a year to less frequently depending on the significance of emissions, waste generation etc. It considers the information needs of relevant interested parties and it is publicly available (e.g. in electronic publications, libraries etc.).~~

~~When producing a statement, the operator may use relevant existing environmental performance indicators, making sure that the indicators chosen:~~

~~i. give an accurate appraisal of the installation's performance~~
~~ii. are understandable and unambiguous~~
~~iii. allow for year on year comparison to assess the development of the environmental performance of the installation~~
~~iv. allow for comparison with sector, national or regional benchmarks as appropriate~~
~~v. allow for comparison with regulatory requirements as appropriate.~~

~~(g) Validation by certification body or external EMS verifier:~~

- ~~having the management system, audit procedure and environmental statement examined and validated by an accredited certification body or an external EMS verifier can, if carried out properly, enhance the credibility of the system.~~

~~(h) Design considerations for end-of-life plant decommissioning~~

- ~~giving consideration to the environmental impact from the eventual decommissioning of the unit at the stage of designing a new plant, as forethought makes decommissioning easier, cleaner and cheaper~~
- ~~decommissioning poses environmental risks for the contamination of land (and groundwater) and generates large quantities of solid waste. Preventive techniques are process-specific but general considerations may include:~~

- ~~i. avoiding underground structures~~
- ~~ii. incorporating features that facilitate dismantling~~
- ~~iii. choosing surface finishes that are easily decontaminated~~
- ~~iv. using an equipment configuration that minimises trapped chemicals and facilitates drain-down or washing~~
- ~~v. designing flexible, self-contained units that enable phased closure~~
- ~~vi. using biodegradable and recyclable materials where possible.~~

~~(i) Development of cleaner technologies:~~

~~– environmental protection should be an inherent feature of any process design activities carried out by the operator, since techniques incorporated at the earliest possible design stage are both more effective and cheaper. Giving consideration to the development of cleaner technologies can for instance occur through R&D activities or studies. As an alternative to internal activities, arrangements can be made to keep abreast with – and where appropriate – commission work by other operators or research institutes active in the relevant field.~~

~~(j) Benchmarking, i.e.:~~

~~– carrying out systematic and regular comparisons with sector, national or regional benchmarks, including for energy efficiency and energy conservation activities, choice of input materials, emissions to air and discharges to water (using for example the European Pollutant Emission Register, EPER), consumption of water and generation of waste.~~

~~Standardised and non-standardised EMSs:~~

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

~~Achieved environmental benefits~~

~~Implementation of and adherence to an EMS focuses the attention of the operator on the environmental performance of the installation. In particular, the maintenance of and compliance with clear operating procedures for both normal and abnormal situations and the associated lines of responsibility should ensure that the installation's permit conditions and other environmental targets and objectives are met at all times.~~

~~Environmental management systems typically ensure the continuous improvement of the environmental performance of the installation. The poorer the starting point is, the more significant short-term improvements can be expected. If the installation already has a good overall environmental performance, the system helps the operator to maintain the high performance level.~~

~~Cross-media effects~~

~~Environmental management techniques are designed to address the overall environmental impact, which is consistent with the integrated approach of the IPPC Directive.~~

~~Operational data~~

~~No specific information reported.~~

~~Applicability~~

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

~~Economics~~

~~It is difficult to accurately determine the costs and economic benefits of introducing and maintaining a good EMS. A number of studies are presented below. However, these are just examples and their results are not entirely coherent. They might not be representative for all sectors across the EU and should thus be treated with caution.~~

~~A Swedish study carried out in 1999 surveyed all 360 ISO-certified and EMAS-registered companies in Sweden. With a response rate of 50 %, it concluded among other things that:~~

- ~~the expenses for introducing and operating EMS are high but not unreasonably so, save in the case of very small companies. Expenses are expected to decrease in the future~~
- ~~a higher degree of co-ordination and integration of EMS with other management systems is seen as a possible way to decrease costs~~
- ~~half of all the environmental objectives and targets give payback within one year through cost savings and/or increased revenue~~
- ~~the largest cost savings were made through decreased expenditure on energy, waste treatment and raw materials~~
- ~~most of the companies think that their position on the market has been strengthened through the EMS. One-third of the companies report increasing revenue due to EMS.~~

~~In some Member States reduced supervision fees are charged if the installation has a certification.~~

~~A number of studies[3] show that there is an inverse relationship between company size and the cost of implementing an EMS. A similar inverse relationship exists for the payback period of invested capital. Both elements imply a less favourable cost-benefit relationship for implementing an EMS in SMEs compared to larger companies.~~

~~According to a Swiss study, the average cost for building and operating ISO 14001 can vary:~~

- ~~for a company with between 1 and 49 employees: CHF 64000 (EUR 44000) for building the EMS and CHF 16000 (EUR 11000) per year for operating it~~
- ~~for an industrial site with more than 250 employees: CHF 367000 (EUR 252000) for building the EMS and CHF 155000 (EUR 106000) per year for operating it.~~

~~These average figures do not necessarily represent the actual cost for a given industrial site because this cost is also highly dependent on the number of significant items (pollutants, energy consumption...) and on the complexity of the problems to be studied.~~

~~A recent German study (Schaltegger, Stefan and Wagner, Marcus, *Umweltmanagement in deutschen Unternehmen - der aktuelle Stand der Praxis*, February 2002, p. 106) shows the following costs for EMAS for different branches. *It can be noted that these figures are much lower than those of the Swiss study quoted above. This is a confirmation of the difficulty to determine the costs of an EMS.*~~

~~Costs for building (EUR):~~
- ~~minimum – 18750~~
- ~~maximum – 75000~~

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[3] ~~E.g. Dyllick and Hamschmidt (2000, 73) quoted in Klemisch H. and R. Holger, *Umweltmanagementsysteme in kleinen und mittleren Unternehmen – Befunde bisheriger Umsetzung*, KNI Papers 01/02, January 2002, p 15; Clausen J., M. Keil and M. Jungwirth, *The State of EMAS in the EU.Eco-Management as a Tool for Sustainable Development – Literature Study*, Institute for Ecological Economy Research (Berlin) and Ecologic – Institute for International and European Environmental Policy (Berlin), 2002, p 15.~~

~~average - 50000~~

~~Costs for validation (EUR):~~
~~minimum - 5000~~
~~maximum - 12500~~
~~average - 6000~~

~~A study by the German Institute of Entrepreneurs (Unternehmerinstitut/Arbeitsgemeinschaft Selbständiger Unternehmer UNI/ASU, 1997, *Umweltmanagementbefragung - Öko-Audit in der mittelständischen Praxis - Evaluierung und Ansätze für eine Effizienzsteigerung von Umweltmanagementsystemen in der Praxis*, Bonn.) gives information about the average savings achieved for EMAS per year and the average payback time. For example, for implementation costs of EUR 80000 they found average savings of EUR 50000 per year, corresponding to a payback time of about one and a half years.~~

~~External costs relating to verification of the system can be estimated from guidance issued by the International Accreditation Forum (http://www.iaf.nu).~~

~~Driving forces for implementation~~

~~Environmental management systems can provide a number of advantages, for example:~~

- ~~improved insight into the environmental aspects of the company~~
- ~~improved basis for decision-making~~
- ~~improved motivation of personnel~~
- ~~additional opportunities for operational cost reduction and product quality improvement~~
- ~~improved environmental performance~~
- ~~improved company image~~
- ~~reduced liability, insurance and non-compliance costs~~
- ~~increased attractiveness for employees, customers and investors~~
- ~~increased trust of regulators, which could lead to reduced regulatory oversight~~
- ~~improved relationship with environmental groups.~~

~~Example plants~~

~~The features described under (a) to (e) above are elements of EN ISO 14001:2004 and the European Community Eco-Management and Audit Scheme (EMAS), whereas the features (f) and (g) are specific to EMAS. These two standardised systems are applied in a number of IPPC installations. As an example, 357 organisations within the EU chemical and chemical products industry (NACE code 24) were EMAS registered in July 2002, most of which operate IPPC installations.~~

~~In the UK, the Environment Agency of England and Wales carried out a survey among IPC (the precursor to IPPC) regulated installations in 2001. It showed that 32 % of respondents were certified to ISO 14001 (corresponding to 21 % of all IPC installations) and 7 % were EMAS registered. All cement works in the UK (around 20) are certified to ISO 14001 and the majority are EMAS registered. In Ireland, where the establishment of an EMS (not necessarily of a standardised nature) is required in IPC licenses, an estimated 100 out of approximately 500 licensed installations have established an EMS according to ISO 14001, with the other 400 installations having opted for a non-standardised EMS.~~

~~Reference literature~~

~~(Regulation (EC) No 761/2001 of the European parliament and of the council allowing voluntary participation by organisations in a Community eco-management and audit scheme (EMAS), OJ L 114, 24/4/2001, http://europa.eu.int/comm/environment/emas/index_en.htm)~~

~~(EN ISO 14001:2004, http://www.iso.ch/iso/en/iso9000-14000/iso14000/iso14000index.html; http://www.tc207.org)~~

4.2.2 Inventory of inputs and outputs

Description

The compilation of relevant basic data on input and ouput streams of resources (e.g. inputs like raw materials, chemicals, energy, water, and outputs like waste gases, waste waters, residues, energy losses). Basic data for streams include information on environmentally important characteristics, like the 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.

As part of the EMS (see Section 4.2.1), an inventory of inputs and outputs that incorporates all of the following features has to be established, maintained and regularly reviewed (including when a significant change occurs):

i. information about the production processes, including:
    a) simplified process flow sheets that show the origin of the emissions to air, water and soil and the associated emission point(s);
    b) descriptions of process-integrated techniques and waste gas/waste water treatment techniques to prevent or reduce emissions, including their performance (e.g. abatement efficiency);
ii. information about the quantity and characteristics of raw materials (e.g. clay, additives) and fuels (e.g. natural gas, coke) used;
iii. information about energy consumption and usage;
iv. information about water consumption and usage (e.g. flow diagrams and water mass balances);
v. information about the quantity and characteristics of residues generated;
vi. information about the quantity and characteristics of the process chemicals used:
    a) the identity and the characteristics of process chemicals (e.g. additives, binders, glazes), including properties with adverse effects on the environment and/or human health;
    b) the quantities of process chemicals used and the location of their use;
vii. 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, NOX, SOX, HCl, HF, TVOC) and their variability;
    c) presence of other substances that may affect the waste gas treatment system (e.g. oxygen, water vapour) or installation safety;
viii. information about the 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 of relevant substances/parameters (e.g. total suspended solids, TOC or COD, hydrocarbon oil index, metals) and their variability.

Achieved environmental benefits
The evaluation and inventory of input/output mass streams described is an essential management tool for the identification of optimisation potential, both environmental and economic. It is a prerequisite for a continuous improvement process.

Environmental performance and operational data
The application of such a management tool requires 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. The level of detail and the degree of formalisation 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
Associated personnel cost.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plant
Widely used.

Reference literature
[39, COM 2022]

4.2.3 Chemicals Management System

Description
The chemicals management system (CMS) is part of the EMS (see Section 4.2.1) and is a set of technical and organisational measures to limit the impact of the use of process chemicals on the environment.

Technical description
In order to improve the overall environmental performance, a chemicals management system (CMS), as part of the EMS, is drawn up and implemented.

The CMS contains the following features:

i. A policy to reduce the consumption of 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 to avoid 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, eco-toxicity and potential to be released into the environment in order to reduce emissions to the environment;

b) the characterisation of the risks associated with the process chemicals, based on the chemicals' hazards classification, pathways through the plant, potential release and level of exposure;
c) the potential for recovery and reuse (See Section 4.4);
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 hazardous substances and substances of very high concern; this may be achieved by changing process(es) or using other process chemicals with no or lower environmental impacts (See Section 4.6);
e) the anticipatory monitoring of regulatory changes related to hazardous substances and substances of very high concern, and the safeguarding of compliance with applicable legal requirements.

The inventory of process chemicals (see Section 4.2.2) may be used to provide and keep the information needed for the selection of process chemicals.

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, disposal of waste containing process chemicals and return of unused process chemicals, to prevent or reduce emissions to the environment.

Achieved environmental benefits

- Improvement of the overall environmental performance.
- Reduction of the use of hazardous chemicals.
- Reduction of emissions of hazardous chemicals to the environment.
- Reduction of the amount of hazardous chemicals in waste.

Environmental performance and operational data
[Note to the TWG: please provide information.]

Cross-media effects
None.

Technical considerations relevant to applicability
The level of detail and degree of formalisation of the CMS will generally be related to the nature, scale and complexity of the installation.

Economics
[Note to the TWG: please provide information.]

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants
Widely used. A total of 30 installations in the data collection reported applying a chemicals management system and 27 installations reported applying an inventory of chemicals.

Reference literature
[19, COM 2023], [35, TWG 2023]

4.2.4 Prevention or reduction of emissions to soil and groundwater

4.2.4.1 Set-up and implementation of a plan for the prevention and control of leaks and spillages

Description

A plan for the prevention and control of leaks and spillages is part of the EMS (see Section 4.2.1) and includes techniques such as:

- site incident plans for small and large spillages;
- identification of the roles and responsibilities of persons involved;
- ensuring staff are environmentally aware and trained to prevent and deal with spillage incidents;
- identification of areas at risk of spillage and/or leaks of hazardous materials and substances of very high concern, and ranking them according to the risk;
- identification of suitable spillage containment and clean-up equipment and regularly ensuring it is available, in good working order and close to points where these incidents may occur;
- waste management guidelines for dealing with waste arising from spillage control;
- regular inspections (at least on an annual basis) of storage and handling areas, testing and calibration of leak detection equipment and prompt repair of leaks from valves, glands, flanges, etc.

Achieved environmental benefits

This technique prevents or minimises the contamination of surface waters, groundwaters and soils, and assists in site decontamination on cessation of activities.

Environmental performance and operational data

Small spills are likely to happen more often and the sum effect of these if not detected and dealt with is significant increases of fugitive emissions to air, soil and groundwater.

Cross-media effects

None.

Technical considerations relevant to applicability

The level of detail and the degree of formalisation of the plan will generally be related to the nature, scale and complexity of the installation, as well as to the type and quantity of liquids used.

Economics

The following costs need to be considered:

- staff time for training and updating plans;
- materials savings through the minimisation of spillage;
- use of materials for spillage clean-up.

Driving force for implementation

- Reduced risks of liability from contamination.
- Reduced risks of associated accidents, e.g. preventing slippery floors, risk of fire.

Example plants

Widely used.

Reference literature

[39, COM 2022]

4.2.4.2 Structuring and management of process areas and raw material storage areas

Description
Process areas and raw material storage areas are structured and managed.

This includes techniques such as:

- impermeable (e.g. cemented) floors for process areas and for fuel yards;
- containment bunds for storage tanks;
- separate storage for fuels and additives, close to the production lines; this can be achieved using, for example, compartments or boxes in the storage areas, bunkers;
- dedicated area for unloading process chemicals and fuels.

Technical description
Structuring and management of process areas and storage areas, ensuring that raw materials and fuels are efficiently stored and handled.

The materials are well sorted, kept in a dry area under roofing (see Section 4.2.4.3) or in closed storage containers and can be quickly delivered to the production line.

Achieved environmental benefits

- Prevention or minimisation of the contamination of surface water, groundwater and soil.
- Efficient raw material management.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation

- Efficient raw material management.
- Local conditions.

Example plants
Widely used.

Reference literature
[39, COM 2022]

4.2.4.3 Prevention of contamination of surface run-off water

Description
Production areas and/or areas where process chemicals, fuels, residues or waste are stored or handled are protected against surface run-off water. This is achieved by using at least the following techniques:

- rainage channels and/or an outer kerb bund around the plant;

- roofing with roof guttering of process and/or storage areas.

Technical description
By using drainage channels and/or an outer kerb bund around the plant, surface run-off water is collected and process areas and storage areas (for fuels, chemicals, residues and waste) are protected against surface run-off water.

A roof constructed over the storage area can help keep rainwater out.

Achieved environmental benefits

- Prevention of contamination of surface run-off water.
- Reduction of waste water generation.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided.

Driving force for implementation

- Protection of process and storage areas against surface run-off water.
- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
[39, COM 2022]

4.2.4.4 Collection of potentially contaminated surface run-off water

Description
Surface run-off water from areas that are potentially contaminated is collected separately and only discharged after appropriate measures are taken, e.g. monitoring (see Section 4.2.6), treatment (see Section 4.8), reuse (see Section 4.5.5).

Achieved environmental benefits

- Avoidance of cross-contamination of uncontaminated water streams.
- Reduction of waste water generation.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable.

Economics
Costs associated with the collection and potential treatment processes.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
[39, COM 2022]

4.2.4.5 Safe handling and storage of fuels and chemicals

Description
Storage and handling of fuels and chemicals avoiding leakages and penetration into the ground.

Technical description
This includes techniques such as:

- storage in roofed and ventilated areas with floors impermeable to the liquids concerned;
- use of oil-tight trays or cellars for hydraulic stations and oil- or grease-lubricated equipment;
- collection of spilled liquid;
- construction of loading/unloading areas for fuels, process chemicals, lubricants, etc. in such a way that potential leaks and spillages are contained and sent to on-site treatment or off-site treatment.

Accidental releases are prevented by periodic checks and preventive maintenance of seals, gaskets, pumps and piping.

Achieved environmental benefits

- Prevention of contamination of surface and groundwater.
- Avoidance/reduction of generation of waste chemicals.
- Reduction of the amount of waste chemicals unsuitable for further use.

Environmental performance and operational data
No information provided.

Cross-media effects
None.

Technical considerations relevant to applicability
Generally applicable. This technique applies to all new and existing installations.

Economics
No information provided.

Driving force for implementation

- Safety measures and optimisation of operations.
- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
[15, COM 2022]

4.2.4.6 Good housekeeping

Description
A set of measures aiming at preventing, or reducing, the generation of emissions (e.g. regular maintenance and cleaning of equipment, work surfaces, floors and transport routes, and containment as well as rapid clean-up of spillages).

Technical description
This includes techniques such as:

- regular maintenance and cleaning of equipment;
- regular cleaning of work surfaces, floors and transport routes and vehicle tyres;
- visual inspections;
- containment as well as rapid clean-up of any spillages.

Achieved environmental benefits

- Prevention or reduction of fugitive emissions.
- Positive impact on occupational health.

Environmental performance and operational data
No information provided.

Cross-media effects
When maintenance is carried out, additional residues may occur.

Technical considerations relevant to applicability
Generally applicable.

Economics
For many companies, simple, affordable good housekeeping measures are being effectively applied to minimise diffuse emissions, improve efficiency, achieve a cleaner workplace and reduce costs.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants
Widely used.

Reference literature
[39, COM 2022]

4.2.5 Other than normal operating conditions (OTNOC) management plan

Description
A risk-based OTNOC management plan is part of the EMS (see Section 4.2.1) and is a set of measures to reduce the frequency of the occurrence of OTNOC and to reduce emissions during OTNOC.

Technical description
A 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;
ii. appropriate design of critical equipment (e.g. off-gas treatment, waste water treatment);
iii. set-up and implementation of an inspection and preventive maintenance plan for critical equipment (see Section 4.2.1, point xii. of the EMS);
iv. monitoring (i.e. estimating or, where possible, measuring) and recording of emissions during OTNOC and of associated circumstances;
v. periodic assessment of the emission 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 backup systems.

Other than normal operating conditions (OTNOC) are associated (among others) with the following periods/instances:

- start-up;
- shutdown;
- momentary stoppages;
- leaks (chemicals or water solutions);
- malfunction or breakdown of the abatement equipment or part of the equipment, if available;
- malfunction of instruments related to process control or emission monitoring;
- testing of new apparatus;
- calibration of the monitoring system.

In order to reduce the frequency of OTNOC and to reduce emissions during OTNOC, a risk-based OTNOC management plan as part of the environmental management system (see Section 4.2.1) is put into place and may include the elements described above.

Achieved environmental benefits
Emissions associated with shutdown and start-up operations and other OTNOC are in part avoided. Planning for and achieving a reduced number of shutdowns is likely to reduce the mass of pollutants emitted.

Environmental performance and operational data
Preventive maintenance and regular maintenance checks can prevent or avoid malfunctions regarding process control or emission abatement and monitoring equipment.

Preventive maintenance
Preventive maintenance is used to:

- ensure that any maintenance requiring switching off to deactivate emissions control equipment/systems (e.g. containment, extraction systems, off-gas treatment) is planned to take place when there are no emissions (e.g. during shutdown times) or when emission levels are low;

- replace parts and technical components that have suffered wear and tear and that require replacement on a regular basis, preferably planned to take place before breakdowns are likely;
- ensure that parts that are essential to the normal running of emission control equipment are kept in stock, can be replaced or repaired rapidly with minimum call-off times;
- carry out routine and non-routine maintenance including maintenance of covers and pipe joints for liquid and gaseous fuels, lubricants/chemicals storage and delivery systems.

Regular maintenance checks

A maintenance schedule and record of all inspections and maintenance activities is kept and includes the following:

- visually checking for leaking seals, flanges, valves, welds, tanks and vats;
- inspections by external experts where necessary;
- monitoring of key equipment for problems such as vibration, emission leaks and planning repairs (as above);
- test programmes, e.g. pressure-test pipelines and tanks, calibration of metering and monitoring equipment;
- checking the tightness of nuts and bolts;
- checking for wear and tear on machinery, valves and bunds, over-heating bearings, etc.;
- recalibrating metering systems;
- ensuring that extraction and abatement equipment is fully serviceable, if available.

Unplanned maintenance

Process operators and maintenance staff identify and report leaks, broken equipment, fractured pipes, etc. to focus unscheduled maintenance.

Cross-media effects

None.

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

Avoiding plant shutdowns can reduce costs by:

- allowing continuous throughput and hence greater installation utilisation;
- decreasing furnace maintenance due to lower thermal stress on the process.

Driving force for implementation

- Reduction of downtime.
- Maintains product quality and throughput.

Example plants

Widely used.

Reference literature

[39, COM 2022]

4.2.6 Monitoring

4.2.6.1 Monitoring resource consumption, waste generation and material recovery

Description

Real data are required on the precise effects of the activities of the industrial site on the environment. It is thus necessary to conduct a planned, regular sampling and monitoring programme. The parameters monitored include:

- the consumption of water, energy and materials used, including chemical substances and/or mixtures used in the process, expressed as a yearly average;
- the amount of waste water generated, expressed as a yearly average;
- the amount of each type of materials recovered, recycled and/or reused, expressed as a yearly average;
- the amount of each type of residues generated and of each type of waste sent for disposal, expressed as a yearly average.

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 to the most appropriate level (e.g. to process or plant level) and considers any significant changes in the process or plant.

Monitoring, however, is not restricted to analytical measuring. It also includes regular maintenance, and visual and safety checks.

In parallel to this document, and in relation to emissions to air and to water, the reader is referred to the Reference Report on Monitoring of Emissions to Air and Water from IED installations (ROM).

Achieved environmental benefits

Monitoring the parameters mentioned above (see Description) helps to maintain the proper operation of the facility and to detect instances of malfunctioning and thus helps to prevent any possible adverse environmental effects.

Environmental performance and operational data

[Note to TWG: please provide information.]

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

The costs associated with monitoring relate to personnel involved and equipment used.

Driving force for implementation

To ensure the proper operation of the installation.

Example plants

Widely used. A total of 166 plants in the data collection reported data on the yearly specific water consumption, 30 reported data on the yearly specific water discharge, and 135 plants reported data on the yearly amount of waste generated.

Reference literature
[35, TWG 2023]

4.2.6.2 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 responsible for generating 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 helps to maintain the proper operation 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 4-2 and Figure 4-3 summarise the information from the data collection on parameters monitored at emission points that monitor other parameters besides dust in ceramic manufacturing installations for emissions to air. These emission points correspond mainly to combustion processes (e.g. firing, drying) but also include other process steps such as surface treatment decoration or product finishing.

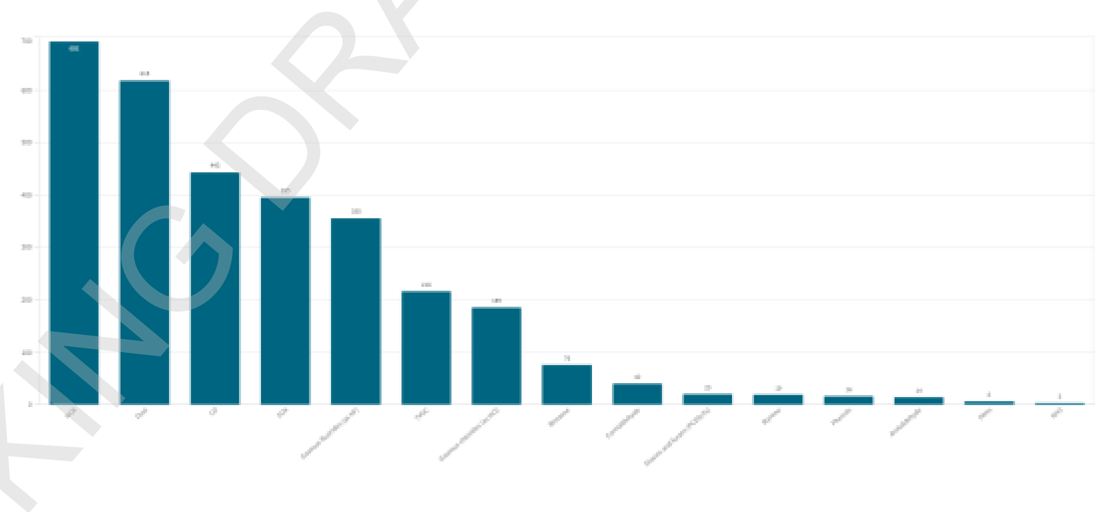


Figure 4-2: Number of emission points for emissions to air that monitor a given parameter (I)

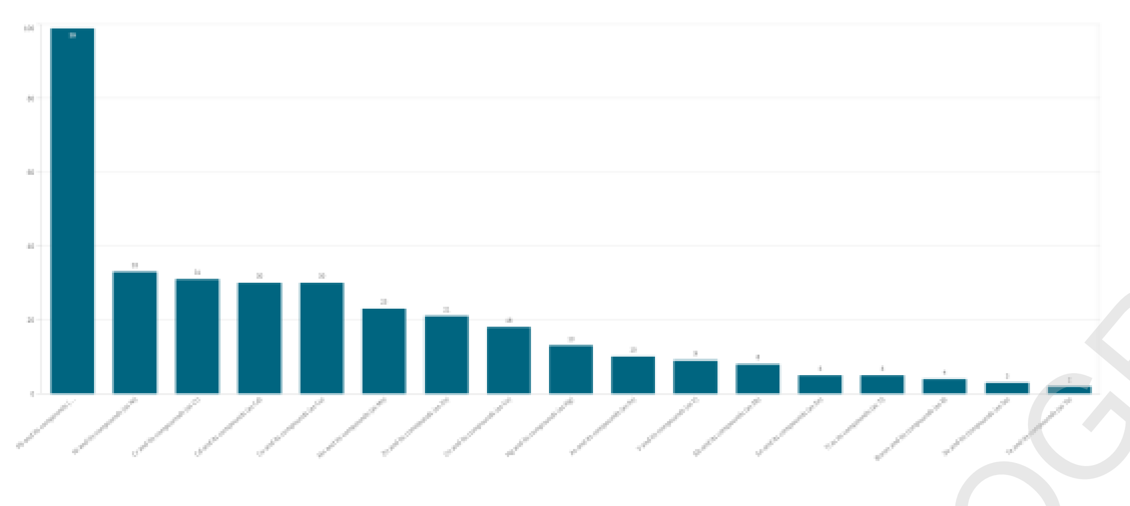


Figure 4-3: Number of emission points for emissions to air that monitor a given parameter (II)

Additionally, dust is the only parameter monitored in 716 emission points that correspond to processes where only dust is monitored (e.g. crushing, milling grinding, mixing, shaping, surface treatment, product finishing).

Cross-media effects
Some equipment, ancillary materials and energy are required for carrying out monitoring.

Technical considerations relevant to applicability
Generally applicable to all ceramic manufacturing installations where there are emissions to air.

Economics
The costs associated with monitoring the waste gas relate to the personnel and equipment used for sampling and measurement.

See the ROM [59, COM 2018] for more details.

Driving force for implementation
Environmental legislation.

Example plants
See examples in Chapter 3.

Reference literature
[59, COM 2018]

4.2.6.3 Monitoring of emissions to water

Description
Regular monitoring of emissions to water.

Technical description
Monitoring of the relevant parameters can be accomplished by online measurements (that facilitate rapid intervention and control of the waste water treatment plant (WWTP) or analytical results derived from waste water samples. Parameters to be monitored and the frequency of monitoring depend on the activities which 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 4-4 summarises the information from the data collection on parameters monitored in ceramic manufacturing installations for emissions to water.

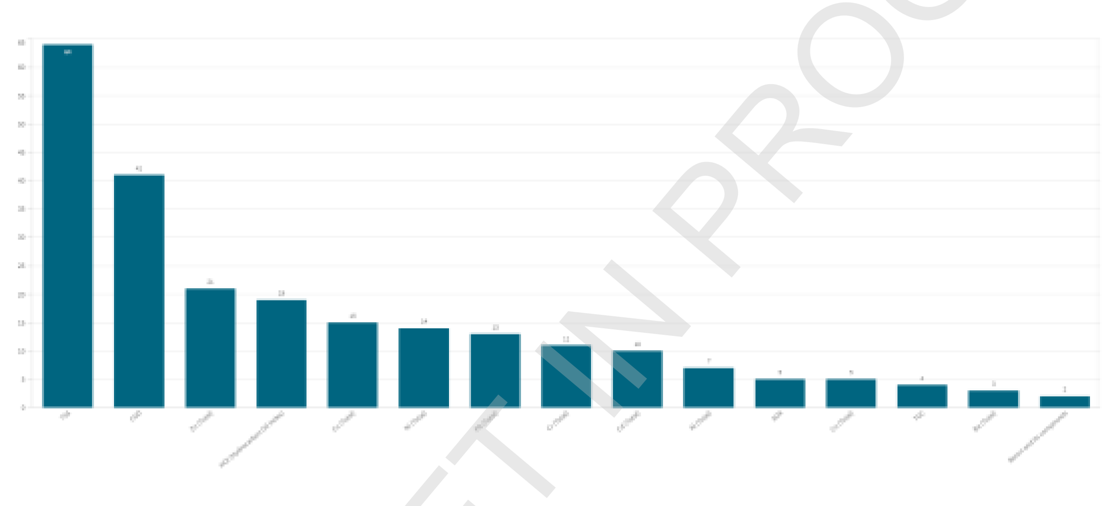


Figure 4-4: Number of emission points for emissions to water that monitor a given parameter

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 chromat).

Technical considerations relevant to applicability

Generally applicable to all ceramic manufacturing installations where there are emissions to water.

Economics

The costs associated with monitoring the effluent waste water of a waste water treatment plant relate to the personnel and equipment used for sampling and measurement.

See the ROM [59, COM 2018] for more details.

Driving force for implementation

Environmental legislation.

Example plants

See examples in Chapter 3.

Reference literature

[59, COM 2018]

4.3 Techniques to reduce the consumption of energy and for decarbonisation

[Note to the TWG: most of the information below was included in Section 4.1 of the 2007 CER BREF. Please provide information to complement and update the techniques in this section, especially on operational data, economics (e.g. CO_2 allowances), decomposition temperatures and cross-media effects]

~~4.1 Reduction of energy consumption (energy efficiency)~~

~~In this context, useful information can also be found in the Energy Efficiency Techniques reference document (ENE), which is currently being prepared.~~

4.3.1 Electrification of processes

Description
This includes techniques, such as:

- electric kilns and dryers;
- electric forklifts and conveyers.

Technical description
The technique consists of a switch from fuel-based processes to electrification as it allows the origin of energy source to be switched. It is not limited to a dedicated process; in fact, it can be considered in each process step of ceramic manufacturing. It includes techniques for thermal processes (e.g. electric kilns and dryers) as well as techniques for mechanical processes (e.g. electric forklifts and conveyers).

Achieved environmental benefits

- Decarbonisation as it allows the use of energy from renewable sources.
- Reduction of emissions such as dust, CO, SO_X and NO_X.

Environmental performance and operational data
[Note to TWG: please provide information.]

Cross-media effects
None.

Technical considerations relevant to applicability
Applicability may be restricted by technical specifications.

The following factors may need to be considered in relation to the applicability for thermal processes (electric or fuel-fired):

- *Availability of electrical power output:* The use of electricity in thermal processes is dependent on the available electrical power output (expressed in MW) that can be delivered from the nearby electrical grid. In some cases, the available power output from the electrical grid may be insufficient to supply the high power output required by electric kiln or dryer. In this case, strong power lines as well as transformers are required. Peak load management is important to coordinate the thermal processes with the power of the grid.
- *Infrastructure and operational modifications:* In ceramic manufacturing, thermal processes are usually continuously operated with a high product capacity. Switching to electric kilns and/or dryers may affect the production capacity for these continous processes.
- *Space availability:* In the evaluation of the viability of conversion to electric heating, the power or heat load requirements of the existing kilns and dryers and suitable electrical

supply infrastructure are important considerations. In general, conventional fuel-fired burners deliver a higher power density (kW/m^3) compared to electric heating. Therefore, electric heating elements may require more space compared to conventional burners.

Economics
The choice between the conversion of existing gas-fired kilns to electric ones or their replacement with new electric kilns and/or dryers will be based on the availability of both technical options and their respective costs.

Driving force for implementation
Decarbonisation and integrated pollution prevention in the CER sector.

Example plants
DE_100, AT_022 and BE_040.

In the manufacturing of some technical ceramics electrically heated kilns are used to a certain extent [9, COM 2007].

Reference literature
[35, TWG 2023], [37, COM 2022], [39, COM 2022], [56, COM 2023]

4.3.2 Use of electricity and heat from fossil-free energy sources

[Note to the TWG: Please provide information to complement and update, especially on operational data and economics]

Description
Use of electricity and heat generated from fossil-free energy sources (e.g. hydroelectric, solar, wind, alternative fossil-free fuels). This includes the use of electricity from fossil-free energy sources for heating.

Technical description
Using electricity/heat from fossil-free energy sources (e.g. for thermal processes, mechanical processes, transport and transfer) on site. Green energy certificates and/or a Guarantee of Origin as specified in Directive 2018/2001 on the promotion of the use of energy from renewable sources (e.g. hydroelectric, solar, wind, alternative fossil-free fuels) can provide information to the operator on the source of the energy supply. Electric energy may also be generated on site (e.g. solar panels, windmills, cogenearation using fossil-free fuels).

Fossil-free fuels, such as green gas and hydrogen can substitute the natural gas that is used for firing and drying by the ceramic plants [46, MIDDEN 2020].

Achieved environmental benefits
- Decarbonisation.
- Prevention or limitation of negative impacts on the environment as a whole, e.g. emissions to air from combustion for thermal processes, water and soil as well as use of resources and waste generation (integrated approach).

Environmental performance and operational data

Cross-media effects
Energy generation from fossil-free energy sources may have other environmental impacts such as air emissions (e.g. dust, SO_X, NO_X) depending on the type of alternative fuel used or noise emissions from wind turbines.

Technical considerations relevant to applicability
The use of alternative fuels may be restricted by technical specifications and the alternative fuel availability.

Economics
Cost will depend on technical and economic factors. The costs of fossil-free energy in comparison to fossil energy is a key economic factor, with sizeable differences across the EU.

Driving force for implementation
Reduction of the dependence from fossil energy and the global markets.

Example plants
Photovoltaic energy on site is widely used. Example of plants with wind turbines are BE_036 and BE_046. Several plants reported using a percentage of fossil-free fuels.

Reference literature
[35, TWG 2023], [15, COM 2022], [56, COM 2023]

4.3.3 Energy efficiency plan and audits

Description
An energy efficiency plan is part of the EMS (see Section 4.2.1) and entails defining and monitoring the specific energy consumption of the activities/processes (e.g. kWh/t of ceramic products manufactured), setting objectives in terms of energy efficiency and implementing actions to achieve these objectives.

Audits (also part of the EMS, see Section 4.2.1) are carried out at least once every year to ensure that the objectives of the energy plan are met and the audits' recommendations are followed up and implemented.

Technical description
Extensive information about energy efficiency can be found in the ENE BREF [60, COM 2009]. Some techniques applicable to increase the energy efficiency of ceramic manufacturing installations are as follows:

a) Appraising the costs and benefits of different energy options.
b) Monitoring energy flows (consumption and generation by source) and targeting areas for reductions.
c) Defining and calculating the specific energy consumption of the activity (or activities), and setting key performance indicators on an annual basis (e.g. MWh/t of ceramic product).
d) Carrying out an energy survey to identify the opportunities for further energy savings.
e) Using heat recovery techniques to recover heat from flue-gases and from product cooling air.
f) Using combined heat and power (CHP) (see Section 4.3.10).
g) Applying operating, maintenance and housekeeping measures to the most relevant energy-consuming systems, such as:
    - air conditioning and cooling systems (leaks, seals, temperature control, evaporator/condenser maintenance);
    - operation of motors and drives (e.g. high-efficiency motors);
    - compressed gas systems (leaks, procedures for use);
    - steam distribution systems (leaks, traps, insulation);
    - room heating and hot water systems;

  - lubrication to avoid high friction losses (e.g. mist lubrication);
  - burner maintenance and control;
  - boiler maintenance, e.g. optimising excess air;
  - other maintenance relevant to the activities within the installation;
  - reviewing equipment requirements on a regular basis.

h) Using techniques that reduce energy consumption and thereby reduce both direct (heat and emissions from on-site generation) and indirect (emissions from a remote power station) emissions. For example:
  - building insulation;
  - use of energy-efficient site lighting;
  - vehicle maintenance;
  - efficient plant layout to reduce pumping distances;
  - phase optimisation of electric motors;
  - heat recovery;
  - ensuring equipment is switched off, if safe to do so, when not in use;
  - ensuring on-site vehicle movements are minimised and engines are switched off when not in use.

i) 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 air (for example by fitting simple control systems).

j) Applying energy efficiency techniques to building services.

Energy audits are carried out at least once a year to to ensure that the objectives of the energy management plan are met. Audits may be carried out using elements of international standards which have been developed to support the implementation of energy audits under the Energy Efficiency Directive, e.g.:

- EN ISO 50001 on energy management systems which provides a framework of requirements for large installations.
- EN ISO 50005:2022 on energy management systems – Guidelines for a phased implementation. This standard provides guidance for organisations to establish a phased approach to implement an energy management system. This phased approach is intended to support and simplify the implementation of an energy management system in particular for small and medium-size installations.
- EN 16247-1:2012 on energy audits – Parts 1 and 3.
- EN ISO 50002:2014 on energy audits – Requirements with guidance for use.

Achieved environmental benefits

- Reduction of energy consumption.
- Reduction of emissions.
- Decarbonisation.

Environmental performance and operational data

Energy management systems are set up to suit local conditions and must be individually adapted to each business. Energy management software can often assist in recording energy demand, but requires metering infrastructure and the utilisation of specific software. Peak load management systems often help to reduce energy costs. By identifying the main energy consumers in the foundry operation, energy efficiency measures can be implemented in a targeted manner. Nevertheless, an energy management system shall also include the possibility not to implement uneconomical energy efficiency measures. An important element of energy management systems is the training of the energy team as well as all employees in the plant.

Cross-media effects
None identified.

Technical considerations relevant to applicability
The level of detail of the energy efficiency plan and of the energy audits will generally be related to the nature, scale and complexity of the installation and the types of energy sources used.

Economics
Associated personnel cost.

Driving force for implementation
Energy savings.

Example plants
Widely used. A total of 62 installations in the data collection reported having implemented an energy management system.

Reference literature
[35, TWG 2023], [60, COM 2009]

4.3.4 Energy balance record

Description
The technique involves drawing up an energy balance record once every year which provides a breakdown of the energy consumption and generation (including energy export) by the type of energy source, for example:

- energy consumption: electricity, natural gas, renewable energy, imported heat and/or cooling;
- energy generation: electricity and/or steam.

Technical description
This includes:

- definition of the energy boundaries of the processes;
- information on energy consumption in terms of delivered energy;
- information on energy exported from the plant;
- energy flow information (e.g. Sankey diagrams or energy balances) showing how the energy is used throughout the processes.

Achieved environmental benefits
Reduction of energy consumption.

Environmental performance and operational data
The reduction of emissions from the energy system can only be evaluated with a proper calculation of the actual emissions generated. The breakdown between generation and consumption can help to optimise the balance between them and hence to optimise the use of energy resources.

Cross-media effects
None identified.

Technical considerations relevant to applicability
The level of detail and the degree of formalisation of the energy balance record will generally be related to the nature, scale and complexity of the installation and the type of energy sources used.

Economics
The requirements are basic and cost little.

Driving force for implementation
Reduction of energy costs.

Example plants
Widely used.

Reference literature
[60, COM 2009]

4.3.5 Selection of an energy-efficient type of kiln

[Note to the TWG: Please provide information to complete the 10-heading template below]

Description
Kiln energy efficiency is taken into consideration in the kiln selection (e.g. kilns that allow longer residence time of air and flue-gases to heat the ware and combustion air are usually more energy-efficient).

Technical description

Achieved environmental benefits
Reduction of energy consumption.

Environmental performance and operational data

Cross-media effects

Technical considerations relevant to applicability
Only applicable to new plants and/or major upgrades.

Economics

Driving force for implementation
Reduction of energy consumption.

Example plants

Reference literature
[39, COM 2022]

4.3.6 Combustion optimisation

For a description of the technique, see Section 4.7.4.4.

4.3.7 Use of general energy-saving techniques

[Note to the TWG: Please provide information to complete the 10-heading template below]

Description
This includes techniques such as:

- burner maintenance and control;

- energy-efficient motors;
- energy-efficient lighting;
- process control systems;
- variable speed drives;
- use of frequency inverters for fans, compressors and pumps;
- optimising air conditioning and building heating.

Technical description

Optimisation of kilns, dryers and their operation will yield major efficiency improvements because drying and firing account for the majority of the total energy consumption. Energy can also be reduced by optimising utilities such as air compressors, fans, motors, pumps and lights.

General energy-saving techniques are applied by process and equipment selection and optimisation.

Energy-efficient motors

Measures include creating a motor management plan, selecting and purchasing motors strategically, performing ongoing maintenance, using properly sized motors, automating motors, using adjustable speed drives, using the correct power factor, minimising voltage imbalances and using soft starters.

Energy-efficient lighting

This can be achieved by turning off lights in unoccupied areas, using occupancy sensors and other lighting controls, upgrading exit signs, replacing magnetic ballasts with electronic ballasts, replacing T-12 tubes with T-8 tubes, reducing the lighting system voltage, replacing mercury lights with metal halide or high-pressure sodium lights, replacing metal halide HID with high-intensity fluorescent lights, using daylighting and using LED lighting (see also the ENE BREF [60, COM 2009]).

Achieved environmental benefits

- Reduction of energy consumption.
- Decarbonisation.

Environmental performance and operational data

Cross-media effects

None identified.

Technical considerations relevant to applicability

Generally applicable.

Economics

Driving force for implementation

Reduction of energy costs.

Example plants

Widely used.

Reference literature

[39, COM 2022], [60, COM 2009]

4.3.8 ~~Improved design of kilns and dryers~~ Maximisation of the thermal efficiency of kilns and dryers

[Note to the TWG: most of the information below was included in Section 4.1.1 of the 2007 CER BREF. Please provide information to complement and update]

Description
This includes techniques such as:

- automatic control of the dryer (e.g. humidity, temperature) and installation of impulsion fans;
- automatic control of kilns (e.g. temperature, air to fuel ratio and pressure);
- appropriate sealing and thermal insulation of kilns;
- use of lightweight kiln cars/ware carriers/shelves and other firing auxiliaries (e.g. rollers) which require less energy to be heated;
- avoiding unnecessary cooling of dried ware by minimising the distance between the dryer and the kiln;
- extension of the cooling zone of kilns to make the kiln more energy-efficient;
- minimisation of heat losses from kiln door openings;
- reduction of the amount of airflow through rotary kilns in the manufacture of expanded clay.

Technical description
Design of the kiln, the dryer or the combination of them to increase energy efficiency and minimise energy losses.

Most of the measures mentioned above can also be applied to dryers, for instance regarding dryer design (improved thermal insulation, insulated doors or locks, etc.), the firing auxiliaries and the process control, particularly because dryers and kilns are very often connected with a heat recovery system (see Section ~~4.1.2~~ 4.3.9).

Achieved environmental benefits

- Reduced energy consumption.
- Decarbonisation.

Environmental performance and operational data
This depends on the particular individual case-related measure/task; for instance, the specific energy requirements for different products~~,~~ fired in different kiln types (conventional, fast firing, with/without improved insulation) are compared in Table Table 2.14 (manufacture of wall and floor tiles), ~~Table 3.31 (manufacture of wall and floor tiles) and in Table 3.45 (manufacture of sanitaryware~~).

Cross-media effects
No issues.

Technical considerations relevant to applicability
In principle, most of the measures mentioned above can be applied to all ceramic sectors, but the roller hearth technology for instance~~,~~ is mainly applied for the manufacture of wall and floor tiles. However, roof tiles, vitrified clay pipes and sanitaryware can also be fired in roller hearth kilns (see Section 2.2.7.4.3).

Measures concerning especially shuttle, tunnel and roller hearth kilns (e.g. regarding kiln cars and firing auxiliaries) cannot be applied to rotary kilns, in which expanded clay aggregates are manufactured (see Section 2.3.4). Also within the sectors, the applicability of the different kiln technologies depends on the manufactured products; for example, some types of wall and floor tiles need tunnel kilns for firing, to achieve the desired product properties.

Economics

Modernising the kilns and/or dryers being used or even replacing them with new less energy-consuming alternatives like roller hearth kilns – if applicable – can result in considerable energy savings for companies. If they are replaced before the end of their useful life, this requires a substantial capital investment.

Driving force for implementation

Reduction of energy costs.

Example plants

Widely used. A total of 81 installations in the data collection reported applying an improved design of dryers and kilns and 10 installations reported using extended tunnel kilns.

Reference literature

[1, BMLFUW 2003], [3, Ceram-Unie 2003], [4, UBA 2001], [23, TWG 2005], [26, UBA 2005], [30, TWG 2005], [35, TWG 2023], [43, TWG 2022], [46, MIDDEN 2020]

4.3.9 Recovery of excess heat ~~from kilns~~

[Note to the TWG: most of the information below was included in Section 4.1.2 of the 2007 CER BREF. Please provide information to complement and update]

Description

This includes techniques such as:

- heat recovery, e.g. from the cooling zone of the kiln, flue-gases, air compressors;
- use of cooling air as combustion air to avoid heating fresh air.

Technical description

Many ceramic dryers ~~now~~ use hot air recovered from the cooling zones of tunnel kilns, usually supplemented with hot air from gas burners, so the layout of the plant is very important.

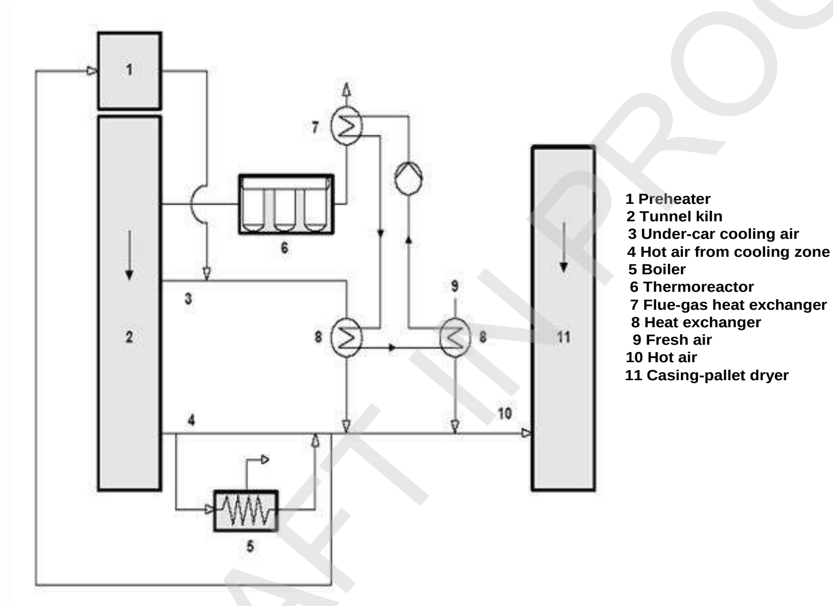
At the exit of the tunnel kilns and roller kilns, air is blown in to cool the fired products coming out of the kiln. This cooling air is heated up in the cooling zone and supports the firing process. A part of the cooling air is sucked out in the middle of the cooling zone and used for the drying process. In roller kilns, the cooling air is also used as combustion air in the burners. In periodically operated chamber kilns, the gas warms (in a heat exchanger) clean air that is used for drying [33, Ramboll 2019].

In particular, low-temperature excess heat can only be managed usefully if the length of the pipes – i.e. the distance between excess heat generation and use – is ~~quite~~ limited. In any case, suitable heat insulation of the pipes is required. Very significant energy savings have been achieved in this way.

Some processes also ~~employ~~ use heat exchangers to recover heat from kiln flue-gases in order to preheat the combustion air, but this application is limited, because of possible corrosion problems caused by acid combustion gases and often flue-gas temperatures that are too low. Heat exchangers using plastic pipes are being developed to solve corrosion problems [46, MIDDEN 2020].

Excess heat from an afterburner can also be used, either in the kiln or in the dryer. One German factory uses thermal oil to transfer excess heat from the afterburner to the dryer, in combination with hot air from the cooling zone of the kiln. The functioning principle of this combined heat recycling system is presented in Figure 4-5 ~~the following figure~~ [4, UBA 2001].

Besides the use of excess heat (4) in the heat recovery boiler (5) and for the heating of the preheater (1), the heat resulting from the cooling of the cleaned flue-gas is recovered in a flue-gas heat exchanger (7) and fed to further heat exchangers (8) by thermal oil, to warm fresh air (9) for the drying process. The warm fresh air is mixed with hot air from the cooling zone (4) of the kiln (2) and fed to a continuously operated casing pallet dryer (11).



Source: [9, COM 2007]

Figure 4-5: Schematic view of an example of a combined heat recycling system

Achieved environmental benefits

- Reduction of energy consumption.
- Decarbonisation.

Environmental performance and operational data

In the case of the combined heat recycling system shown above, the specific natural gas energy requirement for drying and firing is only between 840 kJ/kg and 1 050 kJ/kg fired ware (bricks) [4, UBA 2001], [30, TWG 2005].

Cross-media effects

Slightly increased electrical energy consumption is possible, particularly if heat exchange circuits are used.

Technical considerations relevant to applicability

Recovery of excess heat from kilns, especially from their cooling zones in the form of hot air, can, in principle, be applied in all ceramic sectors to heat dryers. It should be noted~~,~~ that recovery of excess heat from kilns is only applicable if the excess heat is needed at the same time in another process.

Recovery of excess heat from afterburners is limited because the flue-gas may be too cold to achieve efficient energy recovery.

~~The specific example mentioned above (in Germany only very few factories use this technique) cannot be generalised, especially regarding the utilisation of the excess heat of the afterburner, because often the flue-gas from an afterburner is too cold to carry out efficient energy recovery.~~

Economics
Additional costs for pipe insulation have to be taken into account.

Driving force for implementation
~~Reduction of CO_2 emissions.~~
Reduction of energy costs.

Example plants
Widely used. A total of 137 installations in the data collection reported recovering the excess heat from kilns.
~~JUWOE POROTON-Werke Ernst Jungk & Sohn GmbH, Germany, brickwork~~

Reference literature
[4, UBA 2001], [1, BMLFUW 2003], [2, VITO 2003], [3, Ceram-Unie 2003], [23, TWG 2005], [30, TWG 2005], [35, TWG 2023]

4.3.10 Breakage detection before firing

[Note to the TWG: Please provide information to complete the 10-heading template below]

Description
Avoiding firing of ware that does not comply with product specifications to reduce fuel consumption and residue generation by, for example, artificial vision systems.

Technical description

Achieved environmental benefits
- Reduction of energy consumption.
- Decarbonisation.

Environmental performance and operational data

Cross-media effects
None identified.

Technical considerations relevant to applicability

Economics

Driving force for implementation

Example plants
Widely used, e.g. ES_185.

Reference literature
[37, COM 2022], [71, ASCER 2019], [35, TWG 2023]

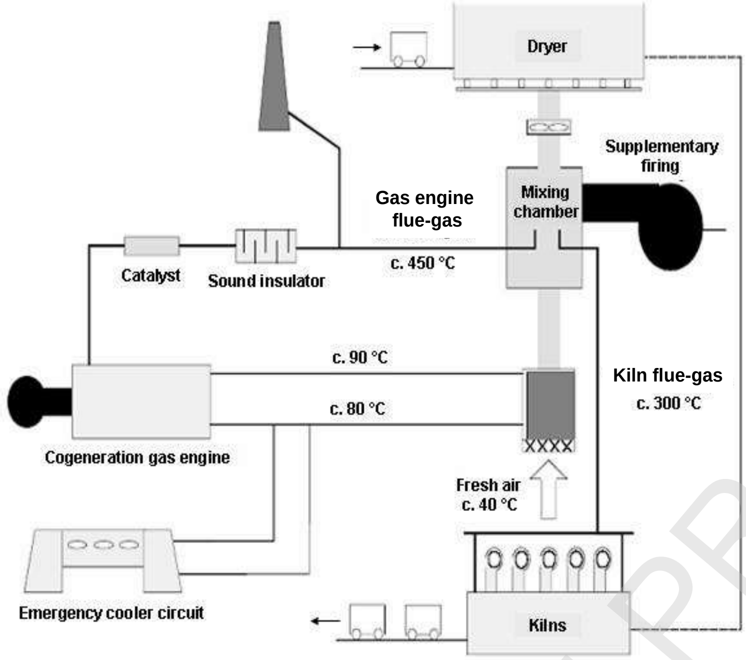
4.3.11 Cogeneration/combined heat and power plants

[Note to the TWG: most of the information below was included in Section 4.1.3 of the 2007 CER BREF. Please provide information to complement and update, especially on operational data and economics]

Description
The employment of cogeneration plants for steam and electricity or of combined heat and power plants ~~is, in principle, useful in the ceramic industry due to the simultaneous demand of~~ to supply heat and electric power.

Technical description
The essential feature of ~~the~~ a cogeneration plant is the driving engine. Gas-fuelled Otto engines, diesel engines and gas turbines with excess heat utilisation are suitable.

Figure 4-12 ~~4.2~~ shows an example ~~for~~ of the utilisation of excess heat from a combined heat and power plant for the production of hot air [4, UBA 2001]. The hot air is used for the brickwork dryer. A proportion of fresh air is necessary for the dryer in addition to the kiln's excess heat. This air is generally taken in from the dryer building, in order to make use of the high-radiation heat components of the kiln and the dryer. This fresh air is mixed with the excess heat from the kiln in front of the dryer feed fan. In the suction pipe for fresh air, an air heater is installed in order to maintain preheating of the fresh air. This heat exchanger is heated by the cooling water of the driving engines. The flue-gases have a temperature of 450 ºC to 550 ºC, depending on the type of engine. They are fed into the mixing chamber and used directly in the dryer. Any heat deficiency is covered by a supplementary gas burner. If no heat is required at the dryer, the uncooled flue-gases from the engines are withdrawn directly via a stack.



Source: [9, COM 2007]

Figure 4-6: Schematic view of hot air generation using a cogeneration gas engine

In some cases, flue-gases, before being introduced in the mixing chamber, can also pass through a boiler to produce vapour which is utilised in the extrusion phase.

Achieved environmental benefits

- Increased energy efficiency.
- Reduction of CO_2 emissions.
- Decarbonisation.

Environmental performance and operational data

Cross-media effects

Driving engines can cause additional emissions ~~in~~to air on site and noise also increases.

Technical considerations relevant to applicability

Applicability in existing plants may be restricted by the plant layout and/or a lack of space.

The heat produced by the combined heat and power plants can be used in the spray-drying process especially for the manufacture of wall and floor tiles and household ceramics. This heat can also be used for dryers if additional heat is needed, for instance in brickworks, as shown in Figure 4-6.

Economics

~~The economic application is strongly dependent on the existing conditions and the ceramic sector. For economic reasons, cogeneration has limited use throughout Europe, e.g. for the manufacture of brick and roof tiles. Nevertheless, the technique should be taken into consideration above all when designing a new plant.~~

~~A less expensive alternative to the utilisation of the excess heat described above is the direct introduction of heat into the dryer (see Section 4.3.9).~~

Driving force for implementation
Implementation of energy-efficient production technology.

Example plants
A total of 35 installations in the data collection reported using a combined heat and power plant; 23 of them correspond to installations for the manufacture of wall and floor tiles.

Reference literature
[4, UBA 2001], [17, Burkart, M. 2004], [23, TWG 2005], [30, TWG 2005], [35, TWG 2023]

4.3.12 Heat pumps for drying of ware

[Note to the TWG: Please provide information to complete the 10-heading template below]

Description
Heat pumps recover low-temperature heat from different sources (e.g. cooling zone of the kiln) in an efficient way for drying purposes. In a heat pump, the refrigerant changes state (liquid/gas), absorbing and releasing heat in the following steps:

1. evaporation;
2. compression;
3. condensation;
4. expansion.

Technical description
Heat pumps allow to use low-temperature waste heat to increase the temperature of the air flow entering/in the dryer.

Compression heat pump:
In a compression heat pump the cycle starts with the evaporation of a refrigerant by a heat source. This vapor is then compressed by a compressor on a high pressure level. In this step, electrical energy is needed for the compression. In the condenser the vapor is then condensed, releasing thermal energy. The liquid is then released through an expansion device/valve, where it expands and cools down for the cycle to start again.

Absorption heat pump:
In an absorption heat pump the refrigerator is always paired with an absorbant. Common pairings are water and lithium bromide or ammonia and water. The refrigerant is in a first step heated up and evaporated at low pressures by a low energy heat source in the evaporator. As example the low energy heat source could be the warm water recovered by a scrubber, i.e. heat present in the exhaust gas of the dryer.
The refrigerant then enters the absorber and is absorbed. This absorption releases energy, which may be used. The now liquid mixture of absorber and refrigerator is pumped into the desorber. Since liquids are negligible compressible, much less electric energy is needed for this step, compared to e.g. compression heat pumps.
In the desorber high temperature heat is used for desorption of the refrigerant at high pressures. For instance, heat from the cooling zone of the tunnel kiln can be used as a source of this heat (e.g. for brick manufacturing). The remaining absorber is then released back to the absorber. Via a heat exchanger the remaining energy of the absorber can be used to preheat the refrigerant-absorber mix entering the desorber.
The refrigerant is then condensed in the condenser. There it again releases heat at medium temperatures that can be used for e.g. drying.

In a last step the refrigerant is released through a valve back to the evaporator, where it partly evaporates and cools down and thus is ready to take up energy again.

Achieved environmental benefits

- Reduction of energy consumption for drying.
- Decarbonisation

Environmental performance and operational data

In a clay block plant in Austria (AT_016), the energy demand for drying has been shown to be reduced up to 80 % and CO_2 emissions up to 80 % by using heat pumps, and the production costs by up to 20 %. In absolute numbers, in AT_016 the energy consumption was reduced by 2 200 MWh per year, primary energy consumption by 1 900 MWh per year, and CO_2 emission by 590 t/a, resulting in EUR 60 500 per year of energy cost savings compared to a natural gas burner for the dryer.

Cross-media effects

Additional electrical energy demand may be required.

Technical considerations relevant to applicability

Generally applicable.

Economics

A comparison of decarbonisation options for the ceramic industry in the Netherlands, based on different techno-economic parameters (marginal abatement cost curves and a business case analysis) and published in January 2021, found heat pumps to be the most economically feasible out of the options compared.

Driving force for implementation

Energy savings.

Example plants

AT_10, AT_016.

Reference literature

[43, TWG 2022], [46, MIDDEN 2020], [85, TWG AT 2023]

4.3.13 Microwave drying

[Note to the TWG: Please provide information to complete the 10-heading template below]

Description

Drying of ware using microwave or high-frequency radiation.

Technical description

Heavy loads on large kiln cars make the heat transfer from the outside to the middle of the setting of ware and into the centre of individual units difficult. Temperature gradients can lead to thermal stresses and damaged products – surface temperatures are frequently higher than those in the centre of the unit or setting. In microwave drying the product is heated directly – including the centre of the units.

Achieved environmental benefits

Environmental performance and operational data

Cross-media effects

Technical considerations relevant to applicability
Only applicable to the manufacture of products with a simple shape.

Economics

Driving force for implementation

Example plants
BG_057.

Reference literature
[9, COM 2007], [35, TWG 2023], [46, MIDDEN 2020]

4.3.14 Compressed air system optimisation

[Note to the TWG: Please provide information to complete the 10-heading template below]

Description
This includes all of the following measures:

- applying appropriate system maintenance to reduce leaks;
- efficient monitoring of operating parameters such as flow, temperature and pressure;
- minimising the pressure drops;
- applying efficient load management;
- reducing the inlet air temperature;
- using an efficient compressor control system.

Technical description
Compressed air is used in numerous applications, e.g. presses, transport and handling of materials. Best practices for energy-efficient compressed air systems include all the following measures:

- Applying an appropriate maintenance system to reduce leaks: The areas where leaks may occur include couplings, hoses, tubes, fittings, pressure regulators, open condensate traps and shut-off valves, pipe joints, disconnects and thread sealants. Effective monitoring of these areas as part of a leak detection and correction programme is key to reduce to a minimum the number and severity of leaks.
- Efficient monitoring of operating parameters such as flow, temperature and pressure: Monitoring systems are in place across the site including pressure gauges on each receiver and differential gauges for dryers and filters, temperature gauges to detect fouling or blockages in compressors, flow meters to control the quantity of air used, and dew point temperature gauges to monitor the efficiency of air dryers.
- Minimising the pressure drops: Excessive pressure drops result in an increase in energy consumption. Flow restrictions (e.g. obstructions) can result in higher operating pressures. Such pressure drops are often observed at the points of use, e.g. leaking hoses, tubes, disconnects, dryers, filters, regulators, valves, nozzles or moisture separators. Pressure drops can be minimised or prevented by good design of the system and good maintenance of the equipment.
- Applying efficient load management: Improving the load management can be achieved by avoiding partial load operation. The use of multi-stage compressors which operate more efficiently than single-stage compressors can save energy.
- Reducing inlet air temperature: When the inlet air temperature is reduced, the energy used by the compressor is also reduced. It is often possible to draw cold air from outside the buiding to reduce the inlet air temperature of compressors.

- Using efficient compressor control systems: Control systems are in place to ensure that unneeded compressors are shut off and to delay the start of additional compressors until needed. This is achieved using the following control systems:
    - start/stop (on/off): the compressor is turned on or off depending on the discharge pressure of the machine;
    - load/unload: use of constant speed controls allowing the motor to run continuously but to unload when the discharge pressure is adequate;
    - modulating or throttling controls: the output of the compressor is modulated to meet the flow requirements;
    - single master sequencing control: individual compressors are taken on-line or off-line in response to the measured system pressure demand;
    - multi-master controls: four or more compressors are handled at the same time using an advanced compressor control system, each compressor is working at a level that produces the most efficient operation.

Achieved environmental benefits
Increased energy efficiency.

Environmental performance and operational data

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally applicable.

Economics

Driving force for implementation
Energy savings.

Example plants
Widly used. BE_038, BE_039, BE_040, BE_041, BE_042, BE_043, BE_044 and BE_045 reported optimisation of the compressed air system.

Reference literature
[35, TWG 2023], [39, COM 2022]

4.3.15 Modification of ~~ceramic bodies~~ product design

[Note to the TWG: most of the information below was included in Section 4.1.5 of the 2007 CER BREF. Please provide information to complement and update, e.g. on economics]

Description
Design of products to make them lighter and to reduce energy and raw material consumption (dematerialisation). This includes techniques such as:

- production of brick slips, thinner facing bricks and thinner wall tiles;
- production of ceramic blocks with invisible holes and similar product characteristics.

Technical description
A sophisticated design of body composition can reduce necessary drying and firing times and so stimulates the use of low-volume, rapid firing kilns such as roller hearth and moving bat types. Therefore, alterations to body composition can assist drying and firing, e.g. in the wall and floor

tile and vitreous clay pipe sectors. This can result in reduced energy consumption in these areas. ~~A similar approach is being researched for thicker walled ceramic products.~~

Pore-forming additives are primarily used to decrease the thermal conductivity of clay blocks by creating micropores. Thus, the thermal mass of the clay blocks is reduced~~,~~ and, as a second advantage of the use of pore-forming additives, less energy is required for the firing~~ is required~~.

In the brick sector, brick slips and thinner facing bricks have been developed as lighter products with the same quality, function and lifespan of classic bricks. Figure 4-7 shows examples of dematerialisation of products.

Source: [43, TWG 2022]

Figure 4-7: Examples of dematerialisation of products

The redesigning of ceramic ware may also reduce the mass – e.g. thinner tiles, multi-perforated bricks, thinner walled blocks or pipes. Where technically feasible, these changes can reduce energy consumption and emissions.

A reduction in the mixing water content required helps to save drying energy. The amount of mixing water needed is mainly dependent on the clay mineral composition and also on the granulometry. Water-saving additives consist of humid products with inorganic sequestering or complexing agents. They allow a reduction of the interfacial surface tension of the mixing water and an immobilisation of troublesome, free cations. The mixing water requirement in the raw material preparation process is reduced and an equal or even better plasticity is achieved. Additionally, the energy requirement of the drying process is minimised.

Automatically adjusting the mixing of water according to the required material plasticity and using water vapour to a certain extent instead of water for mixing~~,~~ lead~~s~~ to a reduction in consumption of water ~~(approx. 3 %)~~, thermal energy ~~(approx. 90 kWh/t product)~~ and electricity ~~(approx. 1.5 kWh/t product)~~.

In any case, the addition of steam in the extrusion ~~part~~ facilitates the exit of the extruded clay and the exact moisture ~~humidity~~ content needed for the clay can be achieved.

A significant reduction in the firing temperature and shortening of the residence time are achieved by the admixture of extremely effective sintering aids, such as earth alkali and high-alkali additives, and of glass-forming agents. However, the use of such additives is only possible in some special cases, not for all ceramic products. Reductions in the final firing temperature ~~of up to 50° K~~ are possible. In order to avoid production breakdowns and a decline in quality, preliminary tests should normally be carried out before their use on large industrial scales.

Achieved environmental benefits

- Reduction of energy consumption.
- Reduction of raw material consumption.
- Reduction emissions in production and transport.
- Decarbonisation.

Environmental performance and operational data

This depends on the particular individual case-related measure/task.

Brick slips use 70 % less material than traditional facing bricks and slim bricks use 28 % less material [56, COM 2023].

Cross-media effects

The use of organic pore-forming agents may result in increased emissions of organic substances and CO to ~~the~~ air. The use of sintering aids increases emissions of CO_2 due to the high content of alkali carbonates.

Technical considerations relevant to applicability

Applicability may be restricted by product specifications.

The utilisation of sintering aids and energy-containing pore-forming additives saves energy especially in brick manufacture. As already described above, the utilisation of energy-containing secondary raw materials, such as sawdust, polystyrene (styropor) or paper-binding agents, is possible in the manufacture of clay blocks. These pore-forming agents can provide up to 25 % of the total energy in the form of secondary energy in backing brick production. The use of pore-forming agents in facing brick production is exceptional because of their effect on the technical properties of bricks (e.g. colour, density).

However, in general, the shape and composition of the products are highly dependent on market requirements and therefore the modification of ceramic bodies is only possible to a limited extent and certainly not for all ceramic products.

Economics

Driving force for implementation

- Higher product output.
- Better product quality.
- Circular economy.

Example plants

~~JUWOE POROTON-Werke Ernst Jungk & Sohn GmbH, Germany, brickwork~~

Widely used. A total of 21 installations in the data collection reported the modification of ceramic bodies as an energy-saving technique and 41 installations reported product design as a technique to decarbonise.

The manufacture of brick slips using moulds was reported by 10 installations in the data collection.

~~and~~ Reference literature

[4, UBA 2001], [1, BMLFUW 2003], [3, Ceram-Unie 2003], [23, TWG 2005], [30, TWG 2005], [35, TWG 2023], [43, TWG 2022], [56, COM 2023]

4.4 ~~Process losses/waste~~ Techniques to reduce residues and to enhance circular economy

This section deals with possibilities for the reduction of solid ~~waste~~ residues occurring in the several steps during the manufacturing processes of ceramic products. ~~The solid process losses generating installations/techniques applied have already been dealt with in this document, for instance in Chapters 2 and 4 regarding dust abatement techniques.~~

4.4.1 Residues management plan

[Note to the TWG: Please provide information to complete the 10-heading template below, e.g. on operational data]

Description
A residues management plan is part of the EMS (see Section 4.2.1) and comprises a set of measures aiming to:

- minimise the generation of residues;
- optimise the reuse, recycling and/or recovery of residues;
- ensure the proper disposal of waste.

Technical description
A variety of techniques can be used for residue optimisation including:

- basic housekeeping techniques;
- statistical measurement techniques;
- application of clean technologies;
- use of process chemicals before their expiry date;
- use of residues as fuel.

In particular, a residue/waste management plan could be based on the five-stage hierarchy of Directive (EU) 2018/851 and the Commission notice on technical guidance on the classification of waste 2018/C 124/01, and include the following:

- Identifying, characterising and quantifying each of the residue/waste streams generated. Maintaining a residue/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 residue/waste which is disposed of or recovered on that site.
- Identifying the current or proposed handling arrangements, and possibilities to implement circular economy.
- Fully describing how each residue 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 residue volumes;
  - established criteria associated for example with the maximum storage time of process chemicals are clearly established and relevant parameters are monitored to avoid the process chemicals perishing or the expiry date being exceeded;
  - separate capture of high-loaded waste streams from low-concentrated effluent to allow more efficient treatment;

  - separate collection of unavoidable solid waste;
  - reduction of packaging;
  - use of returnable containers.

Achieved environmental benefits

- Increased material efficiency.
- Reduced amount of waste sent for disposal.
- Minimisation of residues through recycling of process residues and reuse of recycled materials along with raw material savings.

Environmental performance and operational data

Cross-media effects
None identified.

Technical considerations relevant to applicability
The level of detail and the degree of formalisation of the residues management plan will generally be related to the nature, scale and complexity of the installation.

Economics
Associated personnel cost.

Driving force for implementation

- Reduced cost due to increased material efficiency.
- Legal requirements. The prevention of waste generation is a principle of the IED (Directive 2010/75/EU 2010) and the Waste Framework Directive (WFD, Directive EU/2018/851).

Example plants
Widely used.

Reference literature
[86, EU 2008]

4.4.2 ~~Solid process losses/solid waste~~ Use of process residues as raw materials

~~General considerations concerning re-use of solid process losses as raw materials~~

[Note to the TWG: most of the information below was included in Section 4.5.2.1 of the 2007 CER BREF. Please provide information to complement and update the 10-heading template below, e.g. economics]

Description
This includes techniques such as:

- use of collected dust from all processes in the raw material mix;
- use of unfired broken ware in the raw material mix;
- use of ground fired broken ware in the raw material mix.

Technical description
Dust collected, e.g. while loading, unloading, conveying, mechanically handling and processing raw materials and product grinding, can normally be reused as raw material. For instance, in the storage of raw materials, any filter dust can be fed back directly to the production process or to the silo, when ~~a~~ local air cleaning by a silo top-filter is used.

~~Also, p~~Process losses~~,~~ which are generated before firing~~,~~ can normally be reused as raw materials by adding them to the raw material mixture. Cuttings, used plaster moulds and ~~also~~ dust are the main process losses arising from the shaping process. The cut pieces from the press are often pushed ~~from~~ off the pressing table, collected under the press and directly fed back to the material storage of the press. Furthermore, dust or cut pieces are often fed back as batch components in a casting slip or in stoneware masses. Used plaster moulds can be reused in the cement industry or, after crushing and milling, partly in the fertiliser industry.

Fired products which are unsuitable for sale (broken ware) and broken firing auxiliaries as well as broken refractory material from kilns~~,~~ can in some cases, after being ground, be reused as raw materials.

Achieved environmental benefits

~~Compared to waste disposal in landfills, the re-use of solid process losses entails:~~

- a ~~r~~Reduction of raw materials used.
- a ~~r~~Reduction of pollutants released into the environment.
- Reduction of the amount of waste sent for disposal.
- Minimisation of residues.

Environmental performance and operational data

The amount of fired broken ware that can be introduced in the raw material mix depends on the sector and the product manufactured.

Some examples of recycled content of products reported in the data collection are as follows:

- in the wall and floor tiles sector, ES153 reported products with more than 80 % on-site recycled content, and IT306 and IT307 reported products with 40-60 % on-site recycled content;
- in the brick and roof tile sector, FR219 and IT238 reported on-site recycled content of products of 10-20 %;
- in the tableware and household ceramics sector, PT359 reported manufacturing products with a high recycled content of 20-40 %;
- for non-basic refractory products, the share of on-site recycled content reported for products with high recycled content was more than 80 % of residual cuttings and broken refractory bricks for IT243;
- in the technical ceramics sector, DE100 reported a share of 10-20 % of off-site recycled content [35, TWG 2023]
- in the vitrified clay pipes sector, the amount of chamotte added to the raw material mix varies from 35% for smaller diameter pipes to 50 % for larger diameter pipes [56, COM 2023].

Cross-media effects

None identified.

Technical considerations relevant to applicability

~~But t~~The direct feedback of dust collected in the different process steps may not be possible when central dedusting units are operated, because of the mixing of different raw materials.

Dust originating from a flue-gas cleaning system can only be reused under certain circumstances, because this dust can contain high concentrations of sulphur and fluorine. When added to the raw material mixture, this dust can result in increased emissions of HF and SO_X during the firing process. Also, dust from a flue-gas cleaning system can contain adsorbent particles like lime – for instance, if an adsorption system containing lime is applied – which influences the product properties. Therefore, a separate ~~conduction~~ transfer of different off-gas streams facilitates the optimal utilisation of dusty process losses. In most cases for the manufacture of expanded clay aggregates, the dust can be recycled.

Gypsum generated during flue-gas cleaning, especially in the manufacture of expanded clay aggregates or in the bricks and roof tiles industry, cannot be reused in the process, but is used in the cement industry as a hardening regulator. Materials~~,~~ which cannot be recycled internally~~,~~ leave the plant to be used in other industries or to be supplied to external waste recycling or waste disposal facilities.

Economics

Driving force for implementation

- Solid process losses reused leads to avoidance of ~~– and therefore save – the~~ disposal costs and also some raw material costs, and therefore to savings.
- Circular economy.

Example plants

Widely used. A total of 148 installations in the data collection reported using unfired process losses, 86 installations reported using fired process losses and 72 installations reported using grinding dust or granulates in the raw material mix.

Reference literature

[2, VITO 2003], [3, Ceram-Unie 2003], [4, UBA 2001], [23, TWG 2005], [26, UBA 2005], [28, Schorcht, F. 2005], [35, TWG 2023], [37, COM 2022], [38, COM 2022], [56, COM 2023]

4.4.3 Optimised heating in the kiln

For a description of the technique, see Section 4.7.4.3

4.4.4 ~~Sludge recycling system~~ Use of sludge as raw material

[Note to the TWG: most of the information below was included in Section 4.5.1.1 and 4.5.1.2 of the 2007 CER BREF. Please provide information to complement and update]

Description

This includes techniques such as:

- introduction of sludge in the raw material mix on site with or without pretreatment;
- use of sludge off site as raw material mix in other ceramic sectors.

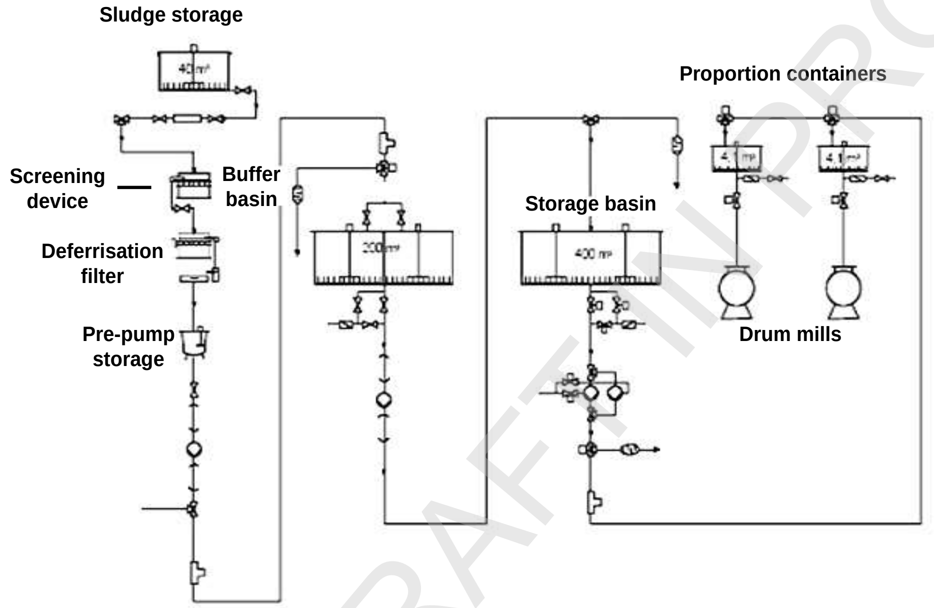
Technical description

~~Recycling involves sludge re-use.~~ Some examples include the following:

- Reuse of sludge in ~~the~~ ceramic bodies, as is the case of ~~with~~ aqueous suspensions and slips containing ceramic materials, for example for the manufacturing of wall and floor tiles.~~; see also Sections 2.3.5 and 3.3.5.~~
- In the bricks and roof tiles sector, the sludge from the water treatment of the water used for wet grinding is used in the raw material mix [33, Ramboll 2019].
- ~~clay block making and in the manufacture of expanded clay aggregates~~ Sludge from the manufacture of household ceramics or sanitaryware can be used as a raw material/additive input in clay block making and in the manufacture of expanded clay aggregates.

Sludge recycling systems can be easily implemented in facilities with raw materials preparation by wet milling, as the sludge can be directly used without needing any subsequent treatment, or just simple physical or physico-chemical treatments, with the additional advantage of being able to use the water that it contains as milling water. If a dry body preparation process is involved, although the sludge addition is no problem, management is more complicated as the sludge needs to be dried first.

~~The following f~~ Figure 4-8 shows the schematic view of a sludge recycling installation from a wall and floor tile plant (wet process) [4, UBA 2001]. The sludge is pumped from the sludge storage to a ~~2~~two-stage screening unit. Afterwards it passes through a deferrisation filter and then it is fed to a pre-pump storage which has a capacity of 3 m^3. From there the sludge is pumped to two 200 m^3 buffer basins, which are alternately filled. After a verification of the sludge characteristics and a positive result from the analysis, the sludge is fed to the main storage basin which has a capacity of 400 m^3. The ceramic sludge is semi-automatically transported from the main storage basin to proportioning containers from where the drum mills for the different batches are fed.



Source: [9, COM 2007]

Figure 4-8: ~~Schematic view of a sludge recycling installation~~ Use of an on-site sludge recycling scheme

Achieved environmental benefits

~~By applying a sludge recycling system, not only is there a reduction of raw material and water consumption, but also a reduction of pollutant releases into the environment can be achieved.~~

- Reduction of raw material consumption.
- Reduction of waste generation.
- Reduction of water consumption.

Environmental performance and operational data

The quantity of sludge produced in a wall and floor tile facility ranges from 0.09 kg/m^2 ~~–~~ to 0.15 kg/m^2 finished product on a dry basis, which, for a product with a body mass of 15-20 kg/m^2, involves 0.4-1.0 % (kg dry sludge/kg ceramic body). If all the sludge arising from the treatment of the waste water produced in the process is reused in the ceramic body preparation process, the addition relative to the body's raw materials is, therefore, around 0.4-1.0 % on a dry basis. It has been found~~,~~ that 1-1.5 %~~per cent~~ sludge addition to the ceramic bodies prepared for the manufacture of tiles~~,~~ does not generally affect the behaviour of the products during the manufacturing process [10, Navarro, J. E. 1998], [32, TWG 2006].

Consequently, both in terms of the mass balance and the resulting change in behaviour, the complete incorporation of sludge in wet milling processes is technically feasible and facilitates process management.

In the case of wet processes in which the ceramic body preparation plant is an independent facility, or if it stands separately from the production facility, the sludge can be returned by road. The aqueous suspensions and sludge can be returned by tankers or conveyed by pipeline.

Cross-media effects
If sludge has to be dried for reuse, energy consumption will rise. Attention should also be paid to possible negative consequences from the fact that pollutants coming from a given phase/section of the process/plant, such as glaze preparation and application, are introduced in a different phase/section, such as ceramic body preparation. The controls of gaseous emissions and process waste water represent a suitable solution to prevent such negative consequences.

Technical considerations relevant to applicability
Using sludge that contains glaze waste as a glaze constituent would, in principle, seem to be a very suitable option. But the main drawback in this process is the considerable heterogeneity across time of the sludge compositions, owing to the diversity of glazes usually found in production at the same time in most companies. And also this sludge cannot be the sole glaze constituent, but is considered an additive (e.g. used as a fluxing agent). Although it may be a very good solution in some cases, especially if only one or a few different glazes are applied in a facility, the use of this kind of sludge in glaze preparation cannot be considered a general solution.

Sludge reuse is, therefore, not applicable in all cases. If there are special requirements on quality or performance, sludge is only reusable in other products ~~(see Section 4.5.1.2)~~.

The melting temperatures of glazes, which are part of the sludge, and the fluxing properties must be taken into consideration, if sludge is to be ~~re-~~used in the manufacturing of building products, because this can affect their product properties.

In wall and floor tiles production, the rate of the use of sludge from engobing/glazing water treatment processes depends on the composition of the sluge and on the products produced. In some cases, it is not possible to use the sludge in the raw material mix due to the presence of coagulation or flocculation agents, pigments, etc. [33, Ramboll 2019].

Economics
Sludge recycling/reuse leads to avoidance of~~ and therefore save the~~ disposal costs, and therefore to savings.

Driving force for implementation
- Saving costs by saving raw material and water consumption and avoiding waste.
- Circular economy.

Example plants
Widely used. A total of 23 installations in the data collection reported using sludge recycling sytems, 17 belong to the wall and floor tiles sector, 3 to the bricks and roof tiles sector, 2 to the sanitaryware sector and 1 to the technical ceramics sector.

Reference literature
[3, Ceram-Unie 2003], [4, UBA 2001], [6, Timillini 2004], [10, Navarro, J. E. 1998], [13, SYKE 2004], [22, SYKE 2004], [23, TWG 2005], [32, TWG 2006], [35, TWG 2023]

4.4.5 Substitution of plaster moulds

[Note to the TWG: most of the information below was included in Section 4.5.2.2 of the 2007 CER BREF. Please provide information to complement and update the 10-heading template below, e.g. on economics]

Description
Replacing plaster moulds with longer-lasting polymer or metal moulds.

Technical description
Processes such as slip casting in plaster moulds can be replaced by pressure slip casting units with polymer moulds, avoiding the use of plaster moulds.

The application of modern techniques in the shaping process provides considerable potential to prevent waste. Processes such as slip casting in plaster moulds can be replaced by pressure slip casting units with polymer moulds. ~~With this method, the use of plaster moulds is avoided, additionally a raw material saving of up to 20 % is achievable and the occurrence of white sludge is reduced.~~ The use of isostatic presses with polymer moulds also avoids the need for plaster moulds. In some sectors, for instance in the manufacture of roof tiles, the use of closed metal moulds instead of open plaster moulds is possible. However, the replacement of plaster moulds is only possible if a new casting unit is built or the old one is totally renewed, which is expensive and, therefore especially for low-volume business, difficult to carry out. In some cases, quality problems can appear ~~by~~ when using plaster moulds because sharp edges tend to occur. Furthermore, the metal moulds have a significantly lower exhaustion rate of the water coming out of the clay during moulding compared to plaster moulds.

The amount of used plaster moulds can also be reduced by an increase of the lifetime of the plaster moulds. The operation of automatic plaster mixers and vacuum plaster mixers permits the production of harder plaster moulds, which means that the lifetime of the moulds is two to three times longer. However, for instance, in the wet pressing process for clay roof tiles, it is usually not possible to increase the hardness of the plaster. An ~~optimum~~ balance between the porosity and surface hardness has to be found to conform with the requirements of water removal and wear resistance.

Achieved environmental benefits

- Raw material saving.
- Reduction of the amount of waste sent for disposal.

Environmental performance and operational data
With pressure slip castings, the use of plaster moulds is avoided~~,~~; additionally, a raw material saving of up to 20 % is achievable and the occurrence of white sludge is reduced.

Cross-media effects
The scrap rate is higher when using metal moulds, 10 % for metal moulds and 3-5 % for gypsum moulds.

Technical considerations relevant to applicability
Gypsum moulds release water and air, which reduces tensions and the rate of scrap. Metal moulds cannot be used to make big, flat surfaces or 90 ° angles.

Economics

Driving force for implementation
Reducing costs by reducing the amount of waste sent for disposal and raw material consumption.

Example plants
BE_041.

Reference literature
[9, COM 2007], [56, COM 2023]

4.4.6 Reduction, reuse and recycling of packaging

[Note to the TWG: Please provide information to complete the 10-heading template below, e.g. on economics]

Description
For product packaging, this includes techniques such as:

- use of light and high-capacity packaging to reduce the specific consumption of packaging (e.g. high-expansion plastic films);
- use of reusable packaging (e.g. reusable pallets, metal boxes);
- use of recycled plastic films;
- use of a reduced amount of printed plastic films (e.g. printed banderole) to facilitate downstream recycling.

For the packaging of chemical substances and mixtures, this includes techniques such as:

- storage in preferably large containers;
- reuse of packaging;
- return to the supplier;
- sending for material recycling.

Technical description

Achieved environmental benefits
Reduction of packaging materials and associated residues.

Environmental performance and operational data
Plastic film contains up to 50 % post-consumer recycled plastic.

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally applicable.

Economics

Driving force for implementation
Circular economy.

Example plants
Widely used. A total of 112 installations in the data collection reported using reusable pallets or other reusable materials, 28 installations reported using light packaging and 19 reported using high-capacity packaging.

Reference literature
[35, TWG 2023], [56, COM 2023]

4.4.7 Use of broken materials in other sectors

[Note to the TWG: Please provide information to complete the 10-heading template, e.g. on operational data and economics]

Description

This includes techniques such as:

- use of fired broken ware as raw material in other ceramic sectors usually after pretreatment (e.g. grinding);
- use of fired broken ware in construction works on site or off site (e.g. roads, tennis courts).

Technical description

Broken ware that cannot be reused in the process can sometimes be used as a raw material input in other industries; for example, broken inorganic bonded abrasive wheels are used as refractory material in steel manufacturing furnaces or as a filler in road construction. Broken bricks can be used, for example, as substrates for green roofs, tennis courts or as aggregates for special concretes.

Achieved environmental benefits

- Reduction of the amount of waste sent for disposal.
- Minimisation of residues.

Environmental performance and operational data

Cross-media effects

Technical considerations relevant to applicability

Generally applicable.

Economics

Driving force for implementation

Circular economy.

Example plants

- In the wall and floor tiles sector, FR_217 reported products with more than 80 % off-site recycled content.
- In the bricks and roof tiles sector, BE_029, BE_929, FR_221 and FR_223 reported 10-20 % of off-site recycled content in products with a high recycled content.
- BE_050 reported using porcelain scrap from another sector.

Reference literature

[9, COM 2007], [35, TWG 2023], [56, COM 2023]

4.4.8 Inkjet printing

[Note to the TWG: Please provide information to complete the 10-heading template below, e.g. on technical description, operational data, economics and driving force]

Description

Digitally controlled ejection of small droplets only on the required spot of the ceramic material to be decorated.

Technical description

Achieved environmental benefits

- Reduction of the ink consumption.
- Reduction of water consumption.
- Reduction of the rate of breakage.

Environmental performance and operational data

Cross-media effects

Technical considerations relevant to applicability
Inkjet printing may be restricted by product specifications.

Economics

Driving force for implementation

Example plants
Widely used in the wall and floor tiles sector. A total of 49 installations in the data collection reported using inkjet printing.

Reference literature
[71, ASCER 2019]

4.4.9 Breakage detection before firing

For a description of the technique, see Section 4.3.10.

4.4.10 Production of small batches of glaze

[Note to the TWG: Please provide information to complete the 10-heading template below]

Description
Glaze is produced in small batches to avoid the generation of surplus glaze.

Technical description

Achieved environmental benefits

- Reduction of surplus glaze.
- Reduction of water consumption.

Environmental performance and operational data

Cross-media effects

Technical considerations relevant to applicability

Economics

Driving force for implementation

Example plants

Reference literature
[71, ASCER 2019]

4.4.11 Modification of product design

For a description of the technique, see Section 4.3.15.

~~**General considerations on plaster moulds, firing auxiliaries and broken ware avoidance/replacement/reduction**~~

~~In the firing process, there are also measures for a direct prevention of waste by the use of modern techniques. If, instead of capsule or rack tunnel kiln firing, fast firing systems like roller hearth kilns are used, the amount of (used) firing auxiliaries can be reduced, but it has to be taken into consideration in this context, that the lifetime of firing auxiliaries depends on the temperature (which is typically higher in roller hearth kilns) and on handling (which is more frequent in fast firing, because firing time is shorter). Additionally, fast firing creates more rejected ceramic products – for instance tiles – when the shape is complex, because it is primarily suited for flat products and therefore, it is not applicable in all cases.~~

~~The ratio of broken ware from the firing process can be reduced by exact electronic controlling of the firing curve and by optimisation of the setting [4, UBA 2001], [23, TWG 2005].~~

4.5 Techniques to reduce water consumption and discharge

4.5.1 Water management plan and audits

[Note to the TWG: Please provide information to complete the 10-heading template below, e.g. on operational data]

Description
A water management plan is part of the EMS (see Section 4.2.1) and includes:

- flow diagrams of processes and water mass balances of the plant as part of the inventory of inputs and outputs mentioned in Section 4.2.2;
- establishment of water efficiency objectives;
- implementation of water optimisation techniques (e.g. control of water usage, reuse/recycling, detection and repair of leaks);

Audits (also part of the EMS, see Section 4.2.1) are carried out at least once every year to ensure that the objectives of the water management plan are met and the audit recommendations are followed up and implemented.

Technical description
The flow diagrams and mass balances are based on the monitoring data and input/output streams inventory. Guidance on water management plans and audits is provided in ISO 46001 ‘Water efficiency management systems – Requirements with guidance for use’.

Achieved environmental benefits
Reduction of water consumption and waste water discharge, including reduced leaks, spillages and emissions to soil and groundwater.

Environmental performance and operational data

Cross-media effects
None identified.

Technical considerations relevant to applicability
The level of detail and the degree of formalisation of the water management plan and audits will generally be related to the nature, scale and complexity of the installation.

Economics

- Staff time.
- Cost of any metering required.

Driving force for implementation

- Legal requirements.
- Reducing cost depending on the pricing and availability of water.

Example plants
Widely used. In the data collection, 25 plants reported implementing a water management plan.

Reference literature
[35, TWG 2023], [51, COM 2020]

4.5.2 Minimisation of water consumption

[Note to the TWG: Most of the text in the section below was part of Section 4.4 'Process waste water' in the 2007 CER BREF. Please provide information to complete the 10-heading template below, e.g. on operational data and technical description]

Description

This includes techniques such as:

- automatic valves to prevent leaks;
- use of high-pressure water cleaning systems;
- use of dry off-gas cleaning systems;
- use of waste water from glazing in glaze preparation;
- dry product finishing (e.g. dry grinding of bricks, dry rectifying of wall and floor tiles).

Technical description

~~Minimising water consumption is fundamental, and to achieve this reduction, the following process optimisation measures can be implemented:~~

- ~~acting on the water circuit, installing automatic valves that prevent leaks of water when it is no longer needed;~~
- ~~installation of a high pressure system in the plant for cleaning purposes (or high pressure cleaning equipment);~~
- ~~switching from wet off-gas cleaning systems to alternative, non-water consuming systems (cleaning by dry off-gas cleaning systems, see Section 4.2.3 and 4.3.4);~~
- ~~installation of 'in-situ' waste glaze collection systems;~~
- ~~installation of slip conveying piping systems;~~

~~separate collection of process waste water streams from different process steps.~~

Achieved environmental benefits

Reduction of water consumption and waste water discharge.

Environmental performance and operational data

Cross-media effects

None identified.

Technical considerations relevant to applicability

Process optimisation measures to minimise water consumption can be applied in all sectors of the ceramic industry.

Economics

This depends on the particular individual ~~case-related~~ measure/task, but minimising water consumption in general leads to reduced fresh water costs.

Driving force for implementation

- Legal requirements.
- ~~Saving costs by running processes in an efficient way.~~ Reduction of water costs.

Example plants

Widely used. In particular:

- 17 installations reported the installation of automatic valves to prevent water leaks;
- 27 installations reported the installation of a high-pressure system for cleaning;
- 13 installations reported using dry waste-gas cleaning systems instead of wet-gas cleaning;
- 7 installations reported using on site waste glaze collection systems;

- 6 installations reported separating the collection of waste water from different process steps.

Reference literature
[9, COM 2007], [35, TWG 2023]

4.5.3 Segregation of polluted and upolluted water streams

[Note to the TWG: Please provide information to complete the 10-heading template below, e.g. on operational data and economics]

Description
Water streams (e.g. surface run-off water, process water, cleaning water) are collected separately, based on the pollutant content and on the required treatment techniques. Waste water streams that can be recycled without treatment are segregated (e.g. cooling water) from waste water streams that require treatment.

Technical description
A detailed technical description of a waste water collection and segregation system can be found in the CWW BREF [34, COM 2016].

Achieved environmental benefits
Reduction of water consumption and waste water discharge.

Environmental performance and operational data

Cross-media effects
None.

Technical considerations relevant to applicability
Applicability to existing plants may be limited by the layout of the water collection system.

Economics

Driving force for implementation

- Legal requirements.
- Reducing cost depending on the pricing and availability of water.

Example plants
BG_057, DK_112, HU_230, IT_306 and IT_307.

Reference literature
[34, COM 2016], [35, TWG 2023]

4.5.4 Prevention of waste water generation from process storage areas

See Section 4.2.4.2 on ‘Structuring and management of process areas and raw material storage areas’.

4.5.5 Water reuse and/or recycling

[Note to the TWG: Part of the text in the section below was part of Section 4.4 'Process waste water' in the 2007 CER BREF. Please provide information to complete the 10-heading template below, e.g. on economics]

Description

Water streams (e.g. process water, effluents from wet scrubbing and spray drying, cooling water, cleaning water) are reused and/or recycled in closed or semi-closed circuits, if necessary after treatment (see Section 4.8.3.6).

Technical description

This includes techniques such as:

- reuse of process waste water in the same process step, in particular repeated reuse of the cleaning water after suitable treatment;
- closed loop cooling systems;
- use of cleaning water as process water.

Achieved environmental benefits

Reduction of water consumption and waste water discharge.

Environmental performance and operational data

~~The optimum solution involves re-using the arising process waste water in the same process step.~~ To determine the maximum amount of reusable process waste water in the plant and to design such solutions, a water balance (a ~~so-called~~ 'mass flow') can be drawn up setting out all points and quantities of arising process waste water as well as all the possible uses of it.

~~In this context,~~ ~~the following table~~ Table 4-2 shows achievable process waste water recycling ratios in different sectors of the ceramic industry. ~~The data are German sector specific average ratios and highest achieved ratios, referring to process waste water produced [4, UBA 2001].~~

[Note to the TWG: for refractories and table and ornamentalware, there are only data available from one installation in the data collection and no data available for technical ceramics and vitrified clay pipes. Please provide information to complete the table below]

Table 4-2: ~~Achievable process waste water recycling ratios in different sectors of the ceramic industry~~ Ratio of recycled/reused water in the total water consumption

~~Sector~~	~~Average~~	~~Highest ratio~~
~~Wall and floor tiles~~	~~70 – 80 %~~	~~100 %~~
~~Household ceramics~~	~~n.a.~~	~~50 %~~
~~Sanitaryware~~	~~30 – 50 %~~	~~50 %~~

Sector	Ratio of recycled/reused water in the total water consumption
Bricks and roof tiles	2 – 100 %
Expanded clay	5 – 68 %
Sanitaryware	10 – 60 %
Wall and floor tiles	15 – 100 %
Source: [35, TWG 2023]	

~~Varying achievable process waste water re-use ratios, referring to the process water required, are reported for the manufacture of different wall and floor tile products: from 10 % (unglazed porcelain stoneware) to 70 % (single-fired glazed tiles and glazed porcelain stoneware) [6, Timillini 2004].~~

Process waste water recycling and reuse ratios are achieved by a combination of the process optimisation measures and application of the process waste water treatment systems~~,~~ mentioned in Section 4.8.

Cross-media effects
None.

Technical considerations relevant to applicability
The degree of water reuse and/or recycling is limited by the water mass balance of the plant, the content of impurities and/or the characteristics of the water streams.

Economics

Driving force for implementation

- Legal requirements.
- Reduction of water costs.

Example plants
Widely used. In particular, 82 installations in the data collection reported reusing and recycling waste water in general or cleaning water.

Reference literature
[34, COM 2016], [35, TWG 2023]

~~4.5 Process waste water~~

~~Water used as a raw material~~

~~Water is a very important raw material in the ceramic manufacturing industries, but the amount used varies greatly between sectors and processes. The water added directly to ceramic body mixes does not lead to a waste water problem, as it is subsequently evaporated into the air during the drying and firing stages. Process waste water is generated mainly when clay materials are flushed out and suspended in running water during the manufacturing process steps.~~

~~Water used as a heat exchange vehicle~~

~~Water performs this function in cooling hydraulic systems and compressors, etc. Water used for this purpose must be clean and show low hardness to prevent scaling in the heat exchangers. The water used can circulate in closed circuits after simple cooling and/or cleaning operations and thus, water consumption corresponds to the amount of evaporated water. Because water in closed circuits for cooling operations is, in most cases, chemically conditioned to avoid corrosion or fermentation of organic matter, treatment with production waste water is usually not possible (in this context, see also the BREF on Industrial Cooling Systems).~~

~~Water used as a scrubbing agent~~

~~Water is also used in off-gas scrubbers (wet flue-gas cleaning systems and wet dust separators). In these systems, recycled process waste water can be used, which has been treated by a simple physical procedure (settling with or without prior chemical treatment), and can be circulated or treated again.~~

~~Water used as a cleaning agent~~

~~Water is used to clean the facilities, especially raw material preparation units, moulds and other casting units, glazing lines, engobing and other decoration units. Cleaning is the operation in which most water is used and which requires suitable management to achieve savings and avoid process waste water. Water consumption can be reduced if the water is treated and re-used several times in cleaning.~~

~~Objectives and solutions for the reduction of process waste water (emissions and consumption)~~

~~The objectives for treating the water arising in ceramic manufacturing processes involve lowering water consumption and achieving minimum process waste water emissions. To reach these objectives, process optimisation measures and process waste water treatment systems are employed.~~

~~Driving force for implementation~~

~~Saving costs by running processes in an efficient way.~~

~~Example plants and reference literature~~

~~[3, Ceram-Unie 2003], [4, UBA 2001], [10, Navarro, J. E. 1998], [13, SYKE 2004], [23, TWG 2005]~~

4.6 Techniques to reduce consumption of hazardous substances

4.6.1 Substitution and reduction of hazardous process chemicals

[Note to the TWG: please provide information to complete the 10-heading template below and specific examples of substitution]

Description
This includes:

- regularly reviewing the inventory of process chemicals (part of the inventory of inputs and outputs see Section 4.2.2) and optimising the formulation of chemicals in additives, binders, glazes, etc.;
- substitution of hazardous chemicals with less hazardous ones (based on the regular analysis of the potential for substitution of the chemicals management system (see Section 4.2.3);
- optimisation of the quantity of chemicals used.

Technical description
In glazes it is possible to substitute lead and reduce boron compounds by applying a two-stage melting process [73, LIFE 2013].

Achieved environmental benefits
Reduction of the pollutant load in effluents.

Environmental performance and operational data

- Reduction of the pollutant load in effluents from the installation.
- Reduction of the consumption of process chemicals.

Cross-media effects
None identified.

Technical considerations relevant to applicability
The substitution of hazardous chemicals may be restricted by the availability of a suitable alternative chemical.

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. Regulation EC No 66/2010 on the EU Ecolabel).
- Chemical regulation (e.g. Regulation EC No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals, REACH).

Example plants
A total of 13 installations in the data collection reported substituting the use of hazardous substances.

Reference literature
[19, COM 2023], [35, TWG 2023]

4.6.2 Automatic systems for the preparation and dosing of process chemicals

[Note to the TWG: please provide information to complete the 10-heading template below, e.g. on operational data and economics]

Description

Automatic systems for weighing, dosing, dissolving, measuring and dispensing, which ensure precise delivery of process chemicals to the production machines, for example as additives, binders, glazes.

Technical description

Tanks in storage facilities, dispensing units and machinery are connected by the pipework equipped with valves, pumps, sensors and meters enabling automated and computerised control and handling of solid and liquid chemicals (e.g. pigments, binders).

Achieved environmental benefits

- Reduction of the pollutant load in effluents from the installation.
- Reduction of the consumption of process chemicals.

Environmental performance and operational data

Cross-media effects

Compressed air and electricity may needed for the operation of the system.

Technical considerations relevant to applicability

Generally applicable.

Economics

Driving force for implementation

- Shorter time for preparation of glazes.
- Reproducibility of mixtures.
- Health and safety requirements.

Example plants

Reference literature

[19, COM 2023], [35, TWG 2023]

4.6.3 Recovery and use of leftover process chemicals

[Note to the TWG: please provide information to complete the 10-heading template below]

Description

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. This includes the reuse of surplus glaze on site.

Technical description

Achieved environmental benefits

- Reduction of the pollutant load in effluents from the installation.

- Reduction of the consumption of process chemicals.

Environmental performance and operational data

Cross-media effects

Technical considerations relevant to applicability

Economics

Driving force for implementation
Chemicals costs.

Example plants
A total of 7 installations in the data collection reported recovering surplus glaze: FR_212 and NL_335 for bricks and roof tiles, BG_057 and ES_155 for sanitaryware and DE_104, DE_108 and IT_263 for wall and floor tiles.

Reference literature
[35, TWG 2023]

4.7 Techniques to reduce emissions to air

4.7.1 Techniques to reduce diffuse emissions of dust

[Note to the TWG: this section has been rewritten based on the information on Section 4.2.1 of the 2007 CER BREF]

Useful information can also be found in the BREF on Emissions from Storage (EFS).

4.7.1.1 Extraction of emissions as close as possible to the emission source

[Note to the TWG: please provide information to complete the 10-heading template below]

Description
Emissions from mechanical processes, surface treatment/decoration, and transfer and handling of materials/products are captured and extracted using enclosures, fixed or movable extraction hoods for example. The extracted air is then dedusted before being released (see Section 4.7.2.2).

Technical description
This includes techniques such as:

- filtration of air displaced in raw material preparation, mixing and shaping and product finishing;
- material handling in closed systems;
- pneumatic conveying systems;
- reduction of air leakage.

Source: [72, TWG 2022]

Figure 4-9: Channelling of dust emissions in wall and floor tiles manufacturing

Source: [56, COM 2023]

Figure 4-10: Channelling of dust emissions in facing brick manufacturing

Achieved environmental benefits

- Reduction of primarily diffuse dust emissions
- Noise reduction is also achiebed by enclosing machinery.

Environmental performance and operational data

This depends on the particular individual case-related measure/task. In any case, regular maintenance and repair ensures that leaking off-gas pipes, storage silos and preparation units or damaged enclosures are repaired quickly.

Cross-media effects

- Pneumatic conveying systems with air circulation may cause an increase of noise emissions and electrical energy consumption.
- When maintenance is carried out, additional waste may occur.

Technical considerations relevant to applicability

Applicability may be restricted by the shape and size of the area to be enclosed.

Economics

This depends on the particular individual case-related measure/task. For old facilities, the enclosure of installations may require a medium- or long-term implementation plan.

Driving force for implementation

- Safety measures and optimisation of operations.
- Legal requirements.
- Raw material savings.
- Local conditions.

Example plants
Widely used. A total of 33 installations in the data collection reported extracting emissions from at least one of the following processes: material discharge, material transport, mixing, product finishing, storage, shaping and surface treatment.

Reference literature
[1, BMLFUW 2003], [2, VITO 2003] [3, Ceram-Unie 2003], [4, UBA 2001], [23, TWG 2005], [26, UBA 2005], [30, TWG 2005], [35, TWG 2023], [61, COM 2019]

4.7.1.2 Cleaning of roads and transport vehicle wheels

[Note to the TWG: please provide information to complete the 10-heading template below, e.g. on operational data and economics]

Description
Roads as well as the wheels of transport vehicles are regularly cleaned, by using mobile vacuum systems, water lagoons, etc.

Technical description
Regularly cleaning and sweeping roads, surfaces and vehicle tyres reduces diffuse emissions.

Achieved environmental benefits
Avoiding the transfer of pollutants to water and air.

Environmental performance and operational data

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally applicable.

Economics

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants
Widely used. A total of 74 installations in the data collection reported cleaning/sweeping of surfaces and roads to reduce diffuse dust emissions.

Reference literature
[9, COM 2007], [35, TWG 2023]

4.7.1.3 Enclosure and/or covering of equipment and storage of raw material

[Note to the TWG: please provide information to complete the 10-heading template below, e.g. on operational data]

Description
This includes techniques such as:

- enclosure/encapsulation of mechanical processes (e.g. grinding, screening, mixing);

- use of covered conveyor belts and elevators;
- installation of equipment in closed buildings;
- storage in silos with level indicators and filters to dedust the air displaced during filling;
- covering of transport vehicles.

Technical description
Enclosed storage building openings can be avoided by curtains in material delivery areas or automatically closing doors and lids.

Achieved environmental benefits
- Reduction of diffuse dust emissions.
- Noise reduction is also possible by enclosing machinery.

Environmental performance and operational data

Cross-media effects
None identified.

Technical considerations relevant to applicability
Applicability may be restricted by the shape and size of the area to be enclosed.

Economics
Cost will depend on technical and economic factors.

Driving force for implementation
- Safety measures and optimisation of operations.
- Legal requirements.
- Raw material savings.
- Local conditions.

Example plants
Widely used. A total of 60 installations in the data collection reported applying techniques to enclose and cover equipment and storage of raw materials. The distribution is as follows:
- enclosed storage was reported by 37 intallations;
- storage silos with level indicators and filters were reported by 29 installations;
- enclosure of grinding, screening or mixing was reported by 21 installations;
- curtains in material delivery areas were reported by 16 installations;
- covered conveyor belts were reported by 15 installations;
- enclosed transport was reported by 10 installations;
- automatically closing doors or lids was reported by 8 installations.

Reference literature
[9, COM 2007], [35, TWG 2023]

4.7.1.4 Limitation of the height of discharge

[Note to the TWG: please provide information to complete the 10-heading template below, e.g. on operational data and economics]

Description

Matching the discharge height to the varying height of the heap, automatically if possible (e.g. conveyor belts with adjustable height).

Technical description

If dust emissions at discharge points of storage sites cannot be avoided, they can be reduced by matching the discharge height to the varying height of the heap, if possible automatically, or by reduction of the unloading velocity.

Achieved environmental benefits

Reduction of diffuse dust emissions.

Environmental performance and operational data

Cross-media effects

None identified.

Technical considerations relevant to applicability

Generally applicable.

Economics

Driving force for implementation

- Safety measures and optimisation of operations.
- Legal requirements.
- Raw material savings.
- Local conditions.

Example plants

A total of 29 installations in the data collection reported applying reduced or adjustable discharge speed and/or height.

Reference literature

[9, COM 2007], [35, TWG 2023]

4.7.1.5 Protection of stockpiles against prevailing winds

[Note to the TWG: please provide information to complete the 10-heading template below, e.g. on operational data]

Description

Protection of bulk storage areas or stockpiles with covers or wind barriers such as screening, walling or vertical greenery, as well as correctly orienting the stockpiles in relation to the prevailing wind.

Technical description

In order to reduce primarily diffuse emissions at bulk storage locations of dusty mineral raw materials into the open air, such storage locations can be enclosed with screening, walling or an enclosure consisting of vertical greenery (artificial or natural wind barriers for open pile wind protection).

Achieved environmental benefits

Reduction of diffuse dust emissions.

Environmental performance and operational data

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally applicable.

Economics
Cost will depend on technical and economic factors.

Driving force for implementation

- Safety measures and optimisation of operations.
- Legal requirements.
- Raw material savings.
- Local conditions.

Example plants
A total of 45 installations in the data collection reported using ‘roofed storage’, 8 ‘screening, walling of storage’ and 2 using ‘wind shields’ to reduce diffuse dust emissions.

Reference literature
[9, COM 2007], [35, TWG 2023]

4.7.1.6 Use of water sprays

[Note to the TWG: please provide information to complete the 10-heading template below, e.g. on operational data]

Description
Installation of water spray systems at the main sources of diffuse dust emissions. The humidification of dust particles aids dust agglomeration and settling.

Technical description
Figure 4-11 shows an example of a water spray system to reduce diffuse dust emissions in bulk storage areas.

Source: [56, COM 2023]

Figure 4-11: Example of a water sprays to reduce diffuse emissions in storage areas

Achieved environmental benefits
Reduction of diffuse dust emissions.

Environmental performance and operational data

Cross-media effects
Water consumption.

Technical considerations relevant to applicability
Applicability may be restricted by a lack of water.

Economics
Cost will depend on technical and economic factors.

Driving force for implementation

- Safety measures and optimisation of operations.
- Legal requirements.
- Raw material savings.
- Local conditions.

Example plants
Widely used. A total of 19 installations in the data collection reported the use of water sprays to reduce dust diffuse emissions.

Reference literature
[35, TWG 2023]

~~4.2.1 Measures for dusty operations~~

~~Description~~

~~Several different measures are presented here, which can be applied individually or in combination:~~

- ~~enclosure of dusty operations, such as grinding, screening and mixing~~
- ~~the use of covered and vented trough or pan mixers~~
- ~~filtration of air displaced whilst charging mixers or dosing equipment~~
- ~~storage silos with adequate capacity, level indicators with cut out switches and with filters to deal with dust-bearing air displaced during filling operations~~
- ~~covered conveyor belts for potentially dusty raw materials~~
- ~~a circulation process is favoured for pneumatic conveying systems~~
- ~~material handling in closed systems maintained under negative pressure and de-dusting of the suction air~~
- ~~reduction of air leakage and spillage points, completion of installation.~~

~~Achieved environmental benefits~~

- ~~reduction of primarily diffuse dust emissions~~
- ~~noise reduction is also possible by enclosing machinery.~~

~~Cross-media effects~~

- ~~pneumatic conveying systems with air circulation may cause an increase of noise emissions and electrical energy consumption~~
- ~~when maintenance is carried out, additional waste may occur.~~

~~Operational data~~

~~This depends on the particular individual case related measure/task. In any case regular maintenance and repair ensures that leaking off-gas pipes, storage silos and preparation units or damaged enclosures are repaired quickly.~~

~~Applicability~~

~~The measures can be carried out in all sectors of the ceramic industry, in old and new facilities, but when handling moist clays, not necessarily all of the measures mentioned above have to be carried out.~~

~~Economics~~

~~This depends on the particular individual case related measure/task. For old facilities the enclosure of installations may require a medium or long-term implementation plan.~~

~~Driving force for implementation~~

- ~~legal requirements~~
- ~~health and safety requirements for the workplace~~
- ~~raw material savings.~~

~~Example plants and reference literature~~

~~[1, BMLFUW 2003], [2, VITO 2003], [3, Ceram-Unie 2003], [4, UBA 2001] [23, TWG 2005], [26, UBA 2005], [30, TWG 2005]~~

~~4.2.2 Measures for bulk storage areas~~

~~Description~~

~~In order to reduce primarily diffuse emissions at bulk storage locations of dusty mineral raw materials into the open air, such storage locations can be enclosed with screening, walling or an enclosure consisting of vertical greenery (artificial or natural wind barriers for open pile wind protection).~~

~~If dust emissions at discharge points of storage sites cannot be avoided, they can be reduced by matching the discharge height to the varying height of the heap, if possible automatically, or by reduction of the unloading velocity. Additionally, the locations can be kept wet – especially in dry areas – using spraying devices (if the point source of dust is locally limited, a water spray injection system can be installed) and can be cleaned with cleaning lorries.~~

~~To prevent the formation of diffuse dust during removal operations, vacuum systems can be used. New buildings can easily be equipped with stationary vacuum cleaning systems, while existing buildings are normally better fitted with mobile systems and flexible connections.~~

~~Achieved environmental benefits~~

~~Reduction of primarily diffuse dust emissions.~~

~~Cross-media effects~~

- ~~the water consumption increases when keeping locations wet~~
- ~~increase in energy consumption from the use of vacuum systems~~
- ~~when maintenance is carried out, additional waste may occur.~~

~~Operational data~~

~~This depends on the particular individual case related measure/task.~~

~~Applicability~~
~~The measures can principally be carried out in all sectors of the ceramic industry, in old and new facilities, but when handling moist clays, not necessarily all of the measures mentioned above, have to be carried out. Also, sometimes dry raw materials are needed for mixing to achieve the desired properties, and therefore wetting can only be applied to a certain extent.~~

~~Economics~~

~~This depends on particular individual case related measure/task. In this context, see also Table 4.7.~~

~~Driving force for implementation~~

- ~~legal requirements~~
- ~~health and safety requirements for the workplace.~~

~~Example plants and reference literature~~

~~[2, VITO 2003], [4, UBA 2001], [17, Burkart, M. 2004], [23, TWG 2005], [26, UBA 2005], [30, TWG 2005]~~

4.7.2 Techniques to reduce channelled emissions in general

4.7.2.1 Limiting the number of emission points

[Note to the TWG: please provide information to complete the 10-heading template below, e.g. on operational data]

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 combination of waste gases is carried out considering technical (e.g. compatibility of the individual waste gas streams), environmental (e.g. maximising recovery of materials or pollutant abatement) 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.

Technical description

Emissions from the same type of processes that are generating waste gases with similar characteristics are combined and treated together for better treatment efficiency and to reduce the energy consumption associated with the operation of multiple abatement systems.

Achieved environmental benefits

- Energy savings.
- Improved abatement efficiency of emissions to air.
- Recovery of materials (e.g. dust).

Environmental performance and operational data

Cross-media effects

None expected.

Technical considerations relevant to applicability

Generally applicable.

Economics

Cost will depend on technical and economic factors.

Driving force for implementation

Reduction of monitoring and abatment costs due to the lower number of emission points.

Example plants

Widely used.

Reference literature

[35, TWG 2023], [38, COM 2022], [56, COM 2023]

4.7.2.2 Fuel choice Substitution of heavy fuel oil and solid fuels by low emission fuels

[Note to the TWG: most of the information below was included in Section 4.1.4 of the 2007 CER BREF. Please provide information to complement and update the 10-heading template below]

Description

Use of fuel (e.g. natural gas, LPG) with a low content of potentially pollution-generating compounds (e.g. low sulphur, ash, nitrogen, fluorine or chlorine in the fuel).

Technical description

The switch of the firing process from heavy fuel oil (HFO) or solid fuels to gaseous fuels (natural gas, liquefied petroleum gas (LPG) and also liquefied natural gas (LNG)) leads to an improved firing efficiency and the virtual elimination of soot emissions in many processes.

Additionally, the use of low-emission fuels can involve other energy-efficient technologies – for example cogeneration with gas turbines – in~~to~~ the manufacturing process. Other savings in (electrical) energy can also be achieved due to the fact that some liquid fuels (in particular HFO) have to be warmed to be pumpable.

Achieved environmental benefits

Solid fuels usually produce fine ash, so the reduction in particulate emissions when burning gas can, in some cases, obviate the need for expensive and energy-consuming dust removal processes. Gas burners lend themselves to sophisticated automatic control systems, leading to fuel savings and reduced wastage of fired ware, hence reduced specific energy consumption. The use of extra light fuel oil ~~EL~~ instead of HFO or solid fuels can also reduce soot emissions from firing processes.

Using natural gas, LPG, LNG or extra light fuel oil ~~EL~~ instead of HFO or solid fuels leads to a reduction in energy-linked SO_2 emissions because of the lower sulphur content (see Table 3.3). Also, natural gas, LPG and LNG have higher hydrogen/carbon ratios than fuel oils or solid fuels, so they produce less carbon dioxide (approx~~.~~imately 25 % less CO_2 in the case of natural gas) for an equivalent heat output.

~~Alternative/secondary fuels of organic origin, e.g. meat and bone meal or biofuels, and of non-organic origin, e.g. waste oil, solvents, as for instance used in the manufacture of expanded clay aggregates (see Section 2.3.4.2.2), reduce the amount of primary fossil fuels and the related CO_2 emissions.~~

Environmental performance and operational data

This depends on the particular individual case-related measure/task.

Cross-media effects

Additional safety aspects – especially explosion risks – have to be taken into consideration, in particular regarding LPG and LNG.

Technical considerations relevant to applicability

Applicable within the constraints associated with the availability of different types of fuel, which may be impacted by the energy policy of the Member State.

In principle, a fuel switch can be applied in all ceramic sectors, but it should be noted~~,~~ that the nature of the fuel can also affect the aesthetic features of the end-product. Thus certain tints, which are very desirable in the marketplace, can only be achieved by (co)incinerating coal or coal dust in kilns. For instance, certain types of special coloured facing bricks cannot be manufactured by burning natural gas alone, but coal dust has to be injected additionally for firing the kiln (Hoffmann kilns are used for these purposes). So, depending on the product type manufactured, a fuel switch is not always possible.

In the manufacturing process of expanded clay aggregates, most of the channelled dust is recycled, which reduces the impact of a fuel switch on ash production.

Economics

The change of HFO or solid fuels to low-emission fuels might involve considerable investment costs, especially if a natural gas supply to the ~~factory~~ plant is not available. In this context, not only the fuel costs, but also the additional transport costs for LPG, LNG and fuel oil EL have to be taken into account.

Driving force for implementation
- Legal requirements.
- Less fluctuation in product quality.
- Reduction of CO_2 emissions and contribution to decarbonisation.

Example plants
Widely used. A total of 156 installation from the data collection reported using only natural gas as fuel.

Reference literature
[1, BMLFUW 2003], [2, VITO 2003], [3, Ceram-Unie 2003], [23, TWG 2005], [26, UBA 2005], [30, TWG 2005], [32, TWG 2006], [35, TWG 2023], [46, MIDDEN 2020]

4.7.2.3 Extraction of emissions as close as possible to the emission source

See Section 4.7.1.1.

4.7.3 Techniques to reduce channelled emissions of dust ~~Emissions of dust (particulate matter)~~

In this section, techniques and measures to prevent ~~diffuse (mainly Sections 4.2.1 and 4.2.2) and~~ channelled ~~(mainly Section 4.2.3)~~ emissions of dust to air are described. In this context, useful information can also be found in the ~~BREF on Emissions from Storage and in the~~ BREFs on Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector (CWW) and on Common Waste Gas Management and Treatment Systems in the Chemical Sector (WGC).

~~**Separation/filter systems**~~

This section describes some techniques which are aimed exclusively at dust removal. Additionally, it can be noted~~,~~ that most of the flue-gas cleaning techniques, which are described in ~~Section 4.3.4~~ Section 4.7.4, are not only suitable for the elimination of ~~SO_x, HF and HCl~~ gaseous compounds, but also for eliminating dust.

4.7.3.1 ~~Centrifugal separators~~ Cyclones

[Note to the TWG: most of the information below was included in Section 4.2.3.1 of the 2007 CER BREF. Please provide information to complete and update the 10-heading template below]

Description
Equipment for the removal of dust from a process off-gas or waste gas stream based on imparting centrifugal forces, usually within a conical chamber.

Technical description
In a centrifugal separator, the dust particles to be eliminated from an off-gas stream are forced out against the outer wall of the unit by centrifugal action and then eliminated through an aperture at the bottom of the unit. Centrifugal forces can be developed by directing the gas flow in a downward spiral motion through a cylindrical vessel (cyclonic separators) or by a rotating impeller fitted in the unit (mechanical centrifugal separators).

Achieved environmental benefits
Reduced emissions of dust to air.

Cross-media effects

- The operation of centrifugal separators is a significant noise source.
- The electricity consumption may increase if an impeller is applied
- When maintenance is carried out, additional waste may occur.

Environmental performance and operational data
Centrifugal separators perform more efficiently with higher pollutant loadings, provided that the device does not become blocked.

Technical considerations relevant to applicability
Generally applicable.

The purification efficiency of centrifugal separators is generally too low to reduce any dust emissions to meet air pollution regulations in the ceramic industry. They are, therefore, only suitable as pre-separators and often used after spray drying, crushing and grinding operations.

Economics
Collection and recovery of separated dust leads to reduced raw material consumption.

Driving force for implementation
Raw material savings.

Example plants ~~and reference literature~~
Widely used. The use of cyclones was reported in 37 emission points from spray drying, 2 from crushing and milling, 1 from drying and 1 from mixing and shaping.

Reference literature
[1, BMLFUW 2003], [2, VITO 2003], [3, Ceram-Unie 2003], [23, TWG 2005] [16, COM 2023], [35, TWG 2023]

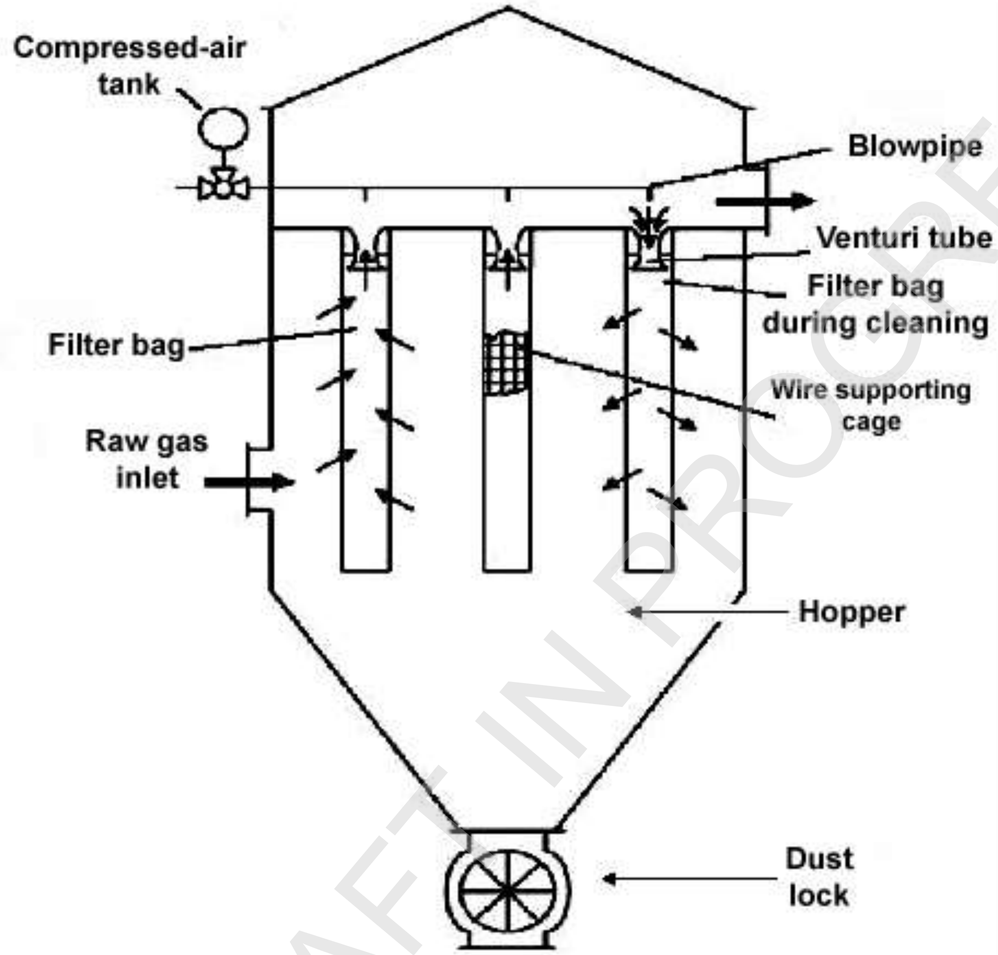
4.7.3.2 Fabric ~~Bag~~ filters

[Note to the TWG: most of the information below was included in Section 4.2.3.2 of the 2007 CER BREF. Please provide information to complete the 10-heading template below, e.g. on operational data and economics and on the use of other type of fabric filters (e.g. cartridge filters)]

Description
Fabric filters, often referred to as bag filters, are constructed from porous woven or felted fabric through which gases are passed to remove particles. The use of a fabric filter requires the selection of a fabric suitable for the characteristics of the waste gas and the maximum operating temperature. Fabric filters can be in the form of sheets, cartridges or bags with a number of the individual fabric filter units housed together in a group.

Technical description
In a bag filter, the off-gas is passed through a filter bag, such that the dust particles are deposited on the filter surface in the form of a filter cake. ~~Bag filter plants achieve high particulate retention, typically over 98 and up to 99 % depending on the particle size.~~

~~The following Figure~~ ~~4.3~~ Figure 4-12 presents the schematic view of a ~~bag~~ fabric filter with pressure pulse regeneration [4, UBA 2001]. Regeneration is performed by a pressure pulse on the clean gas part of the bag filter.

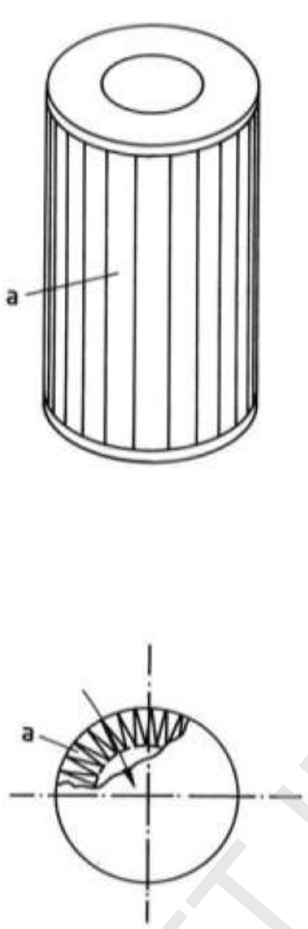


Source: [9, COM 2007]

Figure 4-12: Schematic view of a bag filter with pressure pulse regeneration

In cartridge filters, the filter medium is folded in a star fashion to pack more filtration area into a unit volume. Gas flow is from the outside to the inside. Regeneration is performed by a pressure pulse on the clean gas part of the cartridge filter [74, Cerame-Unie 2023].

Further information is provided in the CWW BREF.



Source: [18, Schmidt, E. 2008]

Figure 4-13: Basic cartridge filter design

Achieved environmental benefits

- Reduced dust emissions to air. Fabric filters are used to remove dust (including PM10 and PM2.5).
- Recovery of material.

Environmental performance and operational data

~~Bag~~Fabric filter plants achieve high particulate retention, typically over 98 % and up to 99 % depending on the particle size.

Filter bags are available in a range of woven fabrics, some of which show good resistance to acids or alkalis. Modern synthetic fabrics include materials which tolerate ~~quite~~ high temperatures but bag filters cannot operate at temperatures which are too high. Examples of widely used filter fabrics are shown in the ~~following~~ Table 4-3, which indicates properties and relative prices [3, Ceram-Unie 2003]. In particular, if a ~~bag~~ fabric filter is applied as part of a dry flue-gas cleaning device for the cleaning of kiln flue-gases (see Section 4.7.4.10), the filter and bag holders need to be corrosion-resistant, in case of condensation. Typical examples of data relating to the operation of fabric filters are listed in Table 4-4. [3, Ceram-Unie 2003], [23, TWG 2005].

Table 4-3: Examples of temperature resistance and the price of filter bags

Filter bag material	Temperature resistance (ºC)	Price (EUR/m^2)
Cotton	80	<5
Polypropylene	100	5
Polyester	150	10 – 12
Nomex (m-Aramid)	220	25
PTFE (Teflon)	280	100 – 120
Source: [9, COM 2007]		

Table 4-4: Examples of operating data for dust removal with fabric filters

Raw gas dust loading	Up to 200 g/m^3
Clean gas dust loading	1 – 20 mg/m^3
Operating temperature	Up to 250 ºC
Operating cost	0.03 – 0.1 EUR/t
Source: [9, COM 2007]	

Cross-media effects

- Operation of fabric filters, especially with pressure pulse regeneration, may cause noise emissions and it might also increase the electricity consumption due to their high pressure drop.
- When maintenance is carried out, additional waste may occur.

Technical considerations relevant to applicability

Generally applicable.

~~Bag~~ Fabric filters for dust removal from off-gases can, in principle, be applied in all sectors of the ceramic industry, especially for dusty operations (dedusting of silos for dry raw material storage, in dry raw materials preparation including spray drying, in dry shaping and in dry machining or grinding processes). Sometimes a combination with cyclone pre-filters is useful (see Section 4.7.3.1 ~~4.2.3.1~~).

In cartridge filters, there is a risk of plugging if the pleats are too tight as a result of dense dust layers which are difficult to clean off [74, Cerame-Unie 2023].

Economics

Figure 4-14 shows investment cost examples for filter plants excluding installation and filter bags.

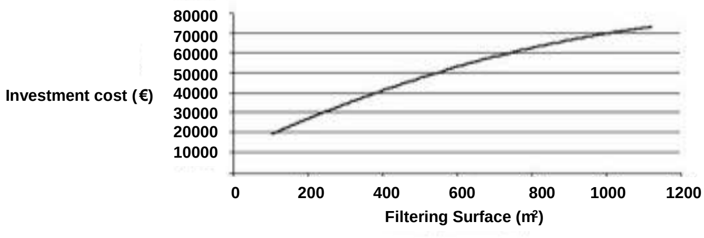


Figure 4-14: Investment cost examples as part of annual costs for filter plants excluding installationand filter bags

Self-cleaning bag filters should be large enough to run at a specific filtering surface load of less than 2 Nm^3/(m^2 x minute),~~ so that clean gas concentrations in the range of 1 – 20 mg/m^3 can be reported [1, BMLFUW 2003], [3, Ceram-Unie 2003], [23, TWG 2005].~~ Collection, recovery and reuse of separated dust leads to reduced raw material consumption.

See Chapter 3 for reported clean gas concentrations using bag filters.

~~Bag~~ Fabric filters cannot operate at temperatures which are too high and – especially in the case of humid off-gases – at temperatures close to the dew point. This is because the filter can clog and will be difficult to dry out and clean again, due to reactions between water and CaO forming a hard crust. This will drastically increase maintenance and electricity costs and production time.

In principle, running costs of ~~bag~~ fabric filters are strongly related to the amount of electricity needed to overcome the pressure drop, as mentioned above.

~~In this context, s~~ See also ~~Table 4~~ Table 4-8.

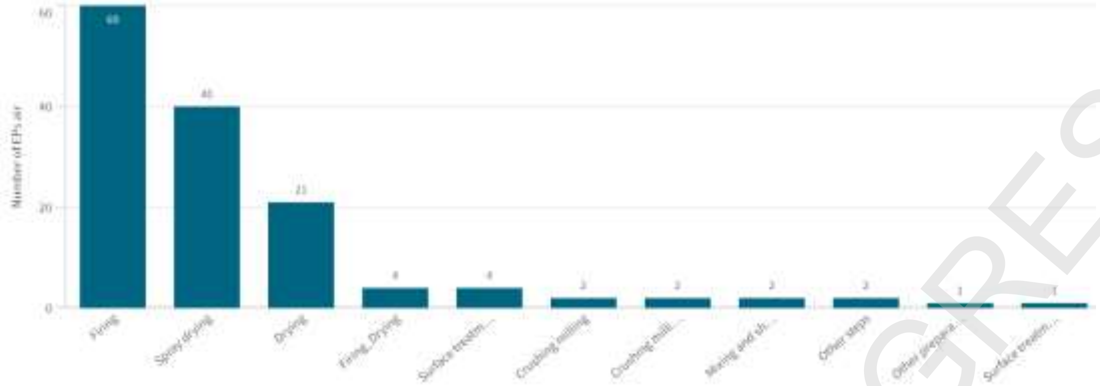
Driving force for implementation

- Legal requirements.
- Possible raw material savings compared to other filter types (e.g. wet dust separator).
- Health and safety requirements for the workplace.

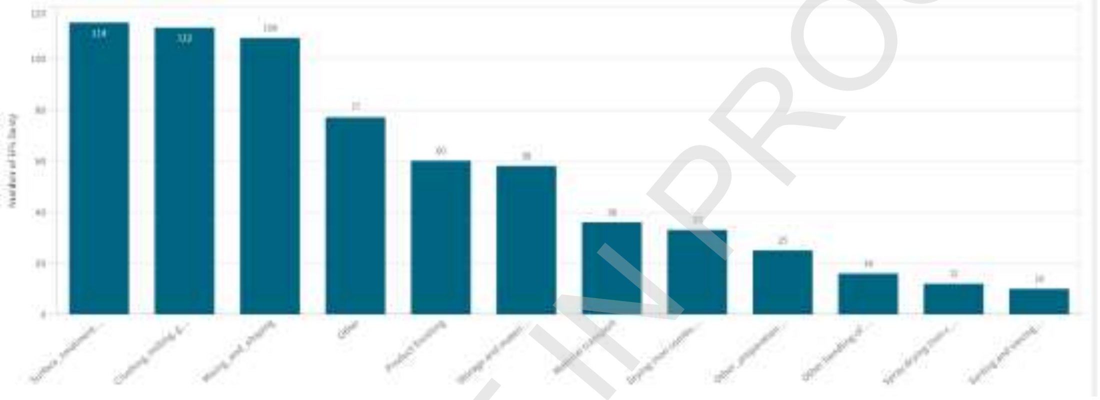
Example plants ~~and reference literature~~

Widely used. Figure 4-15 shows the number of emission points that reported using fabric filters by associated process.

Emission points using bag filters and monitoring dust and other parameters (EPs Air)



Emission points using bag filters and monitoring only dust (EPs Dust)



Source: [35, TWG 2023]

Figure 4-15: Number of emission points using bag filters

~~Tondach Gleinstaetten AG, brick and roof tile plant, Austria~~

Reference literature
[1, BMLFUW 2003], [2, VITO 2003], [3, Ceram-Unie 2003], [4, UBA 2001], [23, TWG 2005], [30, TWG 2005], [16, COM 2023], [18, Schmidt, E. 2008], [35, TWG 2023]

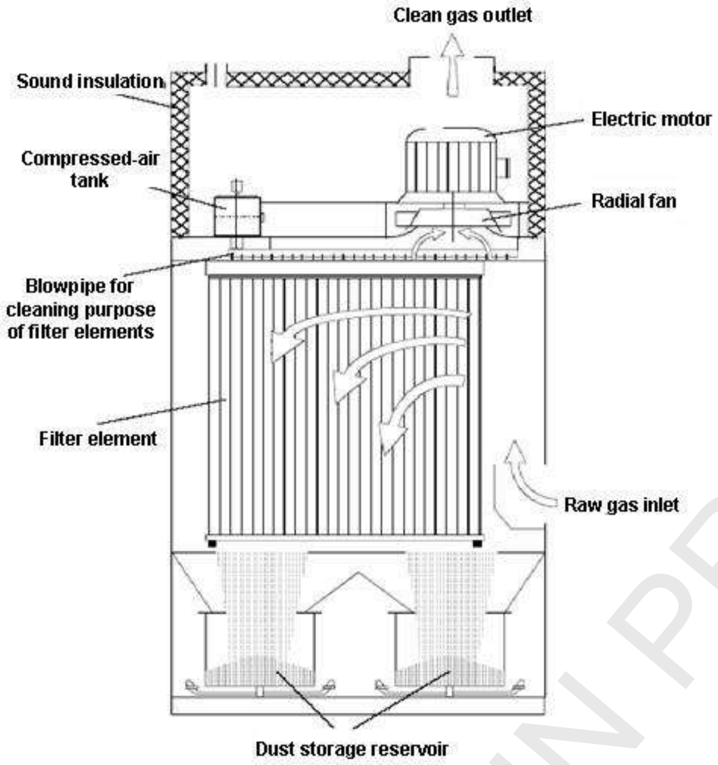
4.7.3.3 Sintered lamellar filters

[Note to the TWG: Most of the information below was included in Section 4.2.3.3 of the 2007 CER BREF. Please provide information to complete and update the 10-heading template below.]

Description
Sintered lamellar filters consist of a rigid filter medium mounted as a compact element.

Technical description
~~The main elements of this filter are the rigid filter media, which are mounted as compact elements in the filter system.~~ The filter elements consist of polytetrafluoroethylene ~~PTFE~~ covered sintered polyethylene, which gives the filter element its hard structure and waterproof characteristics. The main advantages of these ~~modern~~ filter media are a very high dust cleaning efficiency from off-gases in combination with a low pressure drop as well as a high resistance against abrasive wear, resulting especially from rough ceramic particles.

~~The following figure~~ Figure 4-16 presents the schematic view of such a rigid sintered lamellar filter, which is cleaned by a jet impulse self-cleaning system [4, UBA 2001].



Source: [4, UBA 2001]

Figure 4-16: Schematic view of a rigid sintered lamellar filter

Achieved environmental benefits
Reduced dust emissions to air.

Environmental performance and operational data
With these filter elements, cleaning efficiencies of up to 99.99 % ~~per cent~~ with clean gas concentrations of < 1 mg/m^3 are achievable, so it is possible to feed the clean gas back to the workplace [4, UBA 2001].

Cross-media effects

- Operation of a sintered lamellar filter with jet impulse self-cleaning systems may cause noise emissions and additional energy consumption.
- When maintenance is carried out, additional waste may occur.

Technical considerations relevant to applicability
Generally applicable.

The utilisation of sintered lamellar filters permits the separation of wet dust arising, for example, in spray glazing. This filter system makes ~~a~~ the direct feeding back of glazing particles possible, separated from the off-gas of the spraying cabin. An upstream quiescent zone guarantees that the dust in the system is relatively dry. In an ideal case, the separated glaze particles arise as trickling powder in the filter system.

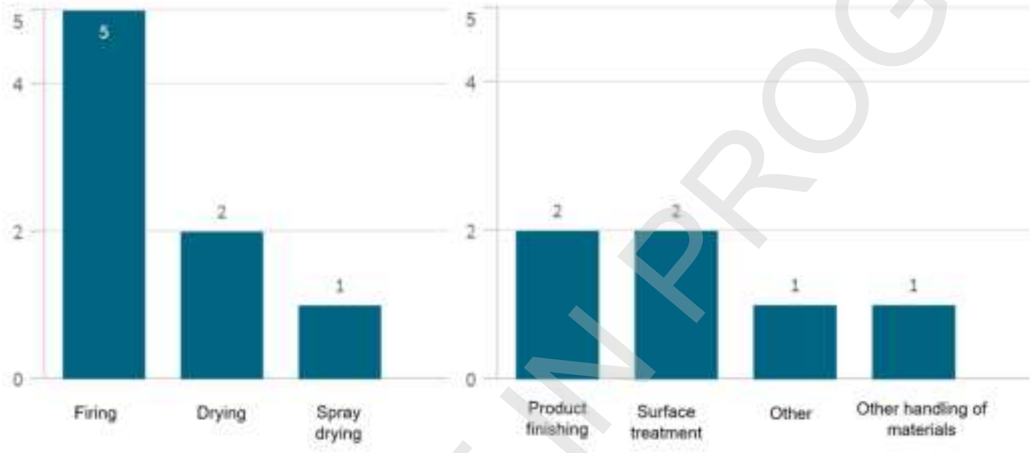
Economics
Usually the investment and operational costs of sintered lamellar filters are considerably higher than the costs for bag filters~~,~~; however, the possibility of feeding back the cleaned off-gas into the workplace area allows the saving of energy costs which would occur~~,~~ if high-volume flows of fresh air would have to be heated up to provide suitable workplace temperatures.

Driving force for implementation

- Legal requirements.
- Health and safety requirements for the workplace.
- Raw material savings.
- Energy savings.

Example plants

The following plants reported using sintered lamellar filters: CZ_060, DE_097, DE_100, HU_228 and PT_360. Figure 4-17 shows the number of emission points that reported using sintered lamellar filters by associated process.



Source: [35, TWG 2023]

Figure 4-17: Number of emission points using sintered lamellar filters

Reference literature

~~Oesterreichische Sanitaer-, Keramik- und Porzellan-Industrie AG, sanitaryware plant, Austria~~ [1, BMLFUW 2003], [4, UBA 2001], [32, TWG 2006], [35, TWG 2023]

4.7.3.4 ~~Wet dust separators~~ Wet dust scrubbing

[Note to the TWG: most of the information below was included in Section 4.2.3.4 of the 2007 CER BREF. Please provide information to complement and update, e.g. on operational data and economics]

Description

The removal of particulate pollutants from a gas stream via mass transfer to a liquid solvent, often water or an aqueous solution. This includes venturi scrubbers.

Wet scrubbing is also used to remove gaseous pollutants (see Section 4.7.4.11)

Technical description

~~With wet dust separators, dust is eliminated from off-gas streams~~ By bringing the gas flow into close contact with a scrubbing liquid (usually water), ~~so that~~ the dust particles are retained in the liquid and can be rinsed away. Wet dust separators can be divided into various types according to their design and working principles (e.g. venturi type).

Achieved environmental benefits

Reduced dust emissions to air.

Enironmental performance and operational data

~~Achievable clean gas concentrations in the range of 20 – 50 mg/m^3 are reported [1, BMLFUW 2003], [4, UBA 2001]. In this context, see also Table 3.33.~~ See Chapter 3 for reported clean gas concentrations using wet dust scrubbing.

Cross-media effects

With the wet removal technique, pollutants are transferred from air to water so a second installation for cleaning the wet waste product (suspension) is essential, and therefore additional energy consumption is also possible.

Technical considerations relevant to applicability

Generally applicable.

Wet dust separators are especially suitable for reducing humid or wet dust emissions, in particular from spray drying processes if they are used in combination with cyclones. They are especially beneficial if the rinsing water can be reused.

Further information is provided in the CWW BREF [34, COM 2016].

Economics

Regarding operating costs, scrubbing liquid and process waste water cleaning has to be taken into consideration. As a rule, smaller units controlling a low-concentration ~~off-~~ flue-gas stream will be much more expensive (per unit flow rate) than a large unit cleaning a high-pollutant-load flow.

Driving force for implementation

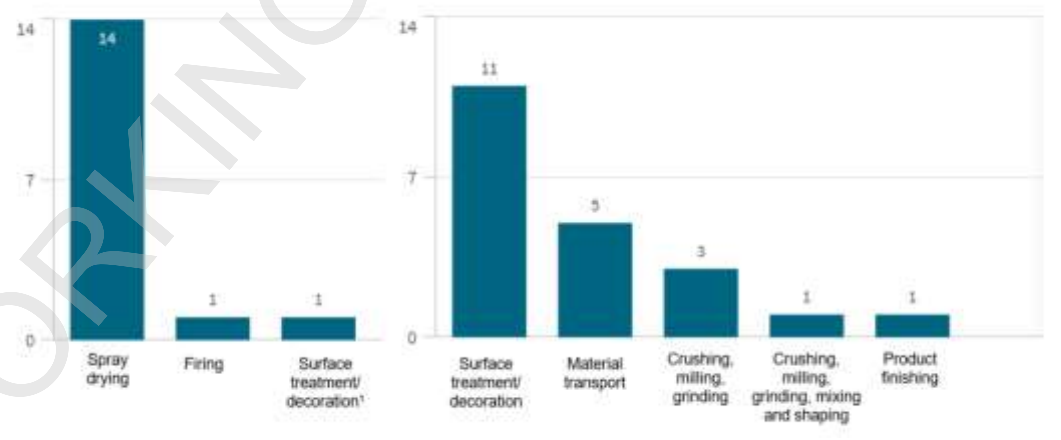
- Legal requirements.
- Health and safety requirements for the workplace.
- Raw material savings.
- Energy savings.

Example plants ~~and~~

~~Oesterreichische Sanitaer-, Keramik- und Porzellan-Industrie AG, sanitaryware plant, Austria~~

The following plants reported using wet dust separators in different process steps: CZ_062, DE_105, ES_155, ES_161, ES_163, ES_176, ES_198, ES_207, FR_219, NL_331 and NL_333.

Figure 4-18 shows the number of emission points that reported using wet dust scrubbing by associated process.



([1]) Surface treatment/decoration processes reported as EPs Air.
Source: [35, TWG 2023]

Figure 4-18: Number of emission points using wet dust scrubbing

Reference literature
[1, BMLFUW 2003], [2, VITO 2003], [4, UBA 2001], [10, Navarro, J. E. 1998], [17, Burkart, M. 2004], [20, Ceram-Unie 2004], [23, TWG 2005], [32, TWG 2006], [35, TWG 2023]

4.7.3.5 Electrostatic precipitators (ESPs)

[Note to the TWG: most of the information below was included in Section 4.2.3.5 of the 2007 CER BREF. Please provide information to complement and update, e.g. on operational data and economics]

Description
Electrostatic precipitators (ESPs) operate such that particles are charged and separated under the influence of an electrical field. ESPs are capable of operating under a wide range of conditions. The 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, but may contain up to seven fields for the most advanced ESPs. ESPs can be of the dry or of the wet type depending on the technique used to collect the dust from the electrodes. Wet ESPs are typically used at the polishing stage to remove residual dust and droplets after wet scrubbing [16, COM 2023].

Technical description
In an electrostatic precipitator, the flue-gases are passed through a chamber with two electrodes. A high voltage (up to 100 kV) is applied to the first electrode, which ionises the flue-gases. The ions generated adhere to the dust particles in the flue-gases~~,~~ and as a result these particles become electrically charged. Electrostatic forces repel the charged dust particles from the first electrode and attract them to the second, on which they are deposited. So the dust particles are removed from the flue-gas stream.

Further information is provided in the CWW BREF [34, COM 2016] and the CGC BREF [16, COM 2023].

Achieved environmental benefits
Reduced dust emissions to air.

Environmental performance and operational data ~~and economics~~
Electrostatic precipitation is used alone or in combination with other waste gas treatment techniques.

~~The following Table 4.5~~ Table 4-5 lists typical operating and cost data for electrostatic precipitators [3, Ceram-Unie 2003], [23, TWG 2005], [26, UBA 2005], [28, Schorcht, F. 2005]. See Chapter 3 for reported clean gas concentrations using bag filters.

[Note to the TWG: please provide information to update the table below]

Table 4-5: Operating and cost data for electrostatic precipitators

Gas volume	Up to 100 000 m^3/h
Gas velocity	0.5 – 3 m/s
Raw gas dust loading	Up to 100 g/m^3
Clean gas dust loading	5 – 50 mg/m^3
Operating temperature	Up to 450 ºC
Voltage	10 – 100 kV
Energy consumption	0.05 – 2 kWh/1 000 m^3
Investment cost	EUR 1 – 3 million
Operating cost	0.1 – 0.2 EUR/t

Source: [9, COM 2007]

~~In this context, s~~ See also ~~Table 4.7~~ Table 4-8.

~~Achievable dust clean gas concentrations of less than 50 mg/m^3 are reported from a manufacturing process of expanded clay aggregates in a rotary kiln, equipped with an electrostatic precipitator (see Section 3.3.4.1)~~ [17, Burkart, M. 2004].

Removal efficiencies for dust typically range from 97 % to more than 99 % [16, COM 2023].

Cross-media effects

- Explosion risks arise, particularly if dry ESP systems are applied.
- The energy consumption increases due to the operation of the ESP (but a lower pressure drop compared to other filter systems may lead to lower electrical energy consumption of flue-gas fans).
- When maintenance is carried out, additional waste may occur.

Further information is provided in the CWW BREF.

Technical considerations relevant to applicability

Generally applicable.

Electrostatic precipitators are used in the ceramic industry primarily in the manufacture of expanded clay aggregates ~~behind~~ in rotary kilns and dry grinding units, where high-volume flows have to be treated at high temperatures with relatively high operating reliability.

Economics

Relatively high maintenance costs have to be taken into consideration~~,~~ when operating an electrostatic precipitator.

Driving force for implementation

- Legal requirements
- Raw material savings.

Example plants

Mostly applied in the manufacture of expanded clay: BE_049, CZ_069, DE_079, FI_375 and PL_344.

~~Plant Hallerndorf-Pautzfeld, Germany (manufacture of expanded clay aggregates), Plant Lamstedt, Germany (manufacture of expanded clay aggregates)~~

Reference literature

[26, UBA 2005], [2, VITO 2003], [3, Ceram-Unie 2003], [17, Burkart, M. 2004], [23, TWG Ceramics, 2005], [28, Schorcht, F. 2005], [30, TWG 2005], [35, TWG 2023], [16, COM 2023], [34, COM 2016]

4.7.4 Techniques to reduce channelled emissions of ~~G~~gaseous compounds

[Note to the TWG: The text in the section below was part of Section 4.3 ‘Gaseous compounds’ in the 2007 CER BREF.]

4.7.4.1 ~~Reducing the input of pollutant precursors~~ Raw materials choice

[Note to the TWG: most of the information below was included in Section 4.3.1 of the 2007 CER BREF. Please provide information to complete and update the 10-heading template below, e.g. on operational data and economics]

Description
Selection of raw materials with low pollutant precursors to prevent emissions. This includes techniques such as:

- use of clays and additives with low sulphur content, low chloride content and low fluoride content to reduce SOX, HCl and HF emissions;
- addition of raw materials with low sulphur and/or low fluoride content (e.g. sand) to reduce emissions;
- minimisation of organic compounds in raw materials (e.g. pore-forming agents, binders);
- use of inorganic pore-forming agents (e.g. perlite).

Technical description and achieved environmental benefits
~~Oxides of s~~Sulphur oxides

- The use of low-sulphur raw materials and additives can significantly reduce SO_X emissions.
- In the case of sulphur-rich raw materials, the addition of low-sulphur body additives (e.g. sand) or low-sulphur clay reduces SO_X emissions by a dilution effect
- The use of low-sulphur fuels, such as natural gas or LPG, leads to significantly reduced SO_X emissions.
- In refractories, organic binders e.g. starch or citric acid, can replace sulphur-containing binders in some cases. This may cause VOC and CO_2 emissions [74, Cerame-Unie 2023].
- A high calcium content in the raw materials promotes the internal adsorption of the released SO_X in the form of calcium sulphate, reducing SO_X emissions. [75, Huybrechts et al. 2007].

~~Oxides of nitrogen~~ Nitrogen oxides
Minimisation of nitrogen compounds in raw materials and additives can reduce NO_X emissions.

Inorganic chlorine compounds
The use of low-chlorine raw materials and additives can significantly reduce chlorine emissions.

Inorganic fluorine compounds

- The use of low-fluorine raw materials and additives can significantly reduce fluoride emissions.
- In the case of fluorine-rich materials, the addition of low-fluoride body additives (e.g. sand) or low-fluoride clay reduces fluoride emissions by a dilution effect.

Volatile organic compounds (VOCs)
Minimisation of organic compounds in raw materials, additives, binders, etc. can reduce VOC emissions in drying and firing. For instance, organic additives such as sawdust and polystyrene are added to the raw material mixture mainly in the manufacture of porous products. However, these organic additives give rise to VOC emissions ~~(in this context see Table 3.4)~~ regarding raw gas values from brick manufacturing processes, using various pore-forming agents~~)~~. The generation of VOC emissions can, in principle, be avoided by switching to inorganic pore-forming additives, e.g. perlite (a glassy volcanic material containing 3-4 % water. On heating (800-1 100 °C) the material expands, due to the steam bubbles formed inside, to between 15 and 20 times its original volume).

In decoration steps, the minimisation of organic compounds in inks can also reduce VOC emissions.

Carbon dioxide
The use of low-carbonate raw materials and the use of low-organic-compound raw materials can significantly reduce CO_2 emissions.

Achieved environmental benefits
Reduced pollutant load in the off-gas.

Environmental performance and operational data
Depends on the raw material.

Cross-media effects
Minimisation of organic compounds in raw materials may increase energy consumption for the firing process.

The minimisation of Ca/Mg carbonates in raw materials may increase emissions of HF and/or SO_X [74, Cerame-Unie 2023].

Technical considerations relevant to applicability
Applicability may be restricted by the characteristics of availability of clays with low pollutant precursors and product quality restrictions.

Reducing the input of pollutant precursors is a preferred measure to reduce pollutants in the flue-gases of a kiln, because the problem is solved at source, but, owing to specific constraints, in reality the applicability is sometimes difficult. Therefore, the use of raw materials and additives, which have low contents of pollutant precursors, can, in principle, be applied to all sectors of the ceramic industry. However, their ~~single~~ individual case-related availability and possible product quality problems (e.g. regarding colour, compressive strength and frost resistance) always have to be taken into consideration and careful testing of the raw material mixtures always has to be carried out.

For instance, inorganic pore-forming additives give rise to technical difficulties, because these substances have a tendency to expand too suddenly and too sharply, so that the pore-forming becomes difficult to control and product quality drops. As a result of this, a switch from organic to inorganic pore-forming additives is probably not feasible in practice. There is one brick works known in Flanders which does use perlite as an additive. However, this involves a form of perlite already expanded and ground, used to make rich Boom clay leaner rather than as a pore-forming agent.

For expanded clay manufacturing, the reduction of VOCs is not possible because VOCs are used for pore-forming.

Also, the pollutant content of the raw materials is a significant but not always the determin~~ant~~ing parameter for the pollutant emissions during firing, because these emissions depend on several criteria, for instance operative parameters of the firing process. Thus, a 50 % decrease in the pollutant content of the raw materials does not always determine the same reduction of the pollutant emission, as experience has also shown the correlation between the fluorine content of clay and the HF emission concentration.

Regarding the sulphur problems, it has to be mentioned that the usual location of the pit near the plant limits the choice of low-sulphur raw materials (see also ‘Economics’).

Economics
For a company that has a pit with a high sulphur content, the use or admixing of low-sulphur clay materials presupposes a supply of clay material extracted by others from elsewhere. This entails

a substantial added cost, due on the one hand to the cost of additional transport (estimated in 1998 as EUR 0.05/tonne/km) and on the other to the increased cost of extraction (estimated in 1998 as EUR 2.5/tonne) which will have to be paid to a third party compared to the cost of clay from their own pit [2, VITO 2003]. The minimisation of organic compounds in raw materials may also increase the costs because of possible higher transportation distances from external suppliers to the plant.

Measures involving the addition of low-sulphur and/or body additives of clay containing calcium (see also Section 4.7.4.2~~4.3.2~~) may involve substantial investment costs (up to EUR 850 000), e.g. for additional storage capacity and for modification of the machinery used in the preparation of the raw materials, shaping and drying. They may also involve additional operational costs and extra material costs.

Driving force for implementation

- Legal requirements.
- Avoidance of expensive end-of-pipe abatement techniques.

Example plants

Widely used. A total of 60 plants reported using either of one or a combination of low-fluoride/chlorine and/or sulphur content in the raw material.

Reference literature

[2, VITO, 2003], [3, Ceram-Unie 2003] [4, UBA 2001], [23, TWG 2005], [30, TWG 2005], [35, TWG 2023]

4.7.4.2 Addition of calcium-rich additives/raw materials

[Note to the TWG: most of the information below was included in Section 4.3.2 of the 2007 CER BREF. Please provide information to complete and update the 10-heading template below, e.g. on operational data, economics (e.g. CO_2 allowances), decomposition temperatures and cross media effects]

Description

This includes techniques such as:

- addition of calcium-rich additives to the raw material mix to retain fluorine, chlorine and sulphur within the ceramic product;
- introduction in the raw material mix of calcium-rich clays, loams or secondary raw materials to reduce the sulphur content of the raw material mix.

Technical description

~~The addition of fine limestone or chalk to ceramic bodies has a dilution effect, but the~~ Calcium-rich additives in the raw material mix (e.g. fine limestone, chalk, paper sludge)~~ also~~ react at relatively low temperatures of between 700 °C and 850 °C with raw materials containing fluoride and chloride, and with sulphur oxides formed during firing from raw materials containing sulphur. ~~, to retain the~~ Fluorine, chlorine and sulphur are retained within the fired body with a possible dilution effect due to the release of CO_2 and H_2O.

This chemical reaction serves to ‘fix’ fluoride by formation of stable calcium fluoride and can significantly reduce HF emissions.

$$CaCO_3 \longrightarrow CaO + CO_2$$
$$CaO + 2HF \longrightarrow CaF_2 + H_2O$$

A similar reaction also serves to ‘fix’ chloride and SO_X within the ceramic body, as mentioned above, and can also significantly reduce HCl and SO_X emissions.

However, the concentration of HF, HCl and SO_X in flue-gases is not necessarily related to the level of CaO in the raw material, because experience shows that even fine carbonates or CaO present in the clay products during the firing process might have little or no effect on the emission levels of HF, HCl and SO_2/SO_3. This mainly occurs due to high firing temperatures inside the kiln, causing the $CaSO_4$, $CaCl_2$ and CaF_2 to decompose. At a temperature of about 850 ºC the CaF_2 starts to decompose. At a high temperature (above 900 ºC) the CaO will also react with silicates to form calcium silicates, reducing the amount of available CaO.

Sulphates decompose in the temperature range between 850 °C and 1 250 °C [75, Huybrechts et al. 2007].

Achieved environmental benefits
Reduced pollutant load of fluorine, chlorine and sulphur oxides in the flue-gas.

Environmental performance and operational data
Calcium-rich additives can induce a decrease of 10 % to 75 % in fluorine emissions (depending on the raw material and the peak firing temperature) but their addition may affect the quality of the end-product; therefore, this measure cannot be applied unlimitedly in practice [4, UBA 2001]

Cross-media effects
The addition of calcium-rich additives may increase energy consumption for firing, this being due on the one hand to the occurrence of endothermic reactions in the kiln and on the other hand~~,~~ to the longer firing times required. Also, the addition of calcium-carbonate-rich additives increases the CO_2 emissions.

Technical considerations relevant to applicability
The main application sectors are~~ is~~ the brick industry and the wall and floor tiles sector, if technical properties of the final product can be fulfilled; ~~in the refractory industry this measure is not usual~~. Quality aspects affected by the addition of lime are as follows:

- Colour: increasing the addition of lime causes a change in colour tending to lighter (more yellow) shades. Slight discolouration is permissible in the manufacture of bricks for interior walls, but such discolouration can give rise to sales problems in the manufacture of facing bricks and therefore it is not possible to utilise these additives in all brick masses. The addition of Fe2O3 may partially compensate for yellow discolouration.
- The concentration of water-soluble sulphates: this increases with increased quantities of added CaCO3. Water-soluble sulphates are partly the cause of efflorescence problems on brickwork.
- Compression strength: adding calcium carbonate can have a slightly positive or as well as a slightly negative effect on compression strength.
- Shrinkage behaviour: adding chalk has a relatively unpredictable effect on the shrinkage behaviour of the product during drying and firing.
- Water absorption: spontaneous water absorption increases with increasing quantities of added CaCO3, and as a result of which the saturation coefficient rises. This results in a reduction in frost resistance of the brick and an increased likelihood of efflorescence. These effects are more tolerable in bricks for interior walls than in facing bricks.
- Expanded clay aggregates are to have a maximum of 3 % CaO,; otherwise, the granule strength is significantly reduced and additionally above 5 %, expansion becomes poor due to excessive fluxing [2, VITO 2003].

Economics
Increased CO_2 emissions, induced by utilisation of calcium-carbonate-rich additives, may increase costs due to legal requirements (e.g. emissions trading). Also, changes in the shrinkage behaviour of ceramic products may affect mechanical processing during manufacture.

Measures involving the addition of low-sulphur and/or body additives of clay containing calcium (see also Section 4.7.4.1) may involve substantial investment costs (up to EUR 850 000), e.g. for additional storage capacity and for modification of the machinery used in the preparation of the raw materials, shaping and drying. They may also involve additional operational costs (extra material costs).

Driving force for implementation

- Legal requirements.
- Avoidance of expensive end-of-pipe abatement techniques.

Example plants

Widely used in bricks and roof tiles and in wall and floor tiles manufacturing.

Reference literature

[2, VITO 2003], [3, Ceram-Unie 2003], [4, UBA 2001], [23, TWG 2005], [30, TWG 2005], [35, TWG 2023]

~~**Process optimisation**~~

4.7.4.3 ~~Optimising the heating curve~~ Optimised heating in the kiln

[Note to the TWG: most of the information below was included in Section 4.3.3.1 and 4.5.2 of the 2007 CER BREF. Please provide information to complete and update the 10-heading template below, e.g. on operational data, economics]

Description

This includes techniques such as:

- optimisation of the heating curve to prevent emissions of HF and SO_2 by controlling the heating rate and temperature;
- adequate setting of ware in the kiln to reduce the ratio of product outside specifications;
- optimised airflow through rotary kilns in the manufacture of expanded clay to reduce the ratio of products outside specifications.

Technical description

The rate of heating as well as the level of the firing temperature can affect NO_X, SO_X and HF emissions:

- Reducing the rate of heating in the lowest temperature range (up to 400 °C), at the beginning of the kiln, promotes the resorption of HF with the formation of CaF2, resulting in a decrease of HF emissions. A similar effect can apply to SOX emissions. They are usually formed by the oxidation of pyrite, and/or the dissociation of calcium sulphate present in the ceramic body.
- By increasing the rate of heating in the temperature range of between 400 °C and the firing temperature, the sintering temperature is reached more rapidly, and, as a result, the release of emissions becomes limited by diffusion, and the emissions decrease. With fast heating, oxygen cannot diffuse into the pieces, avoiding the oxidation of pyrite in the raw material and preventing SOX emissions [75, Huybrechts et al. 2007].
- The height level of the firing temperature affects the decomposition of sulphates. The lower the firing temperature is, the less decomposition there is, hence the lower SOX emissions there are. Reducing the firing temperature can be achieved by adding fluxes to the raw material mixture.
- Faster firing cycles generally result in reduced fluoride emissions. The characteristics of the raw material influence fluorine release, but for any given ceramic product the firing time above ~~the temperature of~~ 800 °C is crucial.
- Control of oxygen levels in firing processes maximises combustion efficiency.

In the firing process, there are also measures for ~~a~~the direct prevention of waste ~~by the use of modern techniques~~. If, instead of capsule or rack tunnel kiln firing, fast firing systems like roller hearth kilns are used, the amount of (used) firing auxiliaries can be reduced, but it has to be taken into consideration in this context~~,~~ that the lifetime of firing auxiliaries depends on the temperature (which is typically higher in roller hearth kilns) and on handling (which is more frequent in fast firing, because firing time is shorter). Additionally, fast firing creates more rejected ceramic products – for instance tiles – when the shape is complex, because it is primarily suited ~~for~~to flat products and therefore, it is not applicable in all cases.

The ratio of broken ware from the firing process can be reduced by exact electronic controlling of the firing curve and by optimisation of the setting [4, UBA 2001] [23, TWG 2005].

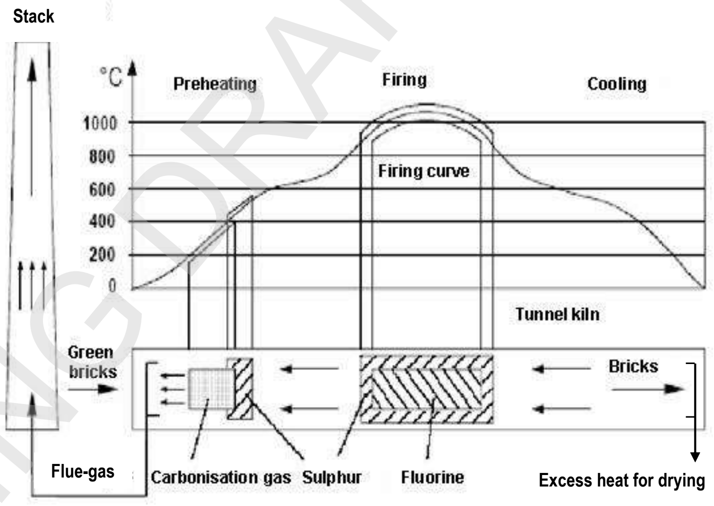
The position of the pieces during firing may also affect emissions. In dense stacks of pieces, the diffusion of oxygen into the stack and of SO_X out is obstructed and emissions may decrease [75, Huybrechts et al. 2007].

Achieved environmental benefits

- Reduction of emissions.
- Reduction of the amount of waste sent for disposal by reducing the ratio of broken fired ware.

Environmental performance and operational data

~~The following figure~~ Figure 4- shows the temperature ranges of a temperature curve example for the release of pollutants during the firing of bricks [4, UBA 2001] [30, TWG 2005].



Source: [9, COM 2007]

Figure 4-19: Temperature ranges of a temperature curve example for the release of pollutants during the firing of bricks

Cross-media effects

~~No issues.~~ None identified.

Technical considerations relevant to applicability
Generally applicable.

Optimisation of the heating curve/process control can be applied in all sectors of the ceramic industry, but it should be noted that, in practice, heating curves in the ~~clay processing~~ ceramic industry are optimised in line with product quality and energy consumption. Therefore, heating curves can only be changed if the technical properties of the final product allow this ~~and additional costs must be taken into account when altering heating curves for emission reasons.~~

Economics

Driving force for implementation

- Legal requirements.
- Avoidance of expensive end-of-pipe abatement techniques.
- Operation of kilns in an energy-efficient way.
- Saving raw material and disposal costs.

Example plants
Widely used. A total of 90 installations in the data collection reported optimising the heating curve as technique to reduce emissions to air, 40 installations reported using electronic control of firing and a total of 8 installations reported applying an optimised setting of ware.

Reference literature
[2, VITO 2003], [3, Ceram-Unie 2003], [4, UBA 2001], [23, TWG 2005], [35, TWG 2023]

4.7.4.4 Combustion optimisation

[Note to the TWG: Please provide information to complete and update the 10-heading template below, e.g. on operational data, economics]

Description
Good design of the combustion chambers, burners and associated equipment/devices is combined with the optimisation of combustion conditions (e.g. the temperature and residence time in the combustion zone, efficient mixing of the fuel and combustion air) and the regular planned maintenance of the combustion system according to suppliers' recommendations. Combustion conditions control is based on the continuous monitoring and automated control of appropriate combustion parameters (e.g. O_2, CO, fuel to air ratio, and unburnt substances). [16, COM 2023]

Technical description
The kiln atmosphere is also important for SO_X emissions due to the sulphur present in the raw material. At a reducing atmosphere, pyrite does not decompose and SO_X is only released due to the decomposition of sulphates [75, Huybrechts et al. 2007].

See the LCP BREF for more information [36, COM 2017].

Achieved environmental benefits

- Reduced emissions of CO and NOX.
- Reduced emissions of SOX from pyrite present in the raw material.
- Optimising of energy consumption

Environmental performance and operational data

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally applicable.

Economics

Driving force for implementation
Legal requirements.

Example plants
Widely used.

Reference literature
[16, COM 2023]

4.7.4.5 Reduction of water vapour levels in the kiln gases

[Note to the TWG: the technique below has not been selected by any installation in the data collection, please provide information about its use. Most of the information below was included in Section 4.3.3.2 of the 2007 CER BREF. Please provide information to complement and update the 10-heading template below, e.g. on operational data, cross-media effects, economics]

Description
Reduction of water vapour in the kiln to obtain lower emission rates of fluorine and SO_X.

Technical description
Reduction of water vapour levels in the kiln gases usually results in lower emission rates for fluoride, because the basic mechanism for the release of fluorine from clay minerals is pyrohydrolysis. In laboratory tests, it was found that reducing the water content in the kiln atmosphere~~,~~ did result in reduced emissions of HF as well as of SO_X. This reaction occurs at temperatures of 800 ºC and upwards.

Achieved environmental benefits
Reduced emissions to air of HF and SO_X.

Environmental performance and operational data

Cross-media effects

Technical considerations relevant to applicability
In practice, a reduction of the water content in the kiln atmosphere would be technically difficult to achieve, given that water is produced during the combustion of the fossil fuels used to heat the kiln. This production of water can be avoided only by heating the kiln either indirectly, for instance with gas-fired radiant-tube burners [5, InfoMil 2003], or by electricity, but this would require a fundamental change in the design of the kiln and entail higher energy consumption.

~~In principle, all over Europe only the firing of kilns with fossil fuels is economically viable for the bricks and roof tiles, vitrified clay pipes, refractory products and expanded clay aggregates sectors. Therefore heating the kiln with electricity or indirectly is not really applicable in these sectors (electrical heating is only carried out for short runs of special products in the case of refractory products). In the wall and floor tiles, table- and ornamentalware, sanitaryware, technical ceramics and inorganic bonded abrasives sectors however, the reduction of water vapour levels in kiln gases by heating the kilns with electricity (in the manufacturing of some technical ceramics electrically heated kilns are used to a certain extent) or indirectly with radiant tube burners [5, InfoMil 2003] (shuttle kilns or small roller hearth kilns can, in principle, be equipped with these burners for smaller scale production), has a more realistic potential of application.~~ In the manufacturing of some technical ceramics, electrically heated kilns are used to a certain extent. Shuttle kilns or small roller hearth kilns can, in principle, be equipped with radiant-tube burners for smaller production.

Economics

Driving force for implementation

- Legal requirements.
- Avoidance of end-of-pipe abatement techniques.

Example plants

Reference literature

[2, VITO 2003], [3, Ceram-Unie 2003], [5, InfoMil 2003], [23, TWG 2005]

4.7.4.6 Internal carbonisation gas combustion

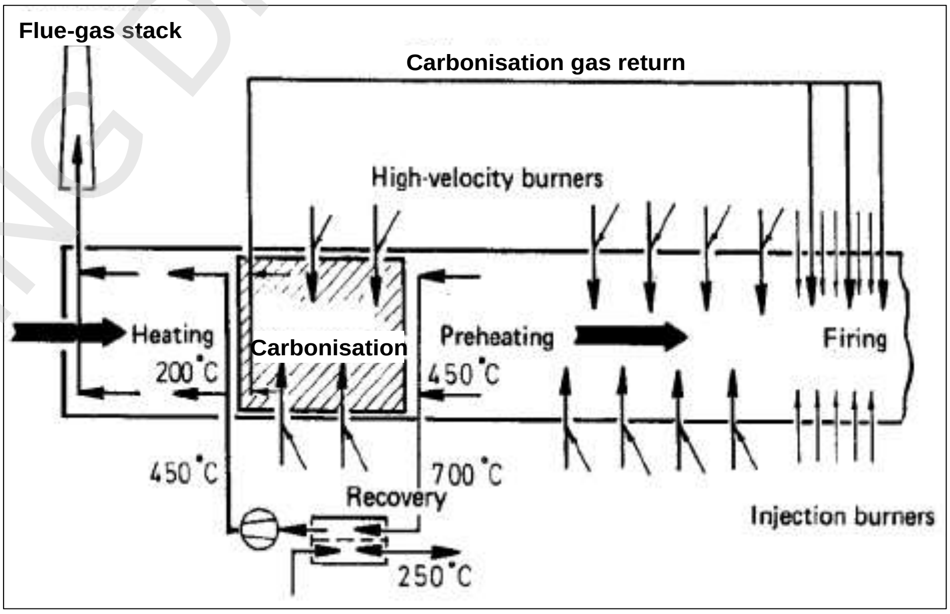
[Note to the TWG: most of the information below was included in Section 4.3.3.3 of the 2007 CER BREF. Please provide information to complement and update the 10-heading template below]

Description

VOC emissions which occur in the heating area of the kiln as a result of decomposition and incomplete combustion of organic components in the raw material mixture (known as carbonisation gases)~~,~~ can be subsequently burned in the kiln, provided the kiln has been specially modified.

Technical description

Internal combustion can be achieved by directing the carbonisation gases from the heating zone of the kiln back to the firing zone, where they will be further burned as a result of the high temperature prevailing there. In order to achieve this, the kiln zone where the VOC emissions occur (known as the carbonisation zone) needs to be separated from the rest of the kiln. This can be achieved by installing one or more sliding doors in the kiln or with a special extraction system for the carbonisation gases. With this technique, not only VOC emissions, but also CO emissions are significantly reduced. ~~The following figure~~ Figure 4-20 shows a schematic view of internal carbonisation gas combustion [4, UBA 2001], [30, TWG 2005].



Source: [9, COM 2007]

Figure 4-20: Schematic view of internal carbonisation gas combustion

Achieved environmental benefits

Reduced emissions to air of VOCs and CO.

Environmental performance and operational data

Systems for internal combustion of carbonisation gases have already been in use for some time in Germany, particularly by a few dozen clay block production sites ~~brickworks~~. These systems enable VOC emissions to be reduced significantly, but suffer from the practical disadvantage that they often interfere with the normal operation of the kiln, and as a result it becomes difficult to control. Doors seizing, for instance, is a known problem in systems which operate with sliding doors in the kiln. The interference of the thermal afterburning inside the kiln, when using a tunnel kiln as a simple counterflow heat exchanger, often leads to problems in the kiln operation mode or to higher operation expenditure. Probably for these reasons, external carbonisation gas afterburning systems have gained increasing favour~~, especially for new plants in recent years~~.

This technique is not applicable for the manufacture of expanded clay aggregates, as there is the problem that drying and firing take place together, which results in gases containing high concentrations of water.

By employing this technique, clean gas values for total-C of approximately 15 mg total-C/m^3 can be obtained, if the raw gas values are 250 mg total-C/m^3 [4, UBA 2001].

Cross-media effects

Carbonisation gas combustion inside the kiln may increase overall energy consumption, especially if additional firing with (high-velocity) burners has to be carried out to burn the carbonisation gases from the heating zone.

Technical considerations relevant to applicability

~~Systems for internal combustion of carbonisation gases have already been in use for some time in Germany, particularly by a few dozen brickworks. These systems enable VOC emissions to be reduced significantly, but suffer from the practical disadvantage that they often interfere with the normal operation of the kiln, and as a result it becomes difficult to control. Doors seizing, for instance, is a known problem in systems which operate with sliding doors in the kiln. The interference of the thermal afterburning inside the kiln, when using a tunnel kiln as a simple counterflow heat exchanger, often leads to problems in the kiln operation mode or to higher operation expenditure. Probably for these reasons, external carbonisation gas afterburning systems have gained increasing favour, especially for new plants in recent years.~~

~~This technique is not applicable for the manufacture of expanded clay aggregates, as there is the problem that drying and firing take place together, which results in gases containing high concentrations of water.~~

~~By employing this technique, clean gas values for total-C of approximately 15 mg total-C/m^3 can be obtained, if the raw gas values are 250 mg total-C/m^3 [4, UBA 2001].~~

Economics

Internal carbonisation gas combustion is, because of the complicated firing and control techniques, a relatively expensive system regarding maintenance costs. ~~In this context, s~~ See Table 4-8.

Driving force for implementation

- Legal requirements.
- Avoidance of end-of-pipe abatement techniques.

Example plants

AT_002, AT_003, DE_075, FR_219, HU_226 and HU_227.

Reference literature
[2, VITO 2003], [3, Ceram-Unie 2003], [4, UBA 2001], [23, TWG 2005]

4.7.4.7 Low-NO_X burners

[Note to the TWG: most of the information below was included in Section 4.3.3.4 of the 2007 CER BREF. Please provide information to complement and update the 10-heading template below, e.g. on operational data, economics and on the type of Low-NO_X burners used in the ceramic industry]

Description
The technique (including ultra-low-NO_X burners) is based on the principles of reducing peak flame temperatures. The air/fuel mixing reduces the availability of oxygen and reduces the peak flame temperature, thus retarding the conversion of fuel-bound nitrogen to NO_X and the formation of thermal NO_X, while maintaining high combustion efficiency.

Technical description
Emissions of nitrogen oxides arise from firing ceramic products, e.g. refractory products at temperatures of above 1 300 °C. These NO_X emissions can be minimised by the operation of special low-NO_X burners. These burners are useful for reducing the flame temperature and thus reducing thermal and (to some extent) fuel-derived NO_X. The NO_X reduction is achieved by supplying rinsing air for lowering the flame temperature or pulsed operation of the burners.

Low-NO_X burners is a general term for a series of burners that combine several design features to reduce the NO_X emission level. The main principles of these burners are the reduction in peak flame temperature, the reduction in residence time in the high-temperature zone and the reduction in oxygen availability in the combustion zone [15, COM 2022]. According to the different principles to reduce the formation of NO_X, low-NO_X burners have been developed as air-staged burners, fuel-staged burners and flue-gas recirculation burners. [36, COM 2017]

Further information on the different type of low-NO_X burners is provided in the LCP BREF [36, COM 2017].

Achieved environmental benefits
Reduced emissions to air of NO_X.

Environmental performance and operational data

Cross-media effects
None identified.

Technical considerations relevant to applicability
Applicability to existing plants may be restricted by design and/or operational constraints.

The applicability and efficiency of low-NO_X burners depend on several factors such as the ultimate firing temperature. Lack of efficiency in some cases at temperatures of above 1 400 °C is reported. ~~In this context, useful additional information can be found in the BREF on Glass Manufacturing, where low-NO_X burners are also mentioned.~~ Also due to product quality requirements of the final product, the use of low-NO_x burners may be restricted [23, TWG 2005], [30, TWG 2005].

Economics

Driving force for implementation
Legal requirements.

Example plants

Widely used. A total of 32 installations in the data collection have reported using low-NO_X burners.

Reference literature

[1, BMLFUW 2003], [3, Ceram-Unie 2003], [4, UBA 2001], [23, TWG 2005], [15, COM 2022], [35, TWG 2023], [36, COM 2017]

~~Sorption plants (adsorbers, absorbers)~~

~~In this context, useful information can also be found in the BREF on Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector.~~

4.7.4.8 Cascade-type packed bed adsorbers

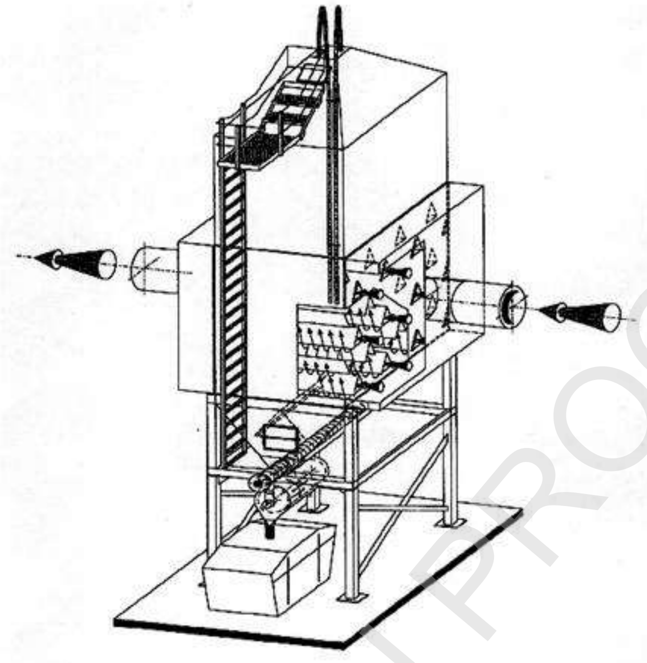
[Note to the TWG: most of the information below was included in Section 4.3.4.1 of the 2007 CER BREF. Please provide information to complement and update the 10-heading template below, e.g. on operational data, economics]

Description

Removal of pollutants by retention on a solid adsorbent (e.g. calcium carbonate, limestone) that falls by gravity into a chamber through which the off-gases are passed. Baffles in the chamber ensure contact of the adsorbent and flue-gases. The spent adsorbent is collected at the bottom of the installation.

Technical description

In a cascade-type packed bed adsorber, the reaction between the adsorbent, usually calcium carbonate ($CaCO_3$, limestone in granules) and the pollutants (mainly HF, SO_X and HCl) in the flue-gas takes place in a chamber, in which the adsorbent sinks by gravity and through which the flue-gases are passed in counter- or crossflow. In order to achieve sufficient reaction time and contact area, baffles are provided in this chamber. These baffles retard the downward velocity of the adsorbent and ensure effective circulation and distribution of flue-gases in the unit. The spent calcium carbonate is collected at the bottom of the installation. An illustration of a crossflow adsorber is shown in Figure 4-21 ~~the following figure~~ [4, UBA 2001].



Source: [9, COM 2007]

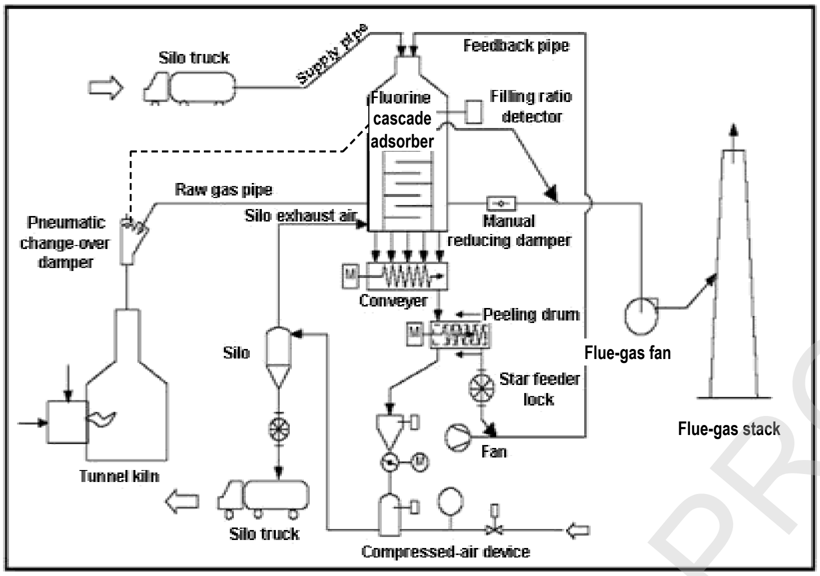
Figure 4-21: Illustration of a crossflow cascade adsorber

In addition to ordinary calcium carbonate, modified types of calcium carbonate, composed of calcium carbonate/calcium hydroxide ($CaCO_3/Ca(OH)_2$) mixtures, can be used as adsorbents. Due to their increased porosity and higher calcium hydroxide content, these have a greater affinity for acid gases.

Because the adsorption of HF, SO_X and HCl mainly takes place on the outside of the calcium carbonate granules, the adsorption efficiency of the granules is quite low. In order to increase the adsorption efficiency when using unmodified calcium carbonate, a peeling technique can be used. In this, the softer outer coating of the spent granules, which consists of calcium fluoride, calcium sulphite, calcium sulphate or calcium chloride, is removed mechanically. The remaining granuleate can be reused as an adsorbent provided its size is large enough so that less waste (in the form of peeled-off saturated limestone) occurs.

In the case of the modified granules, a greater affinity for acid gases is achieved by improved surface qualities; therefore, they cannot be peeled in order to be reused, as is possible with unmodified calcium carbonate.

~~The following figure~~ Figure 4-22 presents a process diagram of a cascade-type packed bed adsorber with peeling drum. The peeled sorption agent is fed back to the storage silo automatically. The quantity of waste is reduced by up to 50 %~~per cent~~ by this measure [4, UBA 2001]



Source: [9, COM 2007]

Figure 4-22: Process diagram of a cascade-type packed bed adsorber with peeling drum

The limestone granulate, saturated with pollutants, is delivered to the peeling drum by a screw conveyor. The outer layer, saturated with the pollutants, is removed by rubbing and taken out together with the small granulate with a particle diameter < 2.5 mm. This contaminated material is discharged by silo trucks. The surface of the remaining granulate with a particle diameter > 2.5 mm becomes reactive again. The recycled granulate is fed back to the storage silo of the adsorber by a star feeder lock and a feedback pipe. The adsorber, the peeling drum and the feedback pipe are a closed system. The peeling and the feeding back take place automatically and continuously.

Achieved environmental benefits

Reduced emissions to air of HF, SO_X and HCl.

Environmental performance and operational data

Calcium carbonate is used in the form of granules with a usual grain size of 4-6 mm, which must meet certain specifications with regard to size, composition and porosity in order to obtain maximum purification efficiency.

See Chapter 3 for reported clean gas concentrations using cascade-type packed bed adsorbers.

Unmodified calcium carbonate granules, preferably softer types of calcium carbonate, are especially suited for removing HF and SO_3. For these compounds, the granules achieve purification efficiencies in excess of 90 % (up to 99 %) and 80 %, respectively. Ordinary calcium carbonate is, however, not very suitable for the removal of SO_2 as SO_2 is less reactive compared to HF and SO_3; the purification efficiency is in the order of magnitude of 20 %. For HCl, the purification efficiency of unmodified calcium carbonate is approximately 50 % [2, VITO 2003], [4, UBA 2001], [30, TWG 2005].

Modified calcium carbonate is more suitable for SO_2 removal and also yields slightly better efficiencies for HF and SO_3 removal. ~~With modified calcium carbonate, purification efficiencies of up to 99 % for HF, up to 85 % for SO_3, 30 up to 85 % for SO_2 for a raw gas concentration of up to 1500 mg SO_2/m^3 and an efficiency of more than 50 % for HCl are achievable. The cleaning efficiency of these systems is up to 100 % for the retention of suspended particulates (see also Section 4.7.5), [4, UBA 2001], [30, TWG 2005].~~

~~Flue-gas with a content of approximately 2500 mg SO_2/m^3 can, under certain circumstances – for example with four adsorbers (packed bed counterflow type with modified calcium carbonate) arranged downstream of each other – be sufficiently filtered to achieve clean gas values of below 500 mg SO_2/m^3. Also a p~~A purification efficiency of the highly loaded raw gas of 85 % for SO_2 can be achieved [4, UBA 2001], whereas with only one adsorber~~,~~ the purification efficiency for SO_2 drops down to approximately 30 %. [2, VITO 2003], [23, TWG 2005].

~~In this context, see also Table 3.2 regarding the distribution of released chloride, Table 3.6, Table 3.7, Table 3.8 and Table 3.9 regarding emissions from brick and roof tile manufacturing processes and Table 3.43 regarding emissions from a sanitaryware manufacturing process, applying packed bed adsorber systems [2, VITO 2003].~~

These adsorbers can deal with gases at temperatures of up to 500 °C without prior cooling and, therefore, are very efficient in reducing HF, SO_X and HCl emissions from kiln flue-gases~~.~~ [4, UBA 2001]

Examples of cleaning efficiencies are:

- up to 99 % for HF (FR222) [35, TWG 2023];
- up to 85 % for SO_2 and SO_3 [9, COM 2007];
- 50 % for HCl [9, COM 2007];
- up to 100 % for dust [9, COM 2007].

Electricity consumption: 641-864 (kWh/day) [9, COM 2007].

Cross-media effects

- High consumption of adsorbents. In comparison to the the stoichiometry of the adsorption reaction, an excess of 2.5 of adsorbent may be required in practice to achieve the cleaning efficiency [9, COM 2007].
- Large amount of waste (due to the relatively high excess dosage of adsorbent).
- Calcium carbonate granules react with the acidic components of the flue-gas to develop CO_2.
- Increased energy consumption due to the operation of the adsorber (in particular to overcome the pressure drop).
- Increased dust emissions as a result of the increase in the dust load arising from the calcium carbonate granules are possible, especially if peeling drums are used.
- Possible noise emissions.
- The reuse of saturated limestone in the claymix may lead to CO_2 emissions during firing [74, Cerame-Unie 2023].

Technical considerations relevant to applicability

Applicability to existing plants may be restricted by a lack of space.

This technique can be applied in several sectors of the ceramic industry, but the amount of space taken up by the system and a lack of flexibility with regard to controls and to the use of other adsorbents should be noted. Other conditions such as raw gas concentrations of HF and SO_X, clay product range, kiln operation, kiln size, kiln production rate, required top burning temperature, flue-gas amount and temperature, total resulting dust load from the adsorber, requirement for a dust filter, possibility of reuse, recycling or deposit of large waste amounts from adsorbers, availability of suitable limestone pellets, increase in electricity demand and total environmental impact must all~~so~~ be taken into consideration.

Economics

Smaller quantities of peeled-off saturated limestone can be added to the manufacture of clay blocks and facing bricks, but it must be taken into account~~,~~ that the calcium sulphate content of the saturated limestone may lead to efflorescence on the bricks. Utilisation of the saturated limestone in the cement, concrete and asphalt industry is also possible. If no reuse is possible, additional disposal costs also have to be considered.

~~In this context, s~~ See ~~Table 4.7~~ Table 4-8.

Driving force for implementation
Legal requirements.

Example plants
~~Wienerberger Ziegelindustrie AG, facing brick plant, Rotenturm, Austria Erlus Baustoffwerke AG, roof tiles plant, Neufahrn, Germany~~
Widely used. A total of 50 plants in the data collection reported 79 emission points using cascade-type packed bed adsorbers.

Reference literature
[1, BMLFUW 2003], [4, UBA 2001], [2, VITO 2003], [3, Ceram-Unie 2003], [23, TWG 2005], [33, Ramboll 2019], [35, TWG 2023]

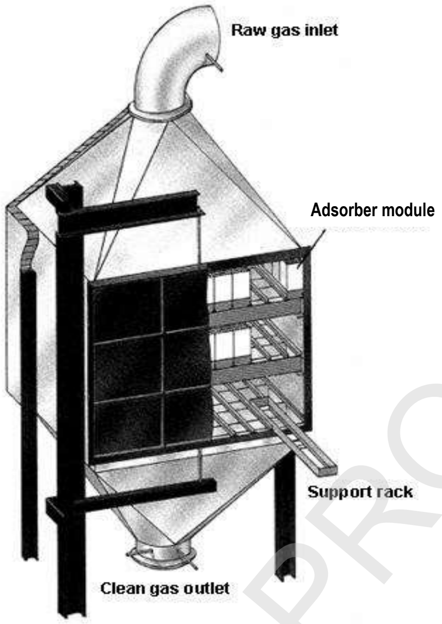
4.7.4.9 Module adsorber systems

[Note to the TWG: most of the information below was included in Section 4.3.4.2 of the 2007 CER BREF. Please provide information to complement and update the 10-heading template below, e.g. on operational data and economics]

Description
The off-gas passes through several layers of honeycomb adsorber modules filled with calcium hydroxide. The HF is converted to CaF_2 and retained in the modules.

Technical description
A process, predominately employed in the separation of gaseous inorganic fluorine compounds, is dry sorption using honeycomb modules made of calcium hydroxide in so-called module adsorber systems. In this process, the flue-gas passes through a simple steel reactor with no moving parts. The reactor houses several layers of honeycomb adsorber modules filled with slaked lime (calcium hydroxide) that chemically converts the HF content of the flue-gases to calcium fluoride (CaF_2) as it passes through the modules. The lifetime of the modules is influenced by the operation time of the plant, the flue-gas volume flow and the fluorine concentration in the raw gas. The modules are allocated in support racks to reduce the module-changing time and to facilitate the handling. Saturated modules are replaced by new ones.

The following figure shows the schematic view of the dry sorption unit using honeycomb modules made of $Ca(OH)_2$ [4, UBA 2001].



Source: [9, COM 2007]

Figure 4-23: Schematic view of a honeycomb module adsorber system

Achieved environmental benefits

Reduced emissions to air of HF.

Environmental performance and operational data

Cross-media effects

- Relatively high consumption of adsorbents.
- Large amount of waste (saturated modules have to be disposed of).
- Increased energy consumption possible, due to the operation of the adsorber (in particular to overcome the pressure drop in the case of flue-gases with higher dust loads).

Technical considerations relevant to applicability

This system is technically simple and robust, because it is built without moving parts and it has a low pressure drop. It is particularly efficient for ~~cleaning~~ treating lower flue-gas flow rates (< 18 000 m^3/h) and when concentrations of inorganic compounds other than HF (SO_2, SO_3, HCl) are low. For this reason, this type of system is applied mainly in the wall and floor tiles, table- and ornamentalware, sanitaryware and technical ceramics industries. Additionally, the capillaries tend to clog if there are higher dust concentrations and, therefore, the system is not really suitable for dedusting purposes.

See Chapter 3 for reported clean gas concentrations using module adsorber systems.

~~In this context, see Table 3.41, where raw and clean gas concentrations from a sanitaryware manufacturing process are listed and where a honeycomb adsorber module system for flue-gas cleaning is applied.~~

Economics

Additionally to the price of the ~~new~~ adsorber modules, the price for disposal of the saturated modules has to taken into account, because reuse is not possible. ~~In this context, s~~ See ~~Table 4.~~Table 4-8.

Driving force for implementation
Legal requirements.

Example plants
CZ_067, CZ_388, CZ_393, DE_104 and IT_310.

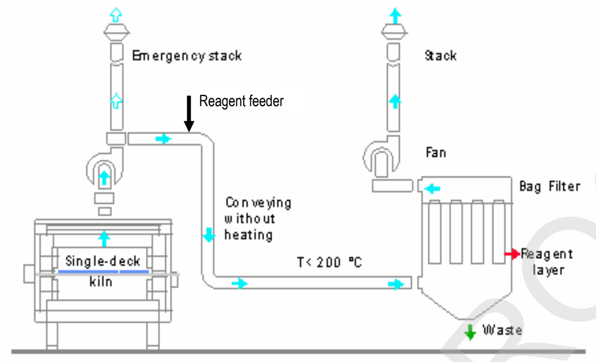
Reference literature
[1, BMLFUW 2003], [4, UBA 2001], [23, TWG 2005]

4.7.4.10 Dry scrubbing ~~flue-gas cleaning with a filter (bag filter or electrostatic precipitator~~)

[Note to the TWG: most of the information below was included in Section 4.3.4.3 of the 2007 CER BREF. Please provide information to complement and update the 10-heading template below, e.g. on operational data and economics]

Description
Dry powder or a suspension/solution of an alkaline reagent (e.g. lime or sodium bicarbonate) is introduced and dispersed in the off-gas stream. The material reacts with the acidic gaseous species (e.g. SO_2, HF, HCl) to form a solid, which is removed by filtration (e.g. fabric filter).

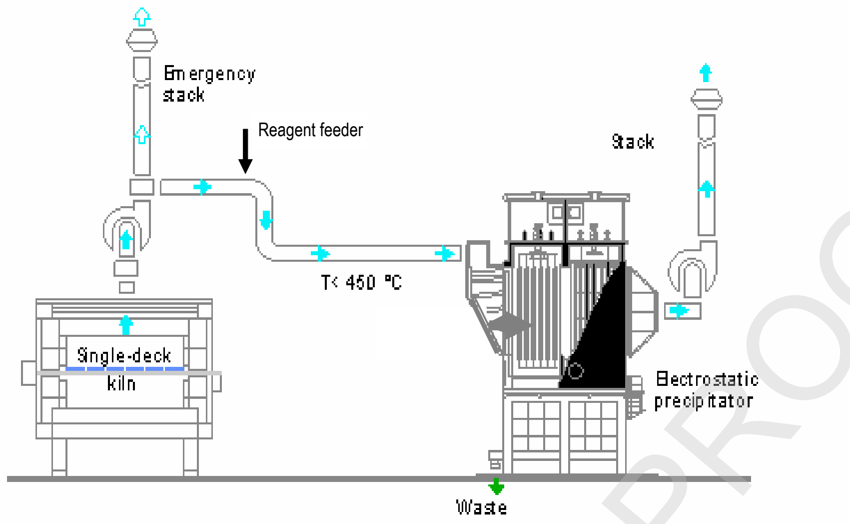
Technical description
With this type of flue-gas cleaning, the adsorbent is blown into the flue-gas stream in dry form. Acid components (sulphur oxides and inorganic chlorine and fluorine compounds) are adsorbed in a reactor or a reactor zone, which can be the flue-gas duct between the kiln and the filter with a certain minimum length, to ensure the necessary contact time. The filter behind the reactor (zone) removes the produced neutralisation salts and the excess adsorbent from the flue-gas stream. A bag filter is mainly used for this purpose because it generates good contact between the adsorbent and the gaseous contaminants. The fabric of the filter bags must be resistant to acid and alkaline conditions, and is also defined by the temperature of the gases to be treated (see ~~Table 4.2~~ Table 4-3). ~~The following figure~~ Figure 4-24 shows a schematic view of dry flue-gas cleaning with a bag filter [10, Navarro, J. E. 1998], [23, TWG 2005].



Source: [9, COM 2007]

Figure 4-24: Schematic view of dry flue-gas cleaning with a bag filter

Electrostatic precipitators may be used in place of bag filters, using the same powdered reagent injection system. They offer the advantage of operating at higher gas temperatures (well over 400 ºC) so no cooling of the flue-gases is necessary, and energy recovery from the cleaned gases is facilitated. On the other hand, the contact between adsorbent and pollutant is not as good as if a bag filter is used. ~~The following figure~~ Figure 4-25 shows a schematic view of dry flue-gas cleaning with an electrostatic precipitator [10, Navarro, J. E. 1998], [23, TWG 2005].



Source: [9, COM 2007]

Figure 4-25: Schematic view of dry flue-gas cleaning with an electrostatic precipitator

A special variant of dry flue-gas cleaning is semi-dry flue-gas cleaning with a filter, also known as conditioned dry flue-gas cleaning. It differs from the dry method because of the use of a small quantity of water. The adsorbent is 'conditioned' by wetting it slightly with water, which increases the reactivity and so the cleaning efficiency is higher. Also, the consumption of adsorbents is lower and the amount of residues is smaller. The disadvantages of this technique are the likelihood of corrosion problems due to the higher humidity of the flue-gases and more complex operating controls [2, VITO 2003].

Achieved environmental benefits

Reduced emissions to air of HF, HCl and SOX.

Environmental performance and operational data

The dry flue-gas cleaning system with a filter has flexibility with regard to controls and to the use of adsorbents. Calcium hydroxide ($Ca(OH)_2$), calcium oxide (CaO) or, more recently, sodium bicarbonate ($NaHCO_3$), which is most suitable for the removal of SO_2, are among the adsorbents which can be used. Additionally, it has to be mentioned that the reaction products of sodium bicarbonate consist of water-soluble salts (sodium sulphate and sodium fluoride) and as a result cannot easily be disposed of by landfill.

For cleaning systems with a bag filter, problems can occur at very high temperatures, where the filter could start burning~~,~~; and at very low temperatures close to the dew point, the filter is easily clogged. The cleaning system with an electrostatic precipitator has the advantage of being able to run at high temperatures, easily exceeding 400 ºC, so that no cooling of the flue-gases is required prior to cleaning, and energy recovery from the clean gases is facilitated.

See Chapter 3 for reported clean gas concentrations using dry scrubbers.

~~A dry flue-gas cleaning system with a bag filter allows the achievement of fluoride concentrations in the treated flue-gas of less than 5 mg/m3 and suspended dust concentrations in the range of 2 – 20 mg/m3.~~ The cleaning efficiency of these systems varies from 90 % up to 99 % for the retention of suspended particulates, 92 % up to 95 % for fluoride retention, 10 % up to 80 % for SO_2, up to 90 % for SO_3 as well as up to 85 % for HCl, if calcium hydroxide is used as the adsorbent [2, VITO 2003], [10, Navarro, J. E. 1998], [23, TWG 2005], [30, TWG 2005].

Additionally to an approximate cleaning efficiency of 99 % for suspended particulates, more than 95 % for fluoride retention, 98-99 % for SO_2 and SO_3 as well as 89 % for HCl~~,~~ can be achieved~~,~~ if sodium bicarbonate is used as the adsorbent in a dry flue-gas cleaning system with a ~~bag~~fabric filter (see Section ~~4.3.6~~ 4.7.5) [4, UBA 2001].

~~Achievable dust clean gas concentrations in the range of 5 – 50 mg/m3 are reported from flue-gas cleaning with electrostatic precipitators (see Section 4.2.3.5).~~

Examples of cleaning efficiencies are:

- up to 96 % for HF;
- up to 99 % for SO_2 and SO_3;
- up to 89 % for HCl;
- up to 99 % for dust.[9, COM 2007]

Cross-media effects

- The consumption of adsorbents causes large amounts of waste.
- The recycling of waste can be problematic, due to the negative effects of calcium on the rheology of ceramic slips.
- Relatively high electrical energy consumption due to the pressure drop across a bag filter, respectively increased electrical energy consumption due to the operation of an ESP.
- Noise may increase if pneumatic filter cleaning systems are applied.
- Carbonate-containing adsorbents react with the acidic components of the flue-gas to develop CO_2.

Technical considerations relevant to applicability
Generally applicable.

The cleaning system with an electrostatic precipitator has the advantage of being able to run at temperatures of up to approx~~.~~imately 450 ºC, so that no cooling of the flue-gases is required prior to cleaning and energy recovery from the clean gases is facilitated.

~~Dry flue-gas cleaning systems with a filter can, in principle, be applied to clean kiln flue-gases in all ceramic sectors, but the disadvantages compared to the packed bed adsorber systems – regarding the greater need for maintenance and problems with the durability of the filter bags (in the case of a system with a bag filter) have to be taken into account.~~ Some disadvantages could be related to the need for maintenance and the durability of the filter bags.

Economics
~~In this context – f~~ For dry ~~sorption~~ scrubbing with a bag filter – see ~~Table 4.7~~ Table 4-8.

- For semi-dry systems, the investment cost is usually slightly higher than for a wholly dry unit.
- Sodium bicarbonate is more expensive than calcium-based adsorbents.
- Additional disposal costs for saturated adsorbents which cannot be reused, have to be taken into account.

Driving force for implementation
Legal requirements.

Example plants

AT_023, AT_025, BE_044, BE_045, BE_046, BE_050, CZ_062, CZ_069, CZ_391, CZ_394 and DK_114.

Reference literature

[2, VITO 2003], [3, Ceram-Unie 2003], [10, Navarro, J. E. 1998], [4, UBA 2001], [17, Burkart, M. 2004], [23, TWG 2005], [26, UBA 2005], [32, TWG 2006], [33, Ramboll 2019], [35, TWG 2023]

4.7.4.11 Wet scrubbing ~~flue-gas cleaning~~

[Note to the TWG: most of the information below was included in Section 4.3.4.4 of the 2007 CER BREF. Please provide information to complement and update the 10-heading template below, e.g. on operational data and economics]

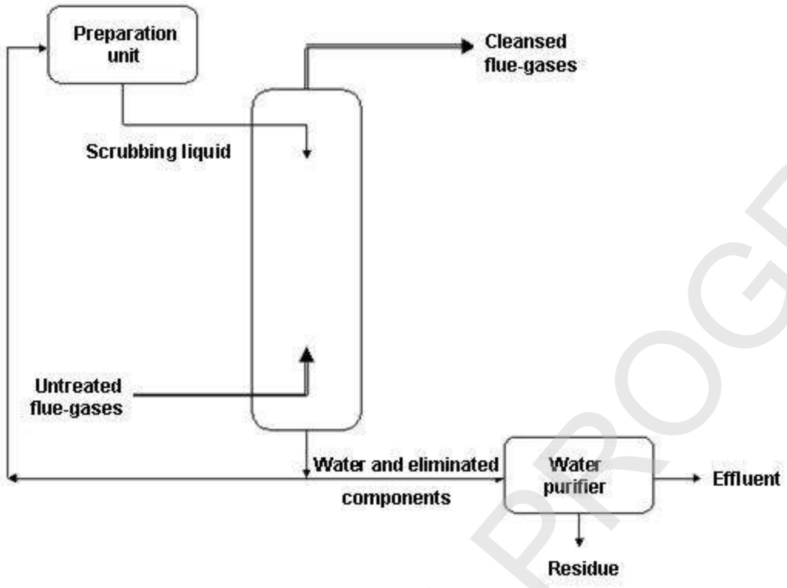
Description

The removal of gaseous or particulate pollutants from a gas stream via mass transfer to a liquid solvent, often water or an aqueous solution. It may involve a chemical reaction (e.g. in an acid or alkaline scrubber). In some cases, the compounds may be recovered from the solvent. This includes venturi scrubbers.

Technical description

With wet flue-gas cleaning, the acid components (sulphur oxides, inorganic chlorine and fluorine compounds) are removed from the flue-gases via mass transfer between the flue-gas and a liquid solvent, often water or an aqueous solution. by placing them in ~~intense~~ contact with water. This results in the components transferring from the gas to the water phase. The extent to which this takes place is dependent on the solubility of the components in question. In order to increase solubility, a base such as calcium carbonate ($CaCO_3$), calcium hydroxide ($Ca(OH)_2$), sodium carbonate (Na_2CO_3), sodium hydroxide (NaOH) or ammonia (NH_3) can be added to the water.

An illustration of a wet flue-gas cleaning unit is shown in Figure 4-26~~the following figure~~ [2, VITO 2003]. A unit such as this consists of a preparation unit for the scrubbing liquid, a scrubbing section, a solid-liquid separator and possibly a water treatment unit and drip collector. Plates or inert packing material (packed columns) may be used in order to increase the contact area. In addition to column scrubbers, there are also jet scrubbers, venturi scrubbers and rotating scrubbers.



Source: [2, VITO 2003]

Figure 4-26: Illustration of a wet flue-gas cleaning unit

In wet scrubbing systems, the flue-gas is cooled down first and then cleaned. Additionally, a neutralisation unit and a solid separation unit are necessary in the wet process.

A special variant of wet flue-gas cleaning is semi-wet flue-gas cleaning, where, due to a lower quantity of water, evaporation is enabled. Consequently, a dry residue is created which has reacted very efficiently and which can be separated using a filter. The method requires higher flue-gas temperatures in order to maintain sufficiently high temperatures at the filter following energy losses due to evaporation. Semi-wet systems have the advantages of a lower consumption of adsorbents, smaller amounts of residues and higher cleaning efficiencies, but they need more complex operating controls [2, VITO 2003].

Further information is provided in the CWW BREF [34, COM 2016].

Achieved environmental benefits
Reduced emissions to air of dust, HF, HCl and SO_X.

Environmental performance and operational data
For removal of HF, HCl and SO_X by wet flue-gas cleaning, lime is generally used as the absorbent. Here, a solution of calcium hydroxide (milk of lime) or a suspension of calcium carbonate in water is atomised in a spray column. As a waste product, usually a slightly impure plaster is formed. Purification efficiencies of 99 % for HF, up to 98 % for SO_2, 95 % for SO_3 and up to 95 % for HCl are achievable [2, VITO 2003], [4, UBA 2001].

Sodium fluoride (NaF), sodium sulphite (Na_2SO_3) and sodium chloride (NaCl) are formed if soda lye (caustic) is applied as a sorption agent in a packed-bed column. The waste occurring in the washing agent has to be disposed of after evaporation. The achievable purification efficiencies,

using soda lye as the washing agent, are 98 % for HF, up to 98 % for SO_2, 96 % for SO_3 and up to 98 % for HCl [4, UBA 2001].
A possible problem with wet flue-gas cleaning is corrosion. Gases leaving the scrubbing towers are saturated with water and can cause corrosion on cooling down to below the dew point. Furthermore, these cold gases diffuse less readily in the atmosphere and give rise to a moisture plume, and as a result it is sometimes advisable to reheat the flue-gases.

See Chapter 3 for reported clean gas concentrations using wet scrubbing.

Examples of cleaning efficiencies are:

- up to 99 % for HF;
- up to 98 % for SO_2 and SO_T;
- up to 98 % for HCl;
- up to 100 % for dust.[9, COM 2007]

Cross-media effects

- High water consumption.
- Generation of process waste water (not to the same extent for semi-wet systems) results in the need for process waste water treatment.
- Relatively high electricity consumption due to the pressure drop across the units.
- Absorbents which contain carbonate, react with the acidic components of the flue-gas to develop CO_2.

Technical considerations relevant to applicability

Generally applicable.

Wet flue-gas cleaning systems can, in principle, be applied in all ceramic sectors. Especially in cases where high SO_2 concentrations are present in the flue-gas and dry sorption plants cannot achieve low clean gas concentrations, the use of wet processes offers an alternative to dry sorption systems. In practice however, the application of wet processes is strongly limited by their high investment and maintenance costs.

Especially in cases in which high concentrations of inorganic pollutants are emitted simultaneously, e.g. for a high SO_2 content above 2 500 mg/m^3, wet processes offer an alternative to dry purification systems.

Economics

Maintenance and reparation costs may be higher than for other abatement techniques [74, Cerame-Unie 2023]. ~~In this context, s~~ See ~~Table 4.7~~ Table 4-8.

Possible shorter life~~time~~ cycles of the systems, caused by corrosion, also have to be taken into account.

Driving force for implementation

Legal requirements.

Example plants

~~Plant Hallerndorf-Pautzfeld, Germany (manufacture of expanded clay aggregates)~~
CZ_064, DE_079, DE_104, ES_161, ES_191, IT_243 and IT_328.

Reference literature

[26, UBA 2005], [2, VITO 2003], [3, Ceram-Unie 2003], [4, UBA 2001], [23, TWG 2005], [34, COM 2016], [35, TWG 2023]

4.7.4.12 Activated carbon filters

[Note to the TWG: most of the information below was included in Section 4.3.4.5 of the 2007 CER BREF. Please provide information to complement and update the 10-heading template below, e.g. on operational data]

Description
Removal of volatile organic compounds (VOCs) through adsorption on an activated carbon filter.

Technical description
Particulate matter and droplets have to be eliminated from the gas stream prior to the carbon filter.

Achieved environmental benefits
Reduced emissions to air of VOCs.

Environmental performance and operational data

Cross-media effects

- Increased amount of waste, if activated carbon has to be disposed of and cannot be regenerated.
- Increased energy consumption due to the operation of the activated carbon filter.

Technical considerations relevant to applicability
Activated carbon filters are only suited for cleaning low off-gas volumes of volatile organic compounds (VOCs), for instance, released as volatile reaction products by heat treatment of resins, which are used as binders.

Whereas some organic compounds (e.g. phenol and naphthalene) are retained by activated carbon, others are not effectively absorbed.

~~Activated carbon filters are applied mainly in the manufacturing process of refractory products.~~

Economics
High costs, especially if the activated carbon filters have to be disposed of and cannot be regenerated.

Driving force for implementation
Legal requirements.

Example plants
IT310.

Reference literature
[3, Ceram-Unie 2003], [4, UBA 2001], [23, TWG 2005], [35, TWG 2023]

4.7.4.13 Biological scrubbers

[Note to the TWG: the technique below has not been selected by any installation in the data collection, please provide information about its use. Most of the information below was included in Section 4.3.4.6 of the 2007 CER BREF. Please provide information to complement and update the 10-heading template below, e.g. on operational data and economics]

Description
Bioscrubbing combines wet gas scrubbing (absorption) and biodegradation; the scrubbing water contains a population of microorganisms suitable to oxidise noxious gaseous compounds. The microorganisms are suspended in water. Hence, the conditions to use bioscrubbers are:

- the existence of the possibility to wash out the waste gas constituents;
- the washed-out constituents must be biodegradable under aerobic conditions [34, COM 2016].

Technical description
Volatile reaction products, which are released by the heat treatment of resins used as binders in the refractory industry, in the manufacture of some technical ceramics and some inorganic bonded abrasives, include ammonia, formaldehyde and phenol. These can be removed from the flue-gases with suitable scrubbing liquids. The application of a biological scrubber is a variant in which the absorbent medium is regenerated.

Achieved environmental benefits
Reduced emissions to air of VOCs.

Environmental performance and operational data

Cross-media effects
- Increased water consumption and process waste water are possible.
- Increased energy consumption due to the operation of the biological scrubber.

Technical considerations relevant to applicability
Biological scrubbers can be applied in the manufacturing processes of refractory products and also in the manufacture of some technical ceramics along with some inorganic bonded abrasives.

The solubility of the pollutants in water and a constant continuous feed into the biological scrubber are necessary conditions.

Economics

Driving force for implementation
Legal requirements.

Example plants

Reference literature
[3, Ceram-Unie 2003], [14, UBA 2004], [23, TWG 2005], [34, COM 2016]

~~**Afterburning**~~

~~In this context, useful information can also be found in the BREF on Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector.~~

4.7.4.14 Thermal oxidation ~~afterburning~~

[Note to the TWG: most of the information below was included in Section 4.3.5.1 of the 2007 CER BREF. Please provide information to complement and update the 10-heading template below, e.g. on operational data and economics]

Description
Abatement technique which oxidises combustible compounds in a waste gas stream with air or oxygen. The waste gas stream is heated above its auto-ignition point in a combustion chamber and maintained at a high temperature long enough to complete its combustion to carbon dioxide and water. The typical combustion temperature is between 800 °C and 1 000 °C.

Several types of thermal oxidation are operated:

- Straight thermal oxidation: thermal oxidation without energy recovery from the combustion.
- Recuperative thermal oxidation: thermal oxidation using the heat of the waste gases by indirect heat transfer.
- Regenerative thermal oxidation: thermal oxidation where the incoming waste gas stream is heated when passing through a ceramic-packed bed before entering the combustion chamber. The purified hot gases exit this chamber by passing through one (or more) ceramic-packed bed(s) (cooled by an incoming waste gas stream in an earlier combustion cycle). This reheated packed bed then begins a new combustion cycle by preheating a new incoming waste gas stream [16, COM 2023].

Technical description

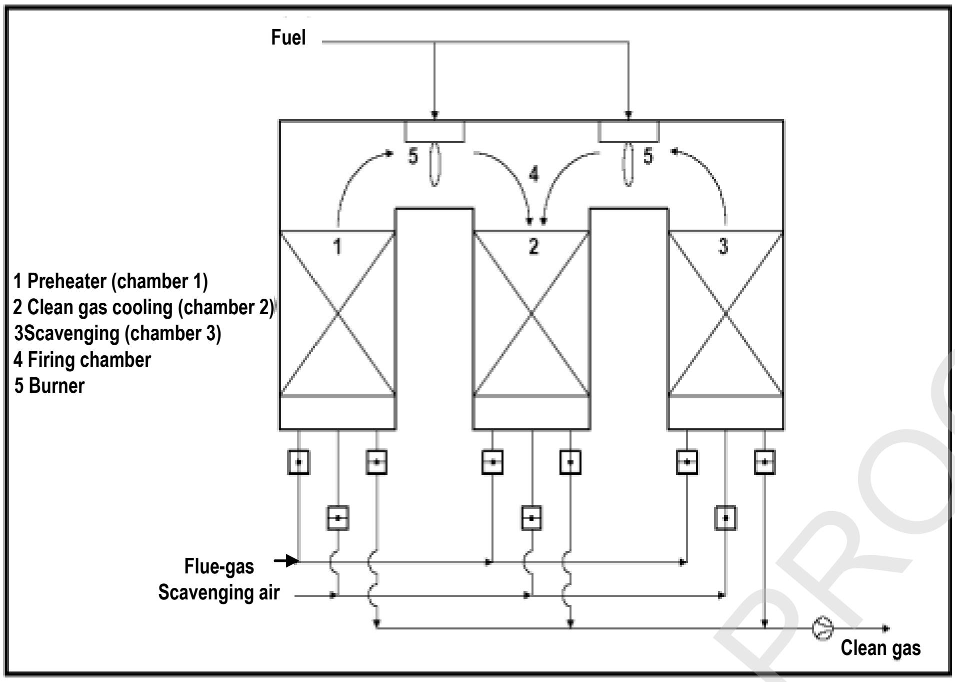
~~Incineration~~ Oxidation of VOCs ~~carbonisation gases~~ outside the kiln can be achieved in thermoreactors. These contain two or three chambers filled with ceramic or SiO_2 elements ~~having~~ with a high heat storage capacity. It is carried out preferably in the case of raw gas values of more than 100-150 mg VOC/m^3, depending on the raw gas characteristics (e.g. temperature, composition).

Flue-gases containing VOCs are passed through the first chamber and absorb the heat stored in it. As they leave the first chamber and enter the incineration compartment, they are already approaching incineration temperature. In the incineration compartment, they are further heated up to 750-800 ºC using burners, such that the organic substances are practically fully burned. The CO present in the flue-gases is also further oxidised into CO_2. Moreover, providing the temperature is at least 800 ºC and the residence period at least 1.5 seconds, 90 % destruction of any dioxins present/formed is achieved.

The hot purified gases leaving the incineration compartment are subsequently passed through the second chamber, where they give up the greater part of their heat again. The gas which has been cooled down leaves the second chamber and is discharged through the chimney. After a certain period of time, when the first chamber has cooled down sufficiently and the second chamber is sufficiently hot, the direction of the gas flow is reversed. The second chamber then heats up the untreated gases and the first chamber cools the purified gases down.

If a third chamber is present in a thermoreactor, it is used to avoid emission peaks when the gas flow direction is reversed. After the gas flow direction has been reversed, small volumes of scavenging air are passed through this chamber to ensure that no untreated gases can reach the stack.

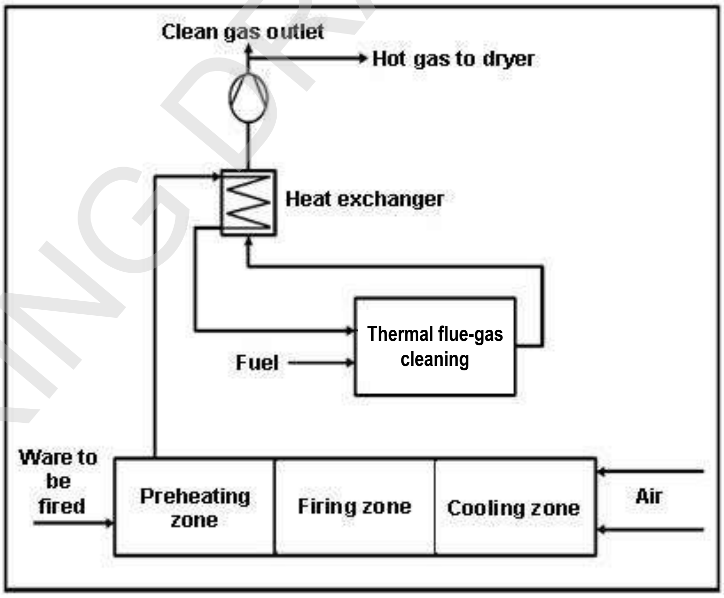
~~The following figure~~ Figure 4-27 shows a schematic view of a thermal afterburning system in a thermoreactor (three-chamber system) [4, UBA 2001], [23, TWG 2005].



Source: [9, COM 2007]

Figure 4-27: Schematic view of a thermal afterburning system in a thermoreactor (three-chamber system)

~~The following figure~~ Figure 4-28 presents flue-gas conduction in an external thermal afterburning system [4, UBA 2001].



Source: [9, COM 2007]

Figure 4-28: Flue-gas conduction in an external thermal afterburning system

For high gas volumes, afterburning systems may have five or seven chambers. In these systems, the flue-gas goes in parallel through two or three chambers where the same step takes place [56, COM 2023].

Achieved environmental benefits

Reduced emissions to air of VOCs and CO.

Environmental performance and operational data

Depending on the required cleaning efficiency, thermoreactors are installed as two- or three-chamber plants. With ~~2~~two-chamber plants, purification efficiencies of between 94 % and 97 % are achievable, whereas ~~3~~three-chamber plants achieve purification efficiencies of more than 99 % without problems [4, UBA 2001].

CO can be reduced by up to 98 % [74, Cerame-Unie 2023].

See Chapter 3 for reported clean gas concentrations using thermal oxidation.

~~In this context, see also Table 3.6 regarding emissions from brick manufacturing processes and Table 3.54 regarding emissions from manufacturing processes of technical ceramics (bonded abrasives). In these manufacturing processes, thermal afterburners are applied for flue-gas cleaning~~.

Cross-media effects

- Additional fuel needed, at least for the start-up of the operation and VOC concentration below auto ignition point.
- Additional NO_X emissions possible.
- Additional CO_2 emissions due to the combustion of VOCs and possible fuel consumption [74, Cerame-Unie 2023].

Technical considerations relevant to applicability

Straight thermal oxidation is generally applicable. Applicability of recuperative and regenerative thermal oxidation to existing plants may be restricted by design and/or operational constraints.

If the VOC and CO concentrations are high enough, ~~incineration~~ oxidation is virtually autothermic. In such cases, no additional energy needs to be added in order to maintain the incineration process. This occurs mainly in the manufacture of highly porous bricks, where large quantities of organic pore-forming substances are added to the raw material mixture.

Thermo-reactors have been used increasingly ~~in recent years~~ in the clay processing industry, especially in clay block manufacture, where organic pore-forming substances are added to the raw material mixture, and also to reduce VOC emissions from the manufacturing processes of other ceramic products, for instance refractory products, technical ceramics and some inorganic bonded abrasives. These systems have the advantage, compared with internal incineration systems, of not interfering with the normal operation of the kiln and that the flue-gas stream is purified in its entirety. ~~There is the problem of high water content in the gases in the manufacture of expanded clay aggregates.~~

In expanded clay, high concentrations of H_2O, SO_2 and dust can cause a fast-occurring blockage of the structures of thermal afterburners [33, Ramboll 2019].

Economics

- To economise on fuel, thermal afterburning of VOCs and CO is carried out preferably with regenerative heat exchange.
- The lower the VOC and CO concentrations in the raw gas, the more energy that needs to be added to keep the thermoreactor in operation and, therefore the higher the cost.

~~In this context, s~~ See ~~Table 4.7~~ Table 4-8.

Driving force for implementation
Legal requirements combined with energy-efficient process techniques.

Example plants
~~Wienerberger Ziegelindustrie AG/Werk Hennersdorf, brick plant, Austria~~
Widely used. In the data collection, 7 plants reported applying thermal oxidation without thermal recovery, 3 reported applying recuperative thermal oxidation and 25 reported applying regenerative thermal oxidation.

Reference literature
[1, BMLFUW 2003], [2, VITO 2003], [3, Ceram-Unie 2003], [4, UBA 2001], [14, UBA 2004], [23, TWG 2005], [32, TWG 2006], [16, COM 2023], [35, TWG 2023], [56, COM 2023]

4.7.4.15 Catalytic afterburning

[Note to the TWG: the technique below has not been selected by any installation in the data collection, please provide information about its use. Most of the information below was included in Section 4.3.5.2 of the 2007 CER BREF. Please provide information to complement and update the 10-heading template below, e.g. operational data and economics]

Description
Abatement technique which oxidises combustible compounds in a waste gas stream with air or oxygen in a catalyst bed. The catalyst enables oxidation at lower temperatures and in smaller equipment compared to thermal oxidation. The typical oxidation temperature is between 200 °C and 600 °C [16, COM 2023].

Technical description
In this VOC abatement technique, volatile organic pollutants are oxidised by passing the flue-gases over a catalytic surface which accelerates the oxidation reaction. The catalyst lowers the temperature for the oxidation of the organic pollutants to temperatures of between 200 ºC and 300 ºC. Catalysts with compounds of metal oxides or noble metals (e.g. Pd, Pt and Rh) are mainly used.

Further information is provided in the CWW BREF [34, COM 2016].

Achieved environmental benefits

- Reduced emissions to air of VOCs and CO.
- Posible energy recovery **[16, COM 2023]**.

Environmental performance and operational data

Cross-media effects
The catalysts involved will readily oxidise SO_2 to SO_3, which is a more toxic and corrosive compound.

Technical considerations relevant to applicability
~~Catalytic oxidation is difficult to apply in the clay processing industry because the catalysts used are quickly poisoned by the impurities present in the flue-gases (e.g. sulphur compounds). Therefore, c~~ The use of the technique may be hampered by catalyst poisons in the waste gases (e.g. sulphur compounds). Catalytic afterburning is employed predominantly for cleaning small flue-gas flows with a high content of total-C, which arise for instance~~,~~ when firing special refractory or technical ceramic products in small kilns or in the drying process.

Economics

Driving force for implementation
Legal requirements.

Example plants
The plants participating in the data collection did not report the use of catalytic afterburning. However, it is used in refractory production [33, Ramboll 2019].

Reference literature
[2, VITO 2003], [3, Ceram-Unie 2003], [4, UBA 2001], [16, COM 2023], [34, COM 2016]

4.7.5 Examples of operational data, efficiencies, consumption and cost data for different flue-gas cleaning techniques

~~The next table~~ Table 4-6 shows some examples of operational data, efficiencies, consumption and cost data for different flue-gas cleaning techniques [2, VITO 2003], [30, TWG 2005].

[Note to the TWG: please provide information to update the tables below]

Table 4-6: Technical parameters, efficiencies, consumption and cost data for flue-gas cleaning techniques

Technique		Cascade-type bed adsorbers	Cascade-type bed adsorbers	Cascade-type bed adsorbers	Dry flue-gas cleaning with a filter	Dry flue-gas cleaning with a filter	Wet flue-gas cleaning	Wet flue-gas cleaning
~~Emission value~~			~~SO_2 <1500 mg/Nm^3~~	~~SO_2 ≥2500 mg/Nm^3~~				
Adsorbent		$CaCO_3$	Modified $CaCO_3$	Modified $CaCO_3$	$Ca(OH)_2$	$NaHCO_3$	Water/$Ca(OH)_2$ or $CaCO_3$	Soda lye (caustic)
Cleaning efficiency	HF	90 % (up to 99 %)	up to 99 %	up to 99 %	80 up to 96 %	> 95 %	92 – 99 %	98 %
	SO_2	8 – 20 %	43 up to 85 %	30 – 43 %	7 up to 80 %	98 – 99 %	20 up to 98 %	90 – 98 %
	SO_3	80 %	80 – 85 %	80 – 85 %	up to 90 %	98 – 99 %	92 – 95 %	94 – 96 %
	HCl	50 %	> 50 %	50 %	10 up to 85 %	89 %	50 up to 95 %	90 – 98 %
	Dust	100 %	100 %	99 %	90 – 99 %	99 %		100 %
Excess dosing of adsorbent [A]		2.5	2.5	2.5	1.35 – 2.00		1.01 – 2.00	
Water consumption (m^3/day) [B]		0	0	0	0		86 – 240	
Electricity consumption (kWh/day) [B]		641 - 864	864	864	1200 – 2880		2352 – 4824	
Costs of absorbent (EUR/tonne)		59	99	99	104		30 – 100	
Investment costs (EUR 10^3) [B, C]		228 – 278	692	692	766 – 1081		511 – 659	

[A] This is taken to mean: the ratio between the quantity of adsorbent required in practice to achieve the stated cleaning efficiency to the quantity of adsorbent that would be required in theory (based on the stoichiometry of the adsorption reaction).

[B] The range refers to the values submitted for four typical companies.

[C] Installation and additional costs.

Reduction efficiencies as a result of process-integrated measures and end-of-pipe techniques are shown in the next two tables. End-of pipe techniques mainly have an effect on the HF reduction. Process-integrated measures only effect the reduction of SO_X. The examples also show the reduction efficiencies regarding the dependency of the sulphur content in the clay [2, VITO 2003] [30, TWG 2005].

Table 4-7: Examples of ~~R~~reduction efficiencies ~~regarding the dependency of~~ depending on–the sulphur content in the raw material used

Example		**1**	**2**	**3**	**4**
Technique		Dry flue-gas cleaning with filter	Cascade-type bed adsorber	Cascade-type bed adsorber	Cascade-type bed adsorber
Raw material		High sulphur clay	High sulphur clay	High sulphur clay	High sulphur clay
Emission value		SO_x>1500 mg/m^3	SO_x>1500 mg/m^3	$SO_x \geq$ 2500 mg/m^3	$SO_x \geq$ 2500 mg/m^3
Process-integrated measures		Addition of raw materials containing low sulphur and calcium	Addition of raw materials containing low sulphur and calcium	Addition of raw materials containing low sulphur and calcium	Addition of raw materials containing low sulphur and calcium; calcium rich additives
Adsorbent		$Ca(OH)_2$	$CaCO_3$	$CaCO_3$	$CaCO_3$
Reduction efficiency	HF	up to 96 %	up to 96 %	up to 92 %	up to 83 %
	SO_x	up to 7 %	up to 8 %	up to 20 %	up to 24 %
	HCl	0 %	up to 18 %	up to 57 %	up to 22 %
	Dust	up to 92 %	up to 39 %	up to 80 %	up to 58 %

Example		**5**	**6**	**7**	**8**
Technique		Dry flue-gas cleaning with filter	Cascade-type bed adsorber	Cascade-type bed adsorber	Cascade-type bed adsorber
Raw material		High sulphur clay	Low sulphur clay	Low sulphur clay	Low sulphur clay
Emission value		SO_x>1500 mg/m^3	SO_x<500 mg/m^3	SO_x<500 mg/m^3	SO_x<500 mg/m^3
Process-integrated measures		-	-	-	-
Adsorbent		$Ca(OH)_2$	$CaCO_3$	$CaCO_3$	$CaCO_3$
Reduction efficiency	HF	up to 95 %	up to 74 %	up to 99 %	up to 99 %
	SO_x	up to 34 %	0 %	up to 76 %	up to 63 %
	HCl	up to 83 %	0 %	up to 94 %	up to 93 %
	Dust	0 %	up to 37 %	up to 83 %	up to 44 %

~~In this context, see Table 3.8 and Table 3.9 regarding the corresponding operating data, raw and clean gas concentrations of clay block and facing brick manufacturing kilns [32, TWG 2006].~~

Some examples of cost data regarding the abatement of emissions such as dust, inorganic gaseous compounds and organic gaseous compounds by using different abatement techniques are shown for investment, maintenance and sorbent as well as operational costs in Table 4-8. However, this information cannot be used to directly compare individual techniques since the real cost will depend on factors such as flow rate, level of control, raw gas values, energy, etc. The aim is to provide a general view of the level of investment that could be involved in the different techniques [3, Ceram-Unie 2003], [2, VITO 2003], [4, UBA 2001], [30, TWG 2005], [32, TWG 2006].

Table 4-8: Costs ~~regarding~~ associated with the abatement of dust, inorganic gaseous compounds and organic gaseous compounds using different abatement techniques

Cleaning system/type	**Field of application**	**Absorbent /adsorbent**	**Common sizes/ flowrates for the ceramic industry** (Am^3/h)1)	**Rough investment guideline** (EUR) *[Note to the TWG: please provide information to update this column]*	**Maintenance** (EUR/yr) *[Note to the TWG please: provide information to update this column]*	**Sorbent cost** (EUR/tonne) (EUR/yr) *[Note to the TWG: please provide information to update this column]*	**Operation cost** EUR/t *[Note to the TWG: please provide information to update this column]*
Dust abatement							
~~Bag~~ Fabric filter/bag house	Complete areas in the plant, preparation, conveying, storage, forming area, handing over locations, etc.		900 to 70000	6000 – 150000 (Depending on size and amount of ductwork)			0.03 – 0.1
Central vacuum cleaner	Complete areas in the plant, preparation, conveying, storage, forming area, handing over locations, Kiln cars etc.		900 to 1000	25000 – 65000 (Depending on amount of ductwork /pipes)			
Kiln car cleaning system (In different execution: Fixed nozzle, moving nozzle, lifting and adjusting of the plateau)	Kiln cars		8000 to 30000	40000 –200000 (Depending on size and execution)			
Electrostatic precipitator	Dust abatement for hot and large off-gas streams		Up to 100000	1000000 – 3000000			0.1 – 0.2
Inorganic gaseous compounds abatement							
Module system	Mainly HF reduction	$Ca(OH)_2$ Honeycomb	Very low flowrates	45000 – 100000	~500	~46000 EUR/yr	

Cleaning system/type	**Field of application**	**Absorbent /adsorbent**	**Common sizes/ flowrates for the ceramic industry** (Am^3/h)1)	**Rough investment guideline** (EUR) *[Note to the TWG: please provide information to update this column]*	**Maintenance** (EUR/yr) *[Note to the TWG please: provide information to update this column]*	**Sorbent cost** (EUR/tonne) (EUR/yr) *[Note to the TWG: please provide information to update this column]*	**Operation cost** EUR/t *[Note to the TWG: please provide information to update this column]*
Cascade type packed bed absorber	Mainly HF reduction	$CaCO_3$	2500 to 140000 (no lower or upper limit)	40000 – 500000	~2000	30 – 55 EUR/tonne (delivered) 4000 – 30000 EUR/yr	23400 – 4800
Cascade type packed bed absorber	Mainly HF,. HCL and SO_x reduction	Modified/fabricated absorbent	2500 to 140000 (no lower or upper limit)	40000 – 500000	~2000	95 – 110 EUR/tonne (delivered) up to 60000 EUR/yr	
Countercurrent type packed bed absorber/ series modules	Mainly HF, HCL, and SO_x reduction	$CaCO_3$ and modified/ fabricated absorbent	2500 to 140000 (no lower or upper limit)	80000 – 800000	~2500	30 – 55 EUR/tonne (delivered) respectively 95 – 110 EUR/tonne (delivered)	
Dry sorption with bag filter (fly stream system)	Mainly HF, HCL, SO_x Particulate reduction	$Ca(OH)_2$ in different qualities	2500 to 140000 (no lower or upper limit)	80000 – 1000000	~4000	95 – 110 EUR/tonne (delivered) 8000 – 45000 EUR/yr	107500 – 130700
Dry sorption with bag filter (fly stream system) with conditioning of the reaction product	Mainly HF, HCL, and SO_x Particulate reduction	$Ca(OH)_2$ in different qualities (with little water added)	2500 to 140000 (no lower or upper limit)	200000 – 1600000	~6500	95 – 110 EUR/tonne (delivered) 8000 – 45000 EUR/yr	107500 – 130700
Wet scrubber	Mainly HCL and SO_x reduction	Alkali water	2500 to 140000 (no lower or upper limit)	400000 – 2000000	up to 8000	95 – 110 EUR/tonne (delivered) 8000 – 45000 EUR/yr +water	
Organic gaseous compounds abatement							
Thermal afterburning in a thermoreactor (external)	VOC reduction		10000 – 50000	180000 – 420000	500 – 4500		
Internal carbonisation gas combustion	VOC reduction			42000 – 300000	500 – 8000		

Cleaning system/type	**Field of application**	**Absorbent /adsorbent**	**Common sizes/ flowrates for the ceramic industry** (Am^3/h)$^{1)}$	**Rough investment guideline** (EUR) *[Note to the TWG: please provide information to update this column]*	**Maintenance** (EUR/yr) *[Note to the TWG please: provide information to update this column]*	**Sorbent cost** (EUR/tonne) (EUR/yr) *[Note to the TWG: please provide information to update this column]*	**Operation cost** EUR/t *[Note to the TWG: please provide information to update this column]*
Note: In the column 'common sizes/flowrates' and in the column 'rough investment guideline' there are ranges. It is reasonable to assume that the small Am^3/h-figures correspond to the low investment figure in EUR and that the high Am^3/h figure corresponds to the high investment figure in EUR. In between the increase is not linear, normally the more Am^3/h are treated, and the cheaper the investment per Am^3 is. $^{1)}$ The flowrates are given in 'actual m^3' (Am^3, as opposed to normal m^3, standard condition) because actual flue-gas has to be treated.							

4.8 Techniques to reduce emissions to water

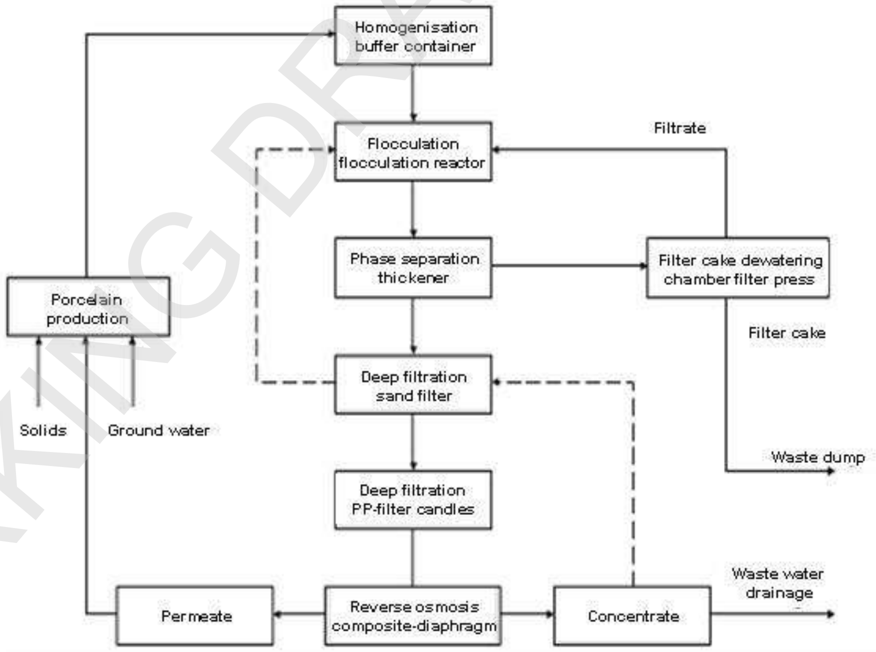
[The information below corresponds to the description in the 10-heading template of the techniques included in section 4.4.5.2 of the 2007 CER BREF in the and of the techniques selected by installations in the data collection]

Further information of the techniques described below is provided in the CWW BREF [34, COM 2016]. By applying one or a combination of the techniques described, significant reductions of process waste water emissions and lower water consumption can be achieved.

Process waste water treatment systems can be applied in all sectors of the ceramic industry, but the particular task has to be taken into consideration:

- ~~i~~If the process waste water is to be reused in the body preparation process, no treatment will in principle, be required, but a homogenising tank will be needed to ensure keeping the most consistent possible characteristics.
- ~~i~~If water is to be reused in cleaning the facilities, water quality will need to be higher, so that sedimentation is required, follow~~ing~~ed by aerating, with or without subsequent chemical treatment to remove odours.
- ~~e~~Excess process waste water which has to be disposed of externally normally requires a combination of homogenisation, flocculation, sedimentation and filtration. Also subsequent reverse osmosis is applied for reducing the amount of discharged process waste water.

As an example, ~~the following figure~~ Figure 4-8 shows a flow diagram of a process waste water purification plant of a porcelain tableware manufacturer which consists of a combination of the process waste water treatment systems mentioned ~~above~~ below [4, UBA 2001].



Source: [9, COM 2007]

Figure 4-29: Flow diagram of a process waste water purification plant

~~In this context, see Table 3.38, which shows the corresponding process waste water analysis regarding the several process steps and Table 3.39, which shows a process waste water analysis of a household ceramics plant, where the cleaning is carried out with a chemical precipitation process.~~

~~See also Table 3.39, which shows the analysis of cleaned process waste water from a technical ceramics (electrical insulator) manufacturing process, where process waste water cleaning is carried out using flocculation, separation with a baffle plate thickener and filtration with a filter press, whereas Table 3.50 also shows pollutant concentrations in process waste water from an electric insulator manufacturer after flocculation, but without filtration.~~

4.8.1 Preliminary, primary and general treatment

4.8.1.1 Neutralisation

[Note to the TWG: the technique below has not been selected by any IED installation in the data collection, please provide information about its use. Most of the information below was included in Section 4.4.5.2 of the 2007 CER BREF. Please provide information to complement and update the 10-heading template below, e.g. on operational data and economics]

Description
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 ($Ca(OH)_2$) is generally used to increase the pH, whereas sulphuric acid (H_2SO4), hydrochloric acid (HCl) or carbon dioxide (CO_2) is generally used to decrease the pH. The precipitation of some substances may occur during neutralisation.

Technical description
Further information is provided in the CWW BREF [34, COM 2016].

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.

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

Driving force
Compliance with legal requirements to limit pollution to a receiving water body.

Example plants

Reference literature
[34, COM 2016], [35, TWG 2023]

4.8.1.2 Homogenisation

[Note to the TWG: please provide information to complement and update the 10-heading template below, e.g. on operational data, applicability and economics]

Description
Use of tanks to obtain a consistent composition in the water to be treated.

Technical description
Homogenisation tanks are used to obtain a consistent composition in the water to be treated, and suppress, as far as possible, problems relating to variations in the constituents. Using such tanks yields improvement in all subsequent treatments, as the resulting homogeneity facilitates control of product additions and consistency in the operating facilities. [9, COM 2007]

Achieved environmental benefits
Yield improvements in subsequent waste water treatments.

Environmental performance and operational data

Cross-media effects
None.

Technical considerations relevant to applicability

Economics

Driving force for implementation

- Legal requirements.
- Reduction of water consumption.

Example plants

Reference literature
[9, COM 2007]

4.8.1.3 Physical separation, e.g. screens, sieves, grit separators, grease separators, oil-water separation, or primary settlement tanks

[Note to the TWG: please provide information to complement and update the 10-heading template below, e.g. on operational data, applicability and economics]

Description
The separation of gross solids, suspended solids and metal particles from the waste water using for example screens, sieves, grit separators, grease separators, hydrocyclones, oil-water separation or primary settlement tanks.

Oil-water separation consists of 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).

Technical description
This technique includes methods such as:

- gravity separation;
- emulsion breaking.

Further information is provided in the CWW BREF [34, COM 2016].

Achieved environmental benefits
Separation of gross solids, suspended solids and oil from water.

Environmental performance and operational data

Cross-media effects
Separated oil is a waste that has to be adequately disposed of.

Technical considerations relevant to applicability

Economics

Driving force for implementation

- Legal requirements.
- Reduction of water consumption.

Example plants
Widely used. The following installations have reported using oil-water separation: FI_375, FR_211, FR_221, FR_223, IT_261, IT_276, IT_277, IT_278, IT_317, PL_345, PT_349, PT_353 and PT_356.

Three other installations have reported using other physical separation: DE_090, PL_343 and PL_344.

Reference literature
[34, COM 2016], [35, TWG 2023]

4.8.2 Physico-chemical treatment

4.8.2.1 Activated carbon adsorption

[Note to the TWG: the technique below has not been selected by any IED installation in the data collection, please provide information about its use. Most of the information below was included in Section 4.4.5.2 of the 2007 CER BREF. Please provide information to complement and update if needed]

Further information is provided in the CWW BREF [34, COM 2016].

Description
Adsorption of organic molecules present in water.

Technical description
This is a very suitable system for removing non-biodegradable organic substances.

Achieved environmental benefits
Removal of organic compounds.

Environmental performance and operational data

Cross-media effects
Consumption of adsorbent.

Technical considerations relevant to applicability

Economics

Driving force for implementation

- Legal requirements.
- Reduction of water consumption.

Example plants

Reference literature

[9, COM 2007], [33, Ramboll 2019], [34, COM 2016], [35, TWG 2023]

4.8.2.2 Chemical precipitation

[Note to the TWG: please provide information to complement and update the 10-heading template below, e.g. on operational data, applicability and economics]

Further information is provided in the CWW BREF [34, COM 2016].

Description

The conversion of dissolved pollutants into insoluble compounds by adding chemical precipitants. The solid precipitates formed are subsequently separated by sedimentation, air flotation or filtration. If necessary, this may be followed by microfiltration or ultrafiltration. Multivalent metal ions (e.g. calcium, aluminium, iron) are used for phosphorus precipitation.

Technical description

The precipitate can be separated from the water portion by an additional process such as sedimentation, flotation or filtration. A precipitation facility usually consists of one or two stirred mixing tanks, where the agent causing precipitation (i.e. precipitation chemicals) and possibly other chemicals (e.g. flocculants) are added, a sedimentation tank and storage tanks for the chemical agents.

Achieved environmental benefits

Removal of precipitable dissolved non-biodegradable or inhibitory pollutants, e.g. metals.

Environmental performance and operational data

Cross-media effects

- Precipitants usually have to be disposed of as sludge.
- The presence of precipitation agents in the treated water may make the reuse of water as raw material impossible.

Technical considerations relevant to applicability

Economics

Driving force for implementation

- Legal requirements.
- Reduction of water consumption.

Example plants

BG_057, DE_097 and IT_289.

Reference literature

[9, COM 2007], [33, Ramboll 2019], [34, COM 2016], [35, TWG 2023]

4.8.2.3 Chemical oxidation

[Note to the TWG: please provide information to complement and update the 10-heading template below, e.g. on operational data, applicability and economics]

Further information is provided in the CWW BREF [34, COM 2016].

Description
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. Ozone is one example of a chemical-oxidising agent applied.

Technical description
Mixing in an oxidation reactor.

Achieved environmental benefits

- Reuse of cooling water.
- Removal of reducible dissolved non-biodegradable or inhibitory pollutants, e.g. AOX.

Environmental performance and operational data

Cross-media effects
Consumption of oxidising agents.

Technical considerations relevant to applicability

Economics

Driving force for implementation
Legal requirements.

Example plants
DE_083.

Reference literature
[9, COM 2007], [34, COM 2016], [35, TWG 2023]

4.8.2.4 Ion exchange

[Note to the TWG: the technique below has not been selected by any installation in the data collection, please provide information about its use. Most of the information below was included in Section 4.4.5.2 of the 2007 CER BREF. Please provide information to complement and update if needed]

Description
The retention of ionic pollutants from waste water and their replacement by more acceptable ions using an ion exchange resin. The pollutants are temporarily retained and afterwards released into a regeneration or backwashing liquid.

Technical description
The undesired ions are replaced by ions from an ion exchange resin, whrere they are temporarily retained and afterwards released into a regeneration or backwashing liquid.

Further information is provided in the CWW BREF [34, COM 2016].

Achieved environmental benefits
Removal of boron from the cleaning water coming from the glaze and application sections.

Environmental performance and operational data

Cross-media effects

- Concentrated solution generated in the regeneration of ion exchange resins that has to be treated.
- Consumption of ion exchange resins and regeneration liquids.

Technical considerations relevant to applicability

Economics

Driving force for implementation

- Legal requirements.
- Reduction of water consumption.

Example plants

Reference literature
[9, COM 2007], [34, COM 2016]

4.8.3 Solids removal

4.8.3.1 Coagulation and flocculation

[Note to the TWG: please provide information to complement and update the 10-heading template below, e.g. on operational data, applicability and economics]

Description
Coagulation and flocculation are used to separate suspended solids from waste water and are often carried out in successive steps. Coagulation is carried out by adding coagulants with charges opposite to those of the suspended solids. Flocculation is carried out by adding polymers, so that collisions of microfloc particles cause them to bond to produce larger flocs.

Technical description
Coagulation and flocculation occur in succesive steps. The purpose of this treatment is to break up colloidal suspensions and produce agglomeration, e.g. by use of alums or polyelectrolyte and/or a combination of lime and metal salts.

Coagulation is first and is done by adding coagulants with charges opposite to those of the suspended solids. The particles stick together into larger particles. A high-energy, rapid mix to properly disperse the coagulant is needed to coagulate solids. Flocculation is a gentle mixing which aims at increasing the particle size by adding polymers, so that collisions of microfloc particles cause them to bond to produce larger flocs.

Further information is provided in the CWW BREF [34, COM 2016].

Achieved environmental benefits
Separation of suspended solids from waste water.

Environmental performance and operational data

Cross-media effects

- The presence of coagulation or flocculation agents in the treated water may make the reuse of water as raw material impossible [33, Ramboll 2019].
- Consumption of coagulants and flocculants.
- Use of energy for mixing.

Technical considerations relevant to applicability

Economics

Driving force for implementation

- Legal requirements.
- Reduction of water consumption.

Example plants

Widely used, e.g. CZ_064, CZ_065, CZ_067, DE_097, ES_155, FR_212, FR_220, HU_229, IT_243, PT_359 and PT_360.

Reference literature

[9, COM 2007], [33, Ramboll 2019], [34, COM 2016], [35, TWG 2023]

4.8.3.2 Filtration

[Note to the TWG: please provide information to complement and update the 10-heading template below, e.g. on operational data, applicability and economics]

Description

Separation of suspended solids from waste water ~~a liquid~~, by putting the suspension through a porous medium that retains the solids and allows the liquid to flow through.

Technical description

The types of filtration used in the ceramic industry are in-depth filters, filter presses, and rotating vacuum filters.

Further information is provided in the CWW BREF [34, COM 2016].

Achieved environmental benefits

Removal of suspended solids and particulate-bound metals.

Environmental performance and operational data

Cross-media effects

Separated material is disposed of as waste or if possible reintroduced in the process.

Technical considerations relevant to applicability

Economics

Driving force for implementation

- Legal requirements.
- Reduction of water consumption.

Example plants
DE_381.

Reference literature
[9, COM 2007], [33, Ramboll 2019], [34, COM 2016], [35, TWG 2023]

4.8.3.3 ~~Aeration~~Flotation

[Note to the TWG: please provide information to complement and update the 10-heading template below, e.g. on operational data and economics]

Description
The separation of solid or liquid particles from waste water by attaching them to fine gas bubbles, usually air. The buoyant particles accumulate at the water surface and are collected with skimmers.

Technical description
This is a physical process that is frequently used in water treatment for different purposes, such as oxidation of the materials to facilitate subsequent flocculation, oxygenation of the organic compounds present in the process waste water, elimination of odours, etc. ~~Aerating~~Flotation equipment may involve surface stirrers or turbines.

Further information is provided in the CWW BREF [34, COM 2016].

Achieved environmental benefits
Removal of suspended solids and oils.

Environmental performance and operational data

Cross-media effects
Separated material is disposed of as waste or if possible reintroduced in the process.

Technical considerations relevant to applicability
Flotation is applied when sedimentation is not appropriate.

Economics

Driving force for implementation

- Legal requirements.
- Reduction of water consumption.

Example plants
ES_183, IT_261, IT_276 and PT_358.

Reference literature
[9, COM 2007], [34, COM 2016], [35, TWG 2023]

4.8.3.4 Reverse osmosis

[Note to the TWG: the technique below has not been selected by any installation in the data collection, please provide information about its use. Most of the information below was included in Section 4.4.5.2 of the 2007 CER BREF. Please provide information to complement and update if needed]

Description
A membrane process in which a pressure difference applied between the compartments separated by the membrane causes water to flow from the more concentrated solution to the less concentrated one.

Technical description
The pressure difference across the membrane makes the liquid pass through.

Further information is provided in the CWW BREF [34, COM 2016].

Achieved environmental benefits
Removal of boron from the cleaning water coming from the glaze and application sections.

Environmental performance and operational data

Cross-media effects

- Concentrated waste stream may need to be disposed of.
- Consumption of energy.

Technical considerations relevant to applicability

Economics

Driving force for implementation

- Legal requirements.
- Reduction of water consumption.

Example plants

Reference literature
[9, COM 2007], [34, COM 2016]

4.8.3.5 Sedimentation

[Note to the TWG: please provide information to complement and update the 10-heading template below, e.g. on operational data, applicability and economics]

Description
Separation of solid particles from a liquid by gravitational settling ~~gravity~~.

Technical description
There are various types of settling tanks; these may be rectangular, round or lamellar.

Further information is provided in the CWW BREF [34, COM 2016].

Achieved environmental benefits
Removal of suspended solids.

Environmental performance and operational data

Cross-media effects
Separated sludge is disposed of as waste.

Technical considerations relevant to applicability

Economics

Driving force for implementation

- Legal requirements.
- Reduction of water consumption.

Example plants

AT_022, DE_105, DE_105, DK_114, FR_217, IT_233, IT_278, NL_331 and PL_336.

Reference literature

[9, COM 2007], [33, Ramboll 2019], [34, COM 2016], [35, TWG 2023]

4.8.3.6 ~~Systems of process waste water treatment~~

~~In this context, useful information can also be found in the BREF on Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector.~~

~~Description and achieved environmental benefits~~

~~The main process waste water treatment systems are as follows:~~

~~**Homogenisation:** homogenisation tanks are used to obtain a consistent composition in the water to be treated, and suppress, as far as possible, problems relating to variations in the constituents. Using such tanks yields improvement in all subsequent treatments, as the resulting homogeneity facilitates control of product additions and consistency in the operating facilities.~~

~~**Aeration:** this is a physical process that is frequently used in water treatment for different purposes, such as oxidation of the materials to facilitate subsequent flocculation, oxygenation of the organic compounds present in the process waste water, elimination of odours, etc. Aerating equipment may involve surface stirrers or turbines.~~

~~**Sedimentation (settling):** this is the partial separation of solid particles from a liquid by gravity. There are various types of settling tanks; these may be rectangular, round or lamellar.~~

~~**Filtration:** filtration involves the separation of suspended solids from a liquid, by putting the suspension through a porous medium that retains the solids and allows the liquid to flow through. The types used in the ceramic industry are in-depth filters, filter presses, and rotating vacuum filters.~~

~~**Activated carbon absorption:** this treatment is based on carbons ability to strongly absorb organic molecules present in water. This is a very suitable system for removing non-biodegradable organic substances.~~

~~**Chemical precipitation:** this is a process for eliminating different dissolved elements by precipitation as insoluble compounds, using reagents such as lime.~~

~~**Coagulation and flocculation:** the purpose of this treatment is to break up colloidal suspensions and produce particle agglomeration, e.g. by use of alums or polyelectrolyte and/or a combination of lime and metal salts.~~

~~**Ion exchange and reverse osmosis:** these processes serve to remove boron from the cleaning water coming from the glaze and application sections. Reverse osmosis is also applied for reducing the amount of process waste water for discharge.~~

~~By applying these measures or a combination of them, significant reductions of process waste water emissions and lower water consumption (see also Table 4-2) can be achieved.~~

~~Cross-media effects~~

~~Sedimentation/filter residues have to be disposed of, if no re-use is possible (especially if flocculation, precipitation or absorption agents are used).~~

~~Economics~~

~~If the process waste water has to be disposed of externally, the compliance with the limits specified in the existing laws requires an expensive combination of several treatment steps including sedimentation, chemical precipitation, flocculation, and a final process, based on either ion exchange or reverse osmosis, as mentioned above.~~

~~If the cleaned water from the process waste water treatment systems can be re-used, this leads to reduced fresh water costs. With a combination of process waste water recycling/re-use measures and process optimisation measures for minimisation of water consumption, costs associated with the disposal of waste materials from the above treatments can be saved.~~

~~Driving force for implementation~~

~~legal requirements~~
~~saving water and raw material consumption.~~

~~Example plants and reference literature~~

~~[1, BMLFUW 2003], [3, Ceram-Unie 2003], [4, UBA 2001], [10, Navarro, J. E. 1998], [13, SYKE 2004], [23, TWG 2005], [30, TWG 2005], [31, Probst, R. 2005]~~

4.9 ~~General considerations concerning~~ Techniques to reduce noise

[Note to the TWG: General considerations about noise were included in Section 4.6 of the 2007 CER BREF.]

This section deals with possibilities for the reduction of noise occurring in the several steps during the manufacturing processes of ceramic products. Some noise-generating installations/techniques applied have already been dealt with in this document on the one hand, and many noise aspects are not really sector-specific on the other hand.

A reduction of sound emissions can often be achieved by directly applying measures at the source of the noise. The main sources of noise are, for example, pneumatic filter cleaning systems, compressors, motors of the preparation units as well as the handling units. Noise protection can be achieved by enclosure of the noisy unit or by building up noise protection walls. Double walls or sheathing in a double shelled construction are very efficient because, additionally, the air between the first and the second wall guarantees a higher noise protection level.

Vibrations and noise from several facilities (for example presses, crushing and mixing facilities) cannot be reduced efficiently by the above-mentioned measures, so the transfer of vibrations and noise has to be avoided by vibration insulation. Metal suspensions, rubber-metal connections and components made of felt, rubber~~,~~ and cork as well as ~~a~~ vibration insulation of the whole base with a layer of bitumen or an individual engine bed are efficient measures to reduce vibration and noise. Further measures to reduce noise emissions at the units are the use of silencers at the source of noise and the replacement of fast-turning fans by larger fans with a slower rotation.

If the above-mentioned noise protection measures cannot be applied and if a transfer of noisy units inside the building is not possible, secondary noise protection measures – often at the building itself – have to be carried out. This can be achieved by thicker walls and sound insulation of the windows (multi-glass windows, which also help by saving heating costs), which have to kept closed during noisy operations. In this context, it has to be mentioned however, that a necessity for closed windows often leads to the installation of (expensive and energy-consuming) ventilation systems because of workplace conditions. Also, a transfer of windows, gates and noisy outdoor installations to a direction away from neighbouring residential areas is possible.

The operation manner of the employees also has an effect on noise emissions. Gates have to be closed if steady through traffic is not necessary, and cautious driving with trucks and forklifts at the site also reduces the noise emissions. Beyond this, time-limiting of noise-intensive work, e.g. the tipping of broken ware or forklift traffic in the open air in the evening or at night, has to be avoided. Also the regular maintenance of the units by greasing, as well as the timely replacement of silencers, leads to a reduction of noise [4, UBA 2001].

Because the driving force of a noise protection measure is normally a legal requirement (protection of neighbourhood or workplace), from the economic point of view it is mainly a matter of expense, especially if construction measures are involved.

4.9.1 Noise management plan

[Note to the TWG: please provide information to complete the 10-heading template below, e.g. on operational data and economics]

Description
To set up, implement and regularly review a noise management plan as part of the environmental management system (EMS) (see Section 4.2.1) that includes all of the following elements:

- a protocol containing appropriate actions and timelines;
- a protocol for monitoring emissions of noise;
- a protocol for responding to identified noise events, e.g. complaints and/or taking corrective actions;
- a noise reduction programme designed to identify the source(s), to measure/estimate noise exposure, to characterise the contributions of the sources to the overall noise emissions and to implement prevention and/or reduction measures.

Technical description
As part of the EMS, a noise management plan is implemented and regularly reviewed. A noise management plan normally includes the following:

- Description of the main sources of noise (including infrequent sources) and the nearest noise-sensitive locations, including the following for each main source of noise within the installation:
  - the source and its location on a scaled plan of the site;
  - whether the noise is continuous/intermittent, fixed or mobile;
  - the hours of operation;
  - a description of the noise, e.g. clatter, whine, hiss, screech, hum, bangs, clicks, thumps or has tonal elements;
  - its contribution to the overall site noise emission, e.g. categorised as high, medium or low unless supporting data are available.
- The above information for the operation of infrequent sources of noise (such as infrequently operated/seasonal operations, cleaning/maintenance activities, on site deliveries/collections/transport or out-of-hours activities, emergency generators or pumps and alarm testing).
- Details of the appropriate noise surveys, measurements, investigations (which can involve detailed assessments of sound power levels for individual plant items) or modelling that may be necessary for either new or existing installations taking into consideration the potential for noise problems.
- Description of a protocol for response to identified noise incidents, e.g. complaints.
- Appropriate actions to be undertaken and timelines.

The overall reduction of noise levels involves developing a noise reduction plan. Here each of the sources needs to be checked and evaluated. Alternative techniques with lower noise levels may be applied and/or point sources may be enclosed.

Useful tools for the effective application of this technique may be:

- periodic noise monitoring;
- development of noise maps and associated noise calculations;
- periodic meetings and discussions with neighbours to identify noise nuisance issues.

Achieved environmental benefits
Reduction of noise emissions and vibration.

Environmental performance and operational data
See Technical description above.

Cross-media effects
None identified.

Technical considerations relevant to applicability
The applicability is restricted to cases where a noise nuisance at sensitive receptors is expected and/or has been substantiated.

Economics

Driving force for implementation

- Legal requirements.
- Local conditions.
- Good relations with neighbours and occupational health and safety.

Example plants
Widely used. A total of 18 installations in the data collection have reported applying a noise and vibration management plan: DE075, DE082, DE083, FR212, HU228, HU230, IT248, IT249, IT262, IT270, IT277, IT282, IT289, IT306, IT307, IT309, IT322 and IT328.

Reference literature
[35, TWG 2023], [61, COM 2019], [70, COM 2018]

4.9.2 Appropiate location of equipment and buildings

[Note to the TWG: please provide information to complete the 10-heading template below, e.g. on operational data]

Description
Increasing the distance between the emitter and the receiver, by using buildings as noise screens and by relocating equipment and/or building openings (e.g. exits or entrances of the buildings).

Technical description
Noise impact is reduced by increasing the distance between the emitter and the receiver, by using buildings as noise screens and by relocating noisy equipment and/or building openings. Furthermore, construction of buildings or natural barriers, such as growing trees and bushes between the protected area and the noisy activity, can be carried out.

Achieved environmental benefits
Reduction of noise perception in the areas nearby.

Environmental performance and operational data

Cross-media effects
None identified.

Technical considerations relevant to applicability
For existing plants, the relocation of equipment and building openings may not be applicable due to a lack of space and/or excessive costs.

Economics
Relocation of equipment and exits entails an associated cost.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants
Widely used. A total of 34 installations reported orientating windows, gates and noisy units away from neighbours.

Reference literature
[34, COM 2016], [35, TWG 2023]

4.9.3 Operational measures

[Note to the TWG: please provide information to complete the 10-heading template below, e.g. on operational data and economics]

Description
These include techniques such as:

- inspection and maintenance of equipment;
- closing of doors and windows of enclosed areas, if possible; or use of self-closing doors;
- equipment operation by experienced staff;
- avoidance of noisy activities at night, if possible;
- provisions for noise control, e.g. during production and maintenance activities, transport and handling of materials.

Technical description
Operational measures are applied in order to prevent or to reduce noise emissions.

Doors and windows of covered areas have to be kept closed during noisy operations.

Noisy activities (e.g. transport) are avoided at night, e.g. reducing the number of material transfer operations, reducing the height from which pieces fall onto hard surfaces.

Achieved environmental benefits
Reduction of noise emissions.

Environmental performance and operational data

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally applicable.

Economics

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants
Widely used. A total of 59 installations in the data collection reported closing widows and gates, 90 reported applying a good maintenance of the installation and 39 reported carrying out noisy outdoor activities only during normal business hours as techniques to reduce noise emissions,

Reference literature
[34, COM 2016], [35, TWG 2023]

4.9.4 Low-noise equipment

[Note to the TWG: please provide information to complete the 10-heading template below, e.g. on operational data]

Description
This includes techniques such as direct drive motors, low-noise compressors, pumps and fans, low-noise transportation equipment.

Technical description
When new equipment is purchased, the associated noise levels are taken into consideration.

Achieved environmental benefits
Reduction of noise emissions.

Environmental performance and operational data

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally applicable.

Economics
Additional investment and maintenance costs may occur due to the noise prevention techniques.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

Reference literature
[39, COM 2022]

4.9.5 Noise control and abatement equipment

[Note to the TWG: please provide information to complete the 10-heading template below, e.g. on operational data]

Description
Installation of low-noise equipment and insertion of obstacles between noise emitters and receivers.

Technical description
This includes techniques such as:

- use of noise reducers;
- use of acoustic insulation of equipment;
- enclosure of noisy equipment and processes (e.g. unloading of raw materials, compressors, fans, finishing);
- use of building materials with good sound insulation properties (e.g. for walls, roofs, windows, doors;
- inserting obstacles between emitters and receivers (e.g. protection walls, embankments).

Achieved environmental benefits
Reduction of noise emissions.

Environmental performance and operational data

Cross-media effects
None identified.

Technical considerations relevant to applicability
Applicability to existing plants may be restricted by a lack of space. For new plants, the design of the plant should make the insertion of obstacles unnecessary.

Economics
Investment cost of the noise control equipment.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants
Widely applied. Examples are:

- noise silencers reported by DE_079, DK_114, FI_375, PL_344 and PT_358;
- sound insulation in air compressors reported by ES_197;
- firing quipped with silencers reported by FR_396;
- enclosure of mills reported by DE_083 and DE_095;
- barriers and walls reported by ES_197 and IT_267.

Reference literature
[35, TWG 2023]

4.10 Techniques to reduce odour

4.10.1 Odour management plan

[Note to the TWG: please provide information to complete the 10-heading template below, e.g. on operational data and economics]

Description
An odour management plan (OMP) is part of the environmental management system (EMS) of the installation (see Section 4.2.1) and includes elements to prevent or reduce odorous nuisances.

Technical description
The odour management plan includes the following:

- A protocol containing appropriate actions and timelines.
- A protocol for conducting odour monitoring. It may be complemented by measurement/estimation of odour exposure (e.g. according to EN 16841-1 or -2) or estimation of odour impact.
- A protocol for response to identified odour incidents (including the management of complaints: identification of operations carried out, weather conditions such as temperature, wind direction, rainfall, communication with the authority and with complainant, etc.)
- An odour prevention and reduction programme designed to identify the source(s), to measure/estimate odour exposure, to characterise the contributions of the sources, and to implement prevention and/or reduction measures.

Achieved environmental benefits
Prevention or reduction of the emissions of those odorous releases that may be offensive and detectable beyond the boundaries of the site.

Environmental performance and operational data

Cross-media effects
None identified.

Technical considerations relevant to applicability
The applicability is restricted to cases where an odour nuisance at sensitive receptors is expected and/or has been substantiated.

Economics

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

Reference literature
[39, COM 2022]

4.10.2 Periodic monitoring of odour emissions

Description
Odour can be monitored using the following:

- EN standards (e.g. dynamic olfactometry according to EN 13725 in order to determine the odour concentration and/or EN 16841-1 or -2 in order to determine the odour exposure).
- Alternative methods (e.g. estimation of odour impact) for which no EN standards are available. In such a case, ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality can be used.

The monitoring frequency is determined in the odour management plan.

Technical description
The techniques include:

- for odour concentration determination (expressed in OUE/m3, to control limit values): dynamic olfactometry (measured according to the European standard EN 13725);
- for odour in ambient air: the grid method (according to the European standard EN 16841-1) or the plume method (according to the European standard EN 16841-2) to determine the odour exposure;
- for odour perception in the surrounding area (impact): odour surveys (see odour intensity mapping and odour wheels);
- electronic noses.

To determine the odour concentration, an air sample must be taken. The sampling techniques are similar to those used for measuring individual compounds. Techniques for odour monitoring are described in the ROM and the CWW BREF [34, COM 2016], [59, COM 2018].

Achieved environmental benefits
Monitoring helps to maintain the proper operation and minimise odorous emissions.

Environmental performance and operational data
See the ROM and the CWW BREF.

Cross-media effects
None identified.

Technical considerations relevant to applicability
The applicability is restricted to cases where an odour nuisance at sensitive receptors is expected and/or has been substantiated.

Economics
See the ROM and the CWW BREF.

Driving force for implementation

- Legal requirements.
- Local conditions.
- Complaints from neighbours.

Example plants
Monitoring of odour emissions was reported by eight installations in the data collection: DE_083, FR_223, IT_259, IT_261, IT_270, IT_277, IT_310 and IT_317.

Reference literature
[34, COM 2016], [39, COM 2022], [59, COM 2018]

5 BEST AVAILABLE TECHNIQUES (BAT) CONCLUSIONS FOR THE CERAMIC MANUFACTURING INDUSTRY

[This chapter will be drafted and shared for comments at a later stage.]

6 EMERGING TECHNIQUES FOR CERAMIC MANUFACTURING

[Note to the TWG: This chapter has been updated and when relevant, it has been rewritten compared to the 2007 CER BREF to include additional emerging techniques. Please provide additional information on emerging techniques to update and complement the 10-heading template]

Article 3(14) of Directive 2010/75/EU defines an 'emerging technique' as a 'novel technique for an industrial activity that, if commercially developed, could provide either a higher general level of protection of the environment or at least the same level of protection of the environment and higher cost savings than existing best available techniques'. This chapter contains those techniques that may appear in the near future and that may be applicable to ceramic manufacturing installations.

6.1 Radiant tube burners

Description
Indirect heating/heating without direct contact to flue-gases to reduce the water content in the kiln.

Technical description
Combustion takes place in tubes and flue-gases not entering into the kiln. Heating applies in an indirect way by radiation. In practice, a reduction of the water content in the kiln atmosphere would be technically difficult to achieve, given that water is produced during the combustion of the fossil fuels used to heat the kiln. This production of water can be avoided by heating the kiln indirectly with gas-fired radiant-tube burners. ~~(see Section 4.3.3.2).~~ For application in the ceramic industry, radiant-tube burners are made of silicon carbide with a high thermal conductivity and a high heat resistance to strongly fluctuating temperatures. With these radiant-tube burners, the kilns are heated indirectly (except the preheating zone of the kiln) and the flame of the burner is placed in a heat resistant tube, where combustion takes place. Heat transfer from the burner to the process is mainly carried out by thermal radiation, the corresponding high values for the heat flux are in a range of between 70 – 120 kW/m^2.

The purpose/principle of this technique is also applied by electric heating.

Achieved environmental benefits
Reduction of water vapour levels in the kiln gases usually results in lower emission rates for fluoride, because the basic mechanism for the release of fluorine from clay minerals is pyrohydrolysis. This reaction occurs at temperatures of 800 ºC and upwards. In laboratory tests, it was found that reducing the water content in the kiln atmosphere, did result in reduced emissions of HF as well as of SO_X.

Environmental performance and operational data

Cross media effects

Technical considerations relevant to applicability
The radiant-tube burners are, in principle, applicable in the wall and floor tiles, table- and ornamentalware, sanitaryware, technical ceramics and inorganic bonded abrasives industries, but the production scale in the sectors bricks and roof tiles, vitrified clay pipes, refractory products and expanded clay aggregates is too large. Projects have proven that they can be applied in roller hearth kilns and shuttle kilns, although the technology is not yet proven for tunnel kilns.

Economics

Driving force for implementation

- Reduction of HF and SOX emissions.
- Preparation step for electric heating.

Example plants

A pilot project in the Netherlands, where a roller hearth kiln was equipped with radiant tube burners for the manufacture of wall and floor tiles, showed HF emissions of between 0.7 mg/m^3 (wall tile manufacture) and 1.2 mg/m^3 (floor tile manufacture), and specific HF emission factors of between 3 – 6 mg/kg. The additional costs for radiant tube burner equipment and operating a kiln with a production capacity of 500 000 m^2 tiles per year were estimated at more than EUR 450 000 [5, InfoMil 2003].

Reference literature

[5, InfoMil 2003]

6.2 Microwave-assisted firing ~~and microwave dryers~~

Description

Firing of ware assisted by microwave or high-frequency radiation.

Technical description

The firing or sintering of ceramic ware is a critical step in the manufacturing process. Heavy loads on large kiln cars make the ~~heat~~ transfer of heat from the outside to the middle of the setting and into the centre of individual bricks difficult. Temperature gradients can lead to thermal stresses and damaged products – surface temperatures are frequently higher than those in the centre of the unit or setting.

~~Considerable research has been conducted on applying microwave energy in the firing of ceramic ware.~~ This process heats the product directly – including the centre of the units. In order to avoid undue heat loss to the kiln structure, microwave energy ~~has been~~ is used in combination with conventional heating such as gas or electrical energy.

Achieved environmental benefits

~~However, e~~Experimental work has indicated a number of significant benefits which should be developed in the future:

- minimisation of thermal stresses throughout the firing cycle;
- product throughputs considerably increased, i.e. much shorter firing cycles;
- energy consumption for firing considerably reduced – but there may be less excess heat available for drying purposes;
- reduction of solid process losses/solid waste;
- quality improvements, including significant gain in mechanical properties;
- enhanced binder removal (from refractory products);
- reduced emissions based upon less energy consumption and higher production output;
- lower fluoride emissions – which are closely related to the time the product spends above 800 ºC.

Environmental performance and operational data

Cross media effects

Electric energy demand.

Technical considerations relevant to applicability

Technical problems, including safety aspects, still need to be solved before the process can be applied economically ~~on~~ in full-scale manufacture kilns and also relatively high electrical energy costs have to be taken into account.

Economics

Driving force for implementation

Example plants

Reference literature
[46, MIDDEN 2020]

~~Microwave energy can, in principle, also be used for drying ceramic ware (see Section 2.2.5.8). The advantages and disadvantages, as listed above for firing, are also valid for drying processes with microwave ovens. Research showed that microwave assisted drying is not applicable for complex product shapes, only for thin shapes [20, Ceram-Unie 2004], [28, Schorcht, F. 2005], [30, TWG 2005].~~

~~6.3 New type of drying system for refractory pReroducts~~

[Note to the TWG: this technique has been deleted due to the information submitted by CERAME-UNIE [33, Ramboll 2019]]

~~Description and achieved environmental benefits~~

~~The drying of large size refractory building components such as ladle lids or the roofs of electric arc furnaces can be very time consuming and energy intensive. By placing heat resistant stainless steel foils (with heating temperatures of up to 1100 °C) or carbon fibres (at lower drying temperatures of less than 250 °C) as the heating element into the refractory mix which needs to be poured, the component can be dried from the inside out. The foils or carbon fibres adapt to the structure and cause no interference.~~

~~As drying takes place from the inside out, the water moves in the same direction as the temperature front. This reduces drying times considerably.~~

~~Controlling the setting temperature improves the quality of the building components substantially, resulting in more even drying with fewer dry cracks and improved structural stability. Improvements were achieved in the following parameters:~~

- ~~cold crushing strength: +50 %~~
- ~~bending strength: +50 %~~
- ~~abrasion resistance: +70 %~~
- ~~extension of service life: +50 %.~~

~~This drying technique results in considerable energy savings, which can be further increased – particularly in the case of very large building components – by insulating the refractory product during drying.~~

~~Cross-media effects~~

~~No issues.~~

~~Operational data and applicability~~

~~Carbon fibres can be used at temperatures of up to approx. 250 ºC, and metal foils at higher temperatures of up to 1100 ºC. Tests with a 9 tonne building component showed that the previous energy requirement for drying was 77000 kWh at residual moisture of 6 %. Installation of heating foils and insulation during drying reduced the energy requirement to 2000 kWh, which corresponds to about 97 % savings. The drying time decreased from about five days to about three days.~~

~~Economics~~

~~Significant cost savings can be achieved, particularly in the case of very large building components with weights of up to 20 tonnes, by reduced energy consumption.~~

~~Driving force for implementation~~

- ~~better quality and longer service life of building components~~
- ~~cost savings~~
- ~~time savings.~~

~~Example plant and reference literature~~

~~The technique is used by several manufacturers, e.g. Wolf GmbH, Urbar, Germany, [30, TWG 2005] [32, TWG 2006]~~

~~6.4 Advanced process waste water management with integrated glaze recovery~~

[Note to the TWG: this technique is considered to be fully implemented [33, Ramboll 2019]]

~~An innovative model waste water treatment system has been built at a ceramics factory, resulting in considerable reductions in pollutants and savings in the manufacture of sanitaryware, tableware and wall and floor tiles.~~

~~The new process waste water system has five modules:~~

- ~~microfiltration: the process waste water from the largest glazing process (white glazing, 80 % of total glaze consumption) is passed through a microfiltration plant for glaze recovery. The recovered glaze is returned to glaze preparation~~
- ~~treatment of a tributary process waste water stream: the process waste water from paste preparation in wall and floor tile manufacture, which is low in volume but highly contaminated, is passed to a separate treatment plant. The resulting sewage sludge, which contains high quality components which help increase the sinter ability of the ceramic body, is sent to paste preparation while the effluent goes to the municipal waste water treatment plant for removal of biodegradable constituents~~
- ~~inclusion of existing sedimentation tanks: the process waste water from glaze preparation is passed through a system of sedimentation tanks, which have been upgraded by additional measures and are monitored automatically. The resulting sewage sludge is also returned to paste preparation in wall and floor tile manufacture while the process waste water is passed to the new, substantially smaller process waste water treatment plant~~
- ~~construction of a new central process waste water treatment plant: the previous process waste water treatment plant handled up to 3500 m^3 of process waste water per day. The developed shed structures in the wall and floor tile works area made it impossible to separate rainwater and production waste water when the first waste water treatment plant was built in the early 1970s. The new centralised plant, which represents current state of the art, collects the process waste water from the factory and pumps it to the new system over ground, so that no mixing with rainwater occurs. An adjustment to the process waste water volumes of 700 – 800 m^3/day, the reduced pollutant loads in process waste water streams, and improved technology have made it possible to design it as a fully automated plant whose operation requires only 20 % of the original personnel needs and generates considerable savings in energy and flocculants. Part of the sewage sludge from this plant can also be re-used in tile production. As its pollutant loads are lower and as it also has lower water content (25 % maximum) because of a new chamber filter press, the remainder can be stored at the factory's own disposal site without any risk. Tests showed that the material is also suitable to be used as a component of the mineral sealing layer of landfill final cover systems~~
- ~~separation of rainwater: as process waste water is separated from the underground sewerage system, costly modernisation of old sewers and shafts is not required. Reduction and automation regarding the use of flocculants promises considerable material and cost savings.~~

~~The redesigning of the system has the following environmental advantages~~

- ~~recovery of white glaze and re-use within the process~~
- ~~saving of landfill capacity~~
- ~~use of biocides and activated charcoal filters is no longer necessary~~
- ~~highly contaminated process waste water is treated separately~~
- ~~in-plant recycling of sewage sludge~~
- ~~biologically polluted process waste water fractions are fed to the municipal waste water treatment plant~~
- ~~no risk from polluted process waste water in the old sewerage system~~
- ~~energy savings due to adaptation of the plants~~
- ~~savings in flocculants for sludge separation.~~

~~Cost advantages~~

- ~~reduction of personnel costs to 20 % of the original number of staff required through automation~~
- ~~reduction of energy costs~~
- ~~reduction in chemical additives~~
- ~~recovery of re-usable glaze~~
- ~~reduction of landfill costs.~~

~~The total costs of the process waste water treatment system are EUR 2.8 million. Because of the resulting savings, the expected payback period is 3 – 4 years.~~

~~Potential disadvantages~~

~~Although the system presented here can be characterised as a model system, the risks that could result when circumstances differ from those described, may lead to the following economic and qualitative disadvantages:~~

- ~~energy costs for the filtration technology may exceed the savings achieved from recovery of raw materials (depending on the original rate of raw material loss)~~
- ~~incorrect design of the microfiltration plant with the consequence of excessive investment costs or insufficient capacity~~
- ~~long phase of research into the use of recovered glaze (colour corrections may be necessary)~~
- ~~mixing of tributary streams is possible to a limited extent only, otherwise the saving effects from high quality recovery are no longer achieved~~
- ~~high technical competence is necessary regarding the overall system~~
- ~~redundancy measures have to be taken into account in the planning phase.~~

~~Conclusion: this kind of implementation of state-of-the-art environmental technology continues to be an industrial trial of model character subject to strictly defined conditions [30, TWG 2005] [32, TWG 2006].~~

~~6.5 Lead-free glazing of high quality table porcelain~~

[Note to the TWG: this technique is considered to be fully implemented]

~~Description and achieved environmental benefits~~

~~Lead glazes have been used in the past mainly for high quality table porcelain. The advantages of lead glazing include perfect surfaces and simple processing techniques in particular due to the melting and wetting behaviour typical of glazes containing lead.~~

~~Lead-free glaze formulations based on alkali boron silicates have been developed by a tableware producer, which are very much like systems containing lead in terms of quality and properties of application. This has led to annual savings in lead oxide of 60 tonnes. The use of minimal quantities of organic process additives means that environmental impacts due to organic emissions during firing are largely avoided.~~

~~The glazes are applied by wet spraying using rheologically adapted glazing suspensions. Process waste water streams generated in the spray booth, such as overspray and water from booth and rack cleaning, as well as glaze dust from the dry separator are treated and re-used for glazing together with fresh glaze. This closed glazing cycle has made it possible to optimise glaze input (glaze losses and actual requirement). The downstream thermal processes drying and firing have been adapted to the new glazing systems and optimised.~~

~~Simple patterns do not require additional firing and can be baked together with the glaze using an under-glaze technique. Complex, coloured on- and in-glaze patterns have to be baked separately.~~

~~Cross-media effects~~

~~A higher energy requirement is needed for the treatment and recovery of process waste water from glaze application.~~

~~Operational data and applicability~~

~~This technique is used for high quality table porcelain. Its use for colourful under-glaze patterns is not yet possible or would require additional investment.~~

~~Economics~~

~~With this technique, the manufacturer currently makes annual savings in lead oxide of 60 tonnes at two production sites. The conversion to this technique was carried out in the framework of a fundamental optimisation of the whole process. The implementation of this technique as part of modern process technology has led to increased economic viability and competitiveness in the world market.~~

~~Driving force for implementation~~

~~Cost savings for feedstock and the prevention of lead emissions.~~

~~Example plants and reference literature~~

~~Villeroy & Boch AG, Germany, [30, TWG 2005], [32, TWG 2006]~~

6.3 Use of recycled glass as flux material

[Note to the TWG: the technique below was proposed to be considered as an emerging technique in the initial positions submitted in 2019. TWG, please provide additional information to complete the 10-heading template.]

Description
Use of recycled glass in the raw material mix as flux material.

Technical description

Achieved environmental benefits
The technique can help to reduce CO_2 emissions from the firing process and provide a commercial use for waste glass streams that are otherwise difficult to recycle. The addition of the recycled glass to the raw material mix will reduce the demand for new raw materials from natural resources. It will also reduce the required firing temperature from around 1 250 °C to around 1 110 °C, as the glass melts at lower temperatures during vitrification, which will provide associated reductions in energy consumption and CO_2 emissions.

Environmental performance and operational data
This would mean energy savings of 10-15 % and a decrease in CO_2 emissions of around 2 000 tonnes/year for a medium-sized plant (with a production capacity of 300 tonnes/day). Moreover, the use of recycled glass as a raw material turns waste into a resource, diversifying and extending the useful life of this material.

Cross-media effects
No information provided.

Technical considerations relevant to applicability
No information provided.

Economics
Economic benefits would arise from this use of a waste stream, as well as the reduced demand for raw materials and reduced energy consumption. For instance, reduction of costs in the stoneware bricks manufacturing process, due to lower energy requirements and a decrease in the cost of the original raw material. This would mean savings of 7.5 % in manufacturing costs.

Driving force for implementation

- Circular economy.
- Reduction of energy consumption.
- Reduction of raw material consumption.

Example plants
A pilot installation for glass treatment to be used in the ceramic manufacturing was set up in Spain.

Reference literature
[76, LIFE CLAYGLASS 2016]

6.4 Advanced oxy-fuel technologies to the firing stage

[Note to the TWG: the technique below was proposed to be considered as an emerging technique for some sectors or as a BAT candidate in the initial positions submitted in 2019. TWG, please provide additional information to complete the 10-heading template below and examples of plants.]

Description
Combustion air is replaced fully or partially with pure oxygen. Oxy-fuel technologies are applied at the firing stage of ceramic tile production in order to facilitate CO_2 sequestration.

Technical description

Achieved environmental benefits
By using pure oxygen instead of air, the exhaust gases contain CO_2, and other flue-gases such as CO, HF, HCl, SO_X and dust and water vapour, which can be easily recovered. As a result, the heating requirement would be reduced, along with the volume of exhaust gases. This technique is a preliminary step for CCS, as the CO_2 concentration in the flue-gas is very high and so the separation is easy.

Environmental performance and operational data
No information provided.

Cross-media effects
Additional effort is required (technical for production and/or financial to purchase) to use pure O_2.

Technical considerations relevant to applicability
The flue-gas stream is massively reduced. However, a completely new stack system may be needed. There is a risk of explosive atmospheres.

Economics
No information provided.

Driving force for implementation
Reduction of energy consumption.

Example plants
A pilot line consisting of a roller hearth kiln with modified burners fed by oxygen-enriched air, improved heat-resistant walls in the kiln (higher emissivity of the flames) and a system for the mineral sequestration of CO_2 was set up. It had a daily production capacity of 120 m^2 of ceramic tiles (Ceramica Alta S.r.l.).

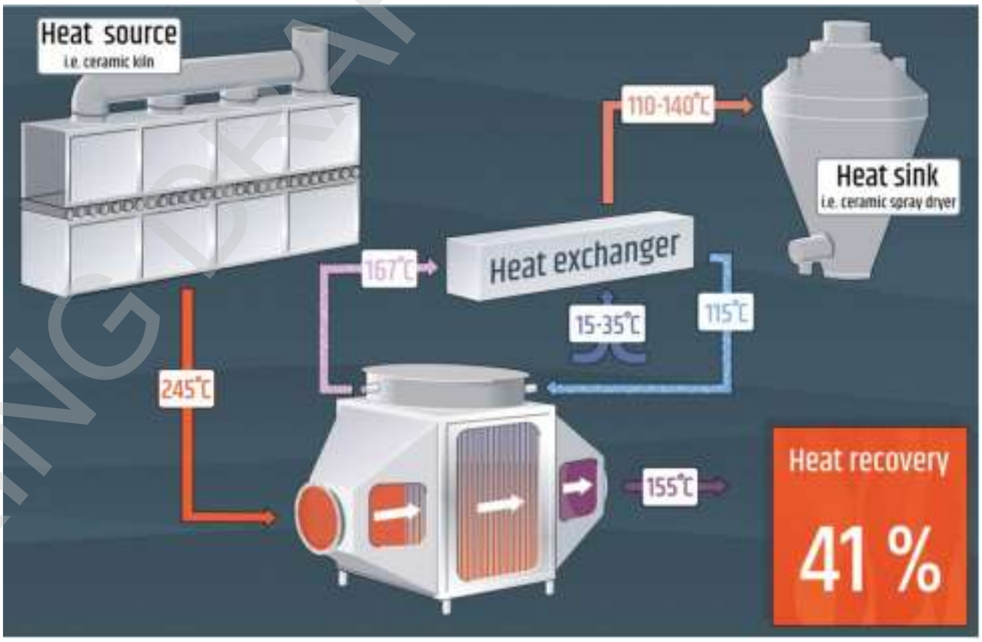
Reference literature
[77, LIFE ZEF-tile 2015]

6.5 Heat pipe technologies

[Note to the TWG: the technique below could be considered as anBAT candidate (merged with 4.3.9). Please provide additional information to complete the 10-heading template below and examples of plants.]

Description
New type of heat exchanger technology (HPHE) using heat pipes for thermal recovery.

Technical description
Figure 6-1 shows the implementation of heat pipe technologies for ceramic manufacturing during firing and spray-drying processes.



Source: [82, ETEKINA 2021]

Figure 6-1: Schematic view of heat pipe technology in ceramic manufacturing

Achieved environmental benefits
Reduction of energy consumption.

Environmental performance and operational data
The new technology achieves more than 40 % heat recovery for ceramic manufacturing during firing and spray-drying processes.

Cross-media effects
No information provided.

Technical considerations relevant to applicability:
No information provided.

Economics
The HPHE prototype is expected to deliver significant improvements and lower costs.

Driving force for implementation
Reduction of energy consumption.

Example plants
Pilot plant, Atlas Concorde, Modena, Italy. (Partner with ETEKINA).

Reference literature
[82, ETEKINA 2021]

6.6 Rapid dryer

[Note to the TWG: the technique below could be considered as a BAT candidate (merged with 4.3.9). Please provide additional information to complete the 10-heading template below and examples of plants.]

Description
The use of a new generation of dryers which can optimise dryer heat flows and manage all drying parameters by a newly designed mechanism and software technology.

Technical description
Drying is an extremely important production stage that involves removing all non-chemically bonded water from the body. Water evaporates and air is used both as the heating fluid and as the means of evacuation of the vapour. So to regulate the drying process, it is essential to control the three air flow characteristics: temperature, relative humidity and speed. With traditional dryers, pieces must be heated with humid warm air to even out the temperature of the ceramic product body before the evaporation process starts. Older traditional dryers do not have a real control system and the drying process takes many hours, which also causes high energy consumption.

The rapid dryers are designed to control the process with a fully automated heat generator and to control other parameters. In particular, it offers environmental benefits for sanitaryware and tableware production.

Achieved environmental benefits
Improved energy savings and a reduced drying cycle compared to traditional dryers.

- Thermal consumption is only 98 kcal/kg compared to the 288 kcal/kg of old dryers.
- Electrical consumption is only 0.003 kWh/kg compared to the 0.019 kWh/kg of old dryers.
- Reduction of emissions.

Environmental performance and operational data
The rapid dryer technology was has been in laboratory environment and achieved the following:

- shorter drying time, i.e. less than 8 hours (which is about 2 hours less than traditional bodies);
- increased mechanical strength of the unfired body (+10 %);
- improved resistance of fire clay to delayed crazing due to its low water absorption;
- new formulations with scrap quantities of up to 7-8 %;
- cost reduction of up to 10 %;
- reduction in CO_2 emissions.

Cross-media effects
None identified.

Technical considerations relevant to applicability
No information provided.

Economics
No information provided.

Driving force for implementation

- Reduction in CO_2 emissions.
- Reduction of energy consumption.

Example plants
Rapid dryer tested at FA CERAMICA, located in Civita, Castellana, Italy.

Reference literature
[79, A. Fortuna, D. M. Fortuna 2022], [80, Rapid Dry Project Team 2022]

7 CONCLUDING REMARKS AND RECOMMENDATIONS FOR FUTURE WORK

[This chapter will be completed after the Final TWG meeting.]

~~Timing of the work process~~

~~The information exchange on Best Available Techniques for Ceramic Manufacturing was carried out from late 2003 to the beginning of 2006 within the international technical working group (TWG) which was established for this purpose. It took approximately two and a half years to draft and develop this document based on the information provided and comments arising from the two consultations and the final TWG meeting. Table 7.1 shows the milestones of the work.~~

~~Table 7.1: Timing of the work process on the BREF on Ceramic Manufacturing~~

~~Start of Ceramics BREF work~~	~~October 2003~~
~~Kick-off meeting~~	~~1 – 2 December 2003~~
~~Draft 1~~	~~October 2004~~
~~Draft 1 comments~~	~~January 2005~~
~~Draft 2~~	~~June 2005~~
~~Draft 2 comments~~	~~September 2005~~
~~Change of the BREF author~~	~~September 2005~~
~~Final TWG meeting~~	~~14 – 17 February 2006~~
~~Final draft~~	~~September 2006~~

~~Sources of information and development of this document~~

~~This document is based on over 30 sources of information, with key information from both industry and Member States. Some reports were elaborated already prior to the kick-off meeting on purpose to provide targeted information for the development of this document and many contributions were also provided after the kick-off meeting. The reports were submitted by CERAME UNIE, the industry association representing the majority of European ceramic manufacturers, and the Member States Austria, Belgium, Finland, Germany, Italy, the Netherlands, Portugal and Spain and can be considered the building blocks of this document. Additional useful information was obtained by visiting ceramic manufacturing sites in Austria, Belgium, Denmark, Finland, France, Germany, Italy and Spain, usually organised and accompanied by TWG members.~~

~~This document was developed based on about 1000 comments to the first draft and more than 750 comments to the second draft from almost all of the TWG members. In this context it has to be noted that in fact the information exchange was carried out within EU-15, because the 10 new Member States of EU-25, with a few exceptions, did not participate actively.~~

~~Based on the information provided and the comments received, the scope and the structure of this document were developed so that the nine major ceramic sectors are covered. These are:~~

- ~~• wall and floor tiles~~
- ~~• bricks and roof tiles~~
- ~~• table- and ornamentalware (household ceramics)~~
- ~~• refractory products~~
- ~~• sanitaryware~~
- ~~• technical ceramics~~
- ~~• vitrified clay pipes~~
- ~~• expanded clay aggregates~~
- ~~• inorganic bonded abrasives.~~

~~The order of the chapters of this document (Executive Summary, Preface, Scope, Chapters 1 – 9 including BAT – Chapter 5 and Concluding Remarks – Chapte 7) follows the standard order of~~

~~the BREF Outline and Guide. This BREF Outline and Guide was given by the Information Exchange Forum (IEF), which is established by the European Commission to assist the IPPC information exchange (in this context, see also the Preface).~~

~~Information gaps that still exist~~

~~Despite much very useful information and many comments provided, regarding several issues, some data problems and the corresponding consequences for the document have to be pointed out:~~

- ~~to a certain extent, a lack of consistent quantitative information regarding actual economic (cost) data for some abatement techniques other than flue-gas cleaning techniques in context with the corresponding performance data. This has resulted in some qualitative rather than quantitative economic statements especially in Chapter 4 and consequently in some BAT conclusions, which are now based mainly on a qualitative approach~~
- ~~the multitude of product groups and individual manufacturing process steps have also led to qualitative rather than quantitative statements especially the BAT conclusions regarding energy efficiency. The data which were submitted in this context, show many specific aspects or details, but lead to the conclusion that, until now, general quantitative statements regarding this issue can hardly been made~~
- ~~regarding the use of alternative (e.g. biogas/biomass) or solid fuels (e.g. coal, petroleum coke) only few emission and consumption data were provided, most of them very late in this document's development process – some of them even during the final TWG meeting – and therefore they could not be fully taken into consideration.~~

~~Level of consensus at the final TWG meeting~~

~~The main discussion items at the final TWG meeting were the BAT conclusions, which were set out on two levels:~~

- ~~generic BAT conclusions, i.e. those that are generally applicable to the whole ceramic industry~~
- ~~sector specific BAT conclusions, i.e. those for the nine major ceramic sectors under the scope.~~

~~The BAT proposals were discussed case by case and in this context, it was also discussed and concluded that the BAT chapter does not set or propose emission limit values but suggests consumption and emission values that are associated with the use of a selection of BAT and that 'Best Available Techniques' for a specific installation will usually be the use of one individual or a combination of the techniques and measures listed in the BAT chapter under the generic and sector specific sections.~~

~~Another discussion point was to explicitly mention in the Concluding Remarks Chapter the difficulties in handling the information which was received very late. This is in particular relevant to petroleum coke as a fuel for the kiln firing process, along with the recommendation for further information gathering in order to help with the updating of this ceramics document.~~

~~A high degree of consensus was achieved during the final TWG meeting, no split views were recorded, and therefore – as also seen retrospectively over the whole information exchange period – the information exchange process can be considered successful.~~

~~Recommendations for future work~~

~~The information exchange and its result, i.e. this document, present an important step forward in achieving the integrated prevention and control of pollution from ceramic manufacturing. Further work could continue the process by providing information from all EU-25 Member States including actual cost data of abatement techniques and more data on energy efficiency~~

~~linked with the corresponding techniques.~~

~~Also more information regarding alternative and solid fuels including all kinds of emission and consumption data, e.g. real measured emission data, will be necessary to obtain a full understanding of the emission behaviour for a future revision of this document.~~

~~Additionally, the BAT associated emission levels (BAT AEL) have to be peer reviewed for a revision of this document, in particular regarding the high BAT AEL range for SOX emissions from the kiln firing process by using raw material with high sulphur content, taking into account advancing abatement techniques.~~

~~For the revision of this document, an oxygen level of 17 % should be considered as the reference level.~~

~~Suggested topics for future R&D work~~

~~In particular regarding the techniques described in the Emerging Techniques Chapter (Chapter 6), some future R&D work will still be necessary and useful, so that these techniques can be considered in the determination of BAT for ceramic manufacturing.~~

~~Besides that, the EC is launching and supporting, through its RTD programmes, a series of projects dealing with clean technologies, emerging effluent treatment and recycling technologies and management strategies. Potentially these projects could provide a useful contribution to future BREF reviews. Readers are therefore invited to inform the EIPPCB of any research results which are relevant to the scope of this document (see also the preface of this document).~~

8 ANNEXES

8.1 List of plants that participated in the data collection

Table 8-1: Plants that participated in the data collection

Plant code	Name of the plant	City	Country	Sector
[AT_001]	Comelli-Ziegel	Kirchbach Zerlach	Austria	Bricks & roof tiles
[AT_002]	Werk Peuerbach	Peuerbach	Austria	Bricks & roof tiles
[AT_003]	Werk Weibern	Weibern	Austria	Bricks & roof tiles
[AT_004]	Leitl	Eferding	Austria	Bricks & roof tiles
[AT_006]	Ziegelwerk Pichler Neuhofen	Neuhofen an der Krems	Austria	Bricks & roof tiles
[AT_009]	Senftenbach	Senftenbach	Austria	Bricks & roof tiles
[AT_010]	Haiding	Haiding	Austria	Bricks & roof tiles
[AT_011]	Göllersdorf	Göllersdorf	Austria	Bricks & roof tiles
[AT_012]	Gleinstätten	Gleinstätten	Austria	Bricks & roof tiles
[AT_013]	Pinkafeld	Pinkafeld	Austria	Bricks & roof tiles
[AT_014]	Hennersdorf	Hennersdorf	Austria	Bricks & roof tiles
[AT_016]	Uttendorf	Uttendorf	Austria	Bricks & roof tiles
[AT_017]	St. Andrä	St. Andrä	Austria	Bricks & roof tiles
[AT_018]	Danreiter	Tumeltsham	Austria	Bricks & roof tiles
[AT_019]	Ziegelwerk Pichler Wels	Wels	Austria	Bricks & roof tiles
[AT_022]	Krummnussbaum	Krummnussbaum	Austria	Refractory products
[AT_023]	Veitsch-Radex Veitsch	Veitsch	Austria	Refractory products
[AT_025]	Werk Radenthein	Radenthein	Austria	Refractory products
[AT_026]@	Gmunden	Gmunden	Austria	Sanitaryware
[AT_028]	Steka	Innsbruck	Austria	Technical ceramics
[BE_029]	Ploegsteert Bristal	Ploegsteert	Belgium	Bricks & roof tiles
[BE_030]	Ploegsteert Barry	Ploegsteert	Belgium	Bricks & roof tiles
[BE_031]	Desta	Hoogstraten	Belgium	Bricks & roof tiles
[BE_033]	Floren	Brecht	Belgium	Bricks & roof tiles
[BE_034]	Kesselt	Lanaken	Belgium	Bricks & roof tiles
[BE_035]	Oudenaarde	Oudenaarde	Belgium	Bricks & roof tiles
[BE_036]	Vandersanden Lanklaar	Lanklaar (Dilsen-Stokkem)	Belgium	Bricks & roof tiles
[BE_037]	Vandersanden Spouwen	Bilzen	Belgium	Bricks & roof tiles
[BE_038]	Péruwelz	Péruwelz	Belgium	Bricks & roof tiles
[BE_039]	Moeskroen	Moeskroen	Belgium	Bricks & roof tiles
[BE_040]	Kortemark	Kortemark	Belgium	Bricks & roof tiles
[BE_041]	Aalbeke	Kortrijk - Aalbeke	Belgium	Bricks & roof tiles
[BE_042]	Lanaken	Lanaken	Belgium	Bricks & roof tiles
[BE_043]	Maaseik	Maaseik	Belgium	Bricks & roof tiles
[BE_044]	Rumst	Rumst	Belgium	Bricks & roof tiles
[BE_045]	Zonnebeke	Zonnebeke	Belgium	Bricks & roof tiles
[BE_046]	Beerse	Beerse	Belgium	Bricks & roof tiles
[BE_047]	Beerse (Steenbakkersdam)	Beerse	Belgium	Bricks & roof tiles
[BE_048]	Malle	Malle	Belgium	Bricks & roof tiles
[BE_049]	Argex	Burcht	Belgium	Expanded clay
[BE_050]	Steinzeug-Keramo nv	Hasselt	Belgium	Vitrified clay pipes

Plant code	Name of the plant	City	Country	Sector
[BE_929]	Ploegsteert Afma	Ploegsteert	Belgium	Bricks & roof tiles
[BG_052]	Ceramic Plant Lukovit	Lukovit	Bulgaria	Bricks & roof tiles
[BG_057]	Kaspichan	Kaspichan	Bulgaria	Sanitaryware
[CZ_060]	Borovany	Borovany	Czech Republic	Wall and floor tiles
[CZ_061]	Rako 3	Lubná u Rakovníka	Czech Republic	Wall and floor tiles
[CZ_062]	Chlumčany	Chlumcany	Czech Republic	Wall and floor tiles
[CZ_064]	Podbořany	Podbořany	Czech Republic	Wall and floor tiles
[CZ_065]	Velké Opatovice	Velké Opatovice	Czech Republic	Refractory products
[CZ_066]	Svitavy	Svitavy	Czech Republic	Refractory products
[CZ_067]	Bechyně	Bechyně	Czech Republic	Sanitaryware
[CZ_068]@	Laufen CZ, Znojmo	Znojmo	Czech Republic	Sanitaryware
[CZ_069]	Liapor Vintirov, CZ	Sokolov	Czech Republic	Expanded clay
[CZ_387]	Holice	Holice	Czech Republic	Bricks & roof tiles
[CZ_388]	Hranice	Hranice	Czech Republic	Bricks & roof tiles
[CZ_389]	Jezernice	Jezernice	Czech Republic	Bricks & roof tiles
[CZ_390]	Kostelec	Kostelec	Czech Republic	Bricks & roof tiles
[CZ_391]	Novosedly	Novosedly	Czech Republic	Bricks & roof tiles
[CZ_392]	Řepov	Řepov	Czech Republic	Bricks & roof tiles
[CZ_393]	Stod	Stod	Czech Republic	Bricks & roof tiles
[CZ_394]	Šlapanice	Šlapanice	Czech Republic	Bricks & roof tiles
[CZ_395]	Týn nad Vltavou	Týn nad Vltavou	Czech Republic	Bricks & roof tiles
[DK_112]	Hammershøj Teglværk	-	Denmark	Bricks & roof tiles
[DK_113]	Strøjer Tegl	Assens	Denmark	Bricks & roof tiles
[DK_114]	Randersvej 75, 8940 Randers SV (Hinge)	Randers SV	Denmark	Expanded clay
[FI_375]	Kuusankosken Leca-soratehdas	Kouvola	Finland	Expanded clay
[FR_211]	La Seguiniere	La Seguiniere	France	Bricks & roof tiles
[FR_212]	Saint Martin des Fontaines	Saint Martin des Fontaines	France	Bricks & roof tiles
[FR_213]	Léguevin	Léguevin	France	Bricks & roof tiles
[FR_214]	Edillians	Saint Germer De Fly	France	Bricks & roof tiles
[FR_216]	Marseille	Marseille	France	Bricks & roof tiles
[FR_217]	St Amans Soult	St Amans Soult	France	Wall and floor tiles
[FR_219]	Lasbordes	Lasbordes	France	Bricks & roof tiles
[FR_220]	Seltz	Seltz	France	Bricks & roof tiles
[FR_221]	Durtal	Durtal	France	Bricks & roof tiles
[FR_222]	Lantenne-Vertière	Lantenne-Vertière	France	Bricks & roof tiles
[FR_223]	Betschdorf	Betschdorf	France	Bricks & roof tiles
[FR_396]	Site de Fournès	Fournès	France	Wall and floor tiles
[DE_071]	Neufahrn/NB	Neufahrn	Germany	Bricks & roof tiles
[DE_073]	Bannberscheid	Bannberscheid	Germany	Bricks & roof tiles
[DE_075]	Zeilarn	Zeilarn	Germany	Bricks & roof tiles
[DE_077]	Buchwäldchen	Calau	Germany	Bricks & roof tiles
[DE_079]	Pautzfeld	Hallerndorf - Pautzfeld	Germany	Expanded clay
[DE_080]@	Mogendorf	Mogendorf	Germany	Expanded clay
[DE_082]	Plant Gochsheim	Kraichtal-Gochsheim	Germany	Refractory products

Plant code	Name of the plant	City	Country	Sector
[DE_083]	Plant Göttingen	Göttingen	Germany	Refractory products
[DE_084]	Plant Melle	Melle	Germany	Refractory products
[DE_085]	Plant Niederdollendorf	Koenigswinter	Germany	Refractory products
[DE_086]	Höhr-Grenzhausen	Höhr-Grenzhausen	Germany	Refractory products
[DE_087]@	Hornberg	Hornberg	Germany	Sanitaryware
[DE_089]@	Mettlach	Mettlach	Germany	Sanitaryware
[DE_090]@	Werk Schönwald	Schoenwald	Germany	Tableware and household ceramics
[DE_094]@	Faiencerie Merzig	Merzig	Germany	Tableware and household ceramics
[DE_095]	Ransbach-Baumbach	Ransbach-Baumbach	Germany	Tableware and household ceramics
[DE_096]@	Marktredwitz MT	Marktredwitz	Germany	Technical ceramics
[DE_097]	Altdorf	Altdorf	Germany	Technical ceramics
[DE_098]@	Werk Wunsiedel	Wunsiedel	Germany	Technical ceramics
[DE_099]@	Waldkraiburg	Waldkraiburg	Germany	Technical ceramics
[DE_100]	Plant Steinbach am Wald	Steinbach am Wald	Germany	Technical ceramics
[DE_102]	Ransbach-Baumbach	Ransbach-Baumbach	Germany	Wall and floor tiles
[DE_103]	Werk Sinzig	Sinzig	Germany	Wall and floor tiles
[DE_104]	Agrob Buchtal GmbH - Witterschlick	Alfter-Witterschlick	Germany	Wall and floor tiles
[DE_105]	Agrob Buchtal GmbH - Schwarzenfeld	Schwarzenfeld	Germany	Wall and floor tiles
[DE_106]	Leisnig	Leisnig	Germany	Wall and floor tiles
[DE_108]	Bremerhaven	Bremerhaven	Germany	Wall and floor tiles
[DE_109]	Dillenburg	Dillenburg	Germany	Wall and floor tiles
[DE_110]	Tile factory	Merzig	Germany	Wall and floor tiles
[DE_111]	Zahna Fliesen GmbH	Zahna-Elster	Germany	Wall and floor tiles
[DE_376]	Werk 1 Bad Schmiedeberg	Bad Schmiedeberg	Germany	Vitrified clay pipes
[DE_381]	Narsdorf	Narsdorf	Germany	Bricks & roof tiles
[DE_382]	Roggden	Roggden	Germany	Bricks & roof tiles
[DE_383]	Walther Dachziegel GmbH	Langenzenn	Germany	Bricks & roof tiles
[DE_385]	Eisenberg Thüringen	Eisenberg	Germany	Bricks & roof tiles
[DE_386]	Bellenberg	Bellenberg	Germany	Bricks & roof tiles
[EL_115]	Kebe Nea Santa	Nea Santa Kilkis	Greece	Bricks & roof tiles
[EL_118]	Xalkis Sasximatari Site	Sximatari	Greece	Bricks & roof tiles
[EL_119]	Xalkis Savasiliko Site	Vasiliko	Greece	Bricks & roof tiles
[HU_226]	Tiszavasvári téglagyár	Tiszavasvári	Hungary	Bricks & roof tiles
[HU_227]	Csabai cserépgyár	Békéscsaba	Hungary	Bricks & roof tiles
[HU_228]	Romhány	Hungary	Hungary	Wall and floor tiles
[HU_229]	Hódmezővásárhely, Hungary	Hódmezővásárhely	Hungary	Sanitary ware
[HU_230]	Tófej	Hungary	Hungary	Wall and floor tiles
[IT_233]	Fornace di Fosdondo	Correggio	Italy	Bricks & roof tiles
[IT_238]	Stabilimento di Bentivoglio	Bentivoglio	Italy	Bricks & roof tiles
[IT_239]	Stabilimento di Cotignola	Cotignola	Italy	Bricks & roof tiles
[IT_241]	Bubano	Mordano, fraz. Bubano	Italy	Bricks & roof tiles
[IT_243]	Stabilimento di Casalpusterlengo	Castelpusterlengo	Italy	Refractory products
[IT_248]	Sede Centrale	Casalgrande	Italy	Wall and floor tiles

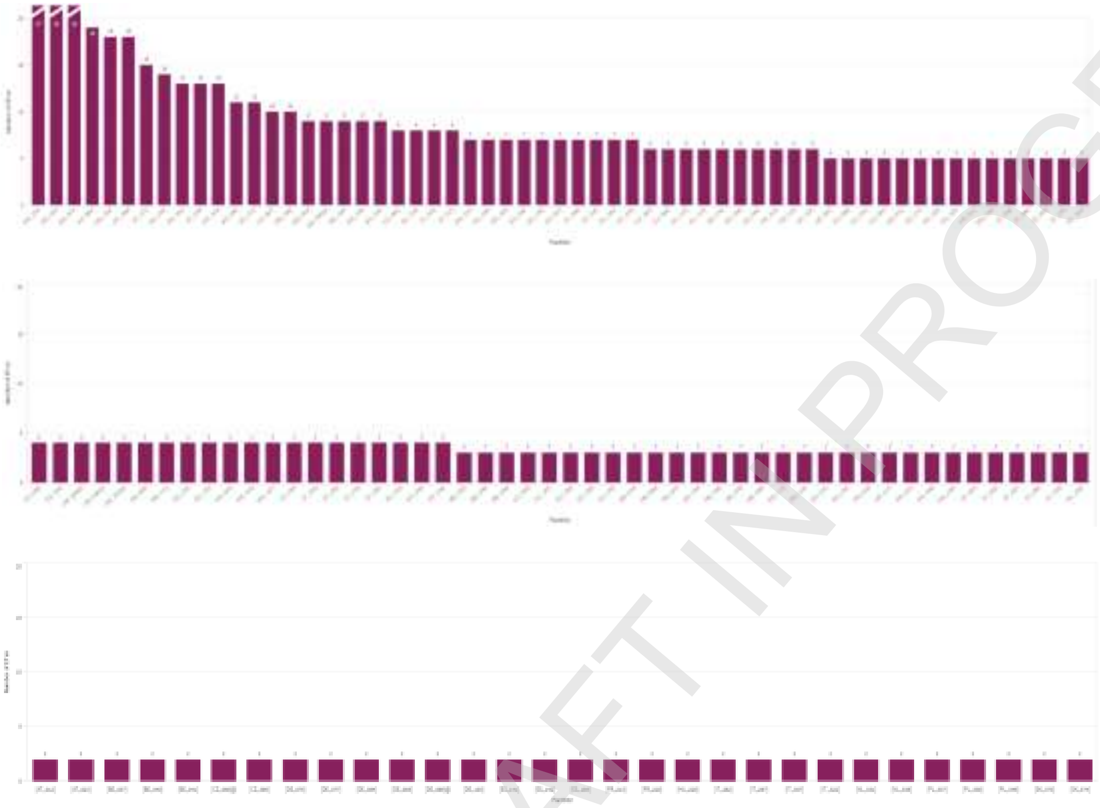
Plant code	Name of the plant	City	Country	Sector
[IT_249]	Dinazzano	Casalgrande	Italy	Wall and floor tiles
[IT_259]	Stabilimento Fiorano Modenese	Fiorano Modendese	Italy	Wall and floor tiles
[IT_261]	Ceramiche Atlas Concorde S.p.A. stab. Finale	Finale Emilia	Italy	Wall and floor tiles
[IT_262]	Fiorano Modenese	Fiorano Modenese	Italy	Wall and floor tiles
[IT_263]	Fiorano Modenese	Fiorano Modenese	Italy	Wall and floor tiles
[IT_267]	Ceramiche Marca Corona S.p.A.	Sassuolo	Italy	Wall and floor tiles
[IT_270]	Ceramiche Refin S.p.A.	Casalgrande	Italy	Wall and floor tiles
[IT_276]	Stabilimento di Borgo Tossignano	BorgoTossignano	Italy	Wall and floor tiles
[IT_277]	Stabilimento 5	Faenza	Italy	Wall and floor tiles
[IT_278]	Stabilimento 2 - Via Correcchio n. 32 - Imola	Imola	Italy	Wall and floor tiles
[IT_282]	Exportceram Fideuro S.p.A.	Montefiorino	Italy	Wall and floor tiles
[IT_286]	Fiorano	Fiorano Modenese	Italy	Wall and floor tiles
[IT_289]	Via Caltagirone 72, Faenza (RA)	Faenza	Italy	Wall and floor tiles
[IT_296]	Stabilimento di Iano	Scandiano	Italy	Wall and floor tiles
[IT_297]	Stabilimento di Iano	Viano	Italy	Wall and floor tiles
[IT_306]	Italcer spa - Stab 01 Rubiera	Rubiera	Italy	Wall and floor tiles
[IT_307]	Italcer spa - Stab 02 Vetto	Vetto	Italy	Wall and floor tiles
[IT_309]	Keritaly S.p.A.	Gonzaga	Italy	Wall and floor tiles
[IT_310]	Laminam S.p.A.- Fiorano Modenese plant	Mo	Italy	Wall and floor tiles
[IT_317]	Mirage Granito Ceramica SPA	Pavullo nel Frignano	Italy	Wall and floor tiles
[IT_322]	UL 4 - Fiorano Modenese	Fiorano Modenese	Italy	Wall and floor tiles
[IT_328]	Sichenia Gruppo Ceramiche S.p.A.	Sassuolo	Italy	Wall and floor tiles
[NL_331]	Steenfabriek Tolkamer	Tolkamer	Netherlands	Bricks & roof tiles
[NL_332]	Haaften	Haaften	Netherlands	Bricks & roof tiles
[NL_333]	De Wolfswaard	Opheusden	Netherlands	Bricks & roof tiles
[NL_335]	Narvik Deest	Deest	Netherlands	Bricks & roof tiles
[PL_336]	Lębork	Lębork	Poland	Bricks & roof tiles
[PL_337]	Dobre	Dobre	Poland	Bricks & roof tiles
[PL_338]	Honoratka	Ślesin	Poland	Bricks & roof tiles
[PL_339]	Gnaszyn	Częstochowa	Poland	Bricks & roof tiles
[PL_340]	Oleśnica	Oleśnica	Poland	Bricks & roof tiles
[PL_341]	Kupno	Kupno	Poland	Bricks & roof tiles
[PL_342]	Paczków	Paczków	Poland	Bricks & roof tiles
[PL_343]	Kunice	Kunice	Poland	Bricks & roof tiles
[PL_344]	Leca Polska Sp. z o.o.	Gniew	Poland	Expanded clay
[PL_345]	Plant 1	Kraków	Poland	Refractory products
[PL_346]	Plant 2	Kraków	Poland	Refractory products
[PT_349]	Lugar do Cruto - Cervães	Cervães - Vila verde	Portugal	Bricks & roof tiles
[PT_353]	CS - Coelho da Silva, S.A.	Porto de Mós	Portugal	Bricks & roof tiles
[PT_356]	Estrada Nacional Ramalhal	Torres Vedras	Portugal	Bricks & roof tiles
[PT_357]	Entroncamento	-	Portugal	Wall and floor tiles

Plant code	Name of the plant	City	Country	Sector
[PT_358]	Leca Portugal, S.A. - Centro Avelar	Leiria	Portugal	Expanded clay
[PT_359]	Ria Stone, SA	Gafanha da Encarnação	Portugal	Tableware and household ceramics
[PT_360]	Ponte da Madalena, Colmeias	Leiria	Portugal	Sanitaryware
[SK_373]	Zlaté Moravce	Zlaté Moravce	Slovakia	Bricks & roof tiles
[SK_374]	Boleráz	Boleráz	Slovakia	Bricks & roof tiles
[ES_130]	Ceramica Peno	Talavera De Reina	Spain	Bricks & roof tiles
[ES_133]	Ceramica Utzubar S.A.	Etxarrianatz	Spain	Bricks & roof tiles
[ES_139]	Gres Acueducto	Otero De Herreros	Spain	Bricks & roof tiles
[ES_141]	Jumisa 1	Yuncler	Spain	Bricks & roof tiles
[ES_142]	Jumisa 2	Pantoja	Spain	Bricks & roof tiles
[ES_144]	Ladrillerias Mallorquinas, SA	Felanitx	Spain	Wall and floor tiles
[ES_151]	Tejas Verea, S.A.	Mesia	Spain	Bricks & roof tiles
[ES_153]	HQ Cantoria	Cantoria	Spain	Wall and floor tiles
[ES_155]	Roca Sanitario, S.A.	Gavà	Spain	Sanitary ware
[ES_158]	Argenta Ceramica	Onda	Spain	Wall and floor tiles
[ES_161]	Azuliber 1, S.L.	Alcora/ Castellon	Spain	Wall and floor tiles
[ES_163]	Ceracasa, S.A.	Alcora	Spain	Wall and floor tiles
[ES_168]	Compacglass, S.L. (Factory 3)	Onda	Spain	Wall and floor tiles
[ES_171]	Cottocer, S.L.	Onda	Spain	Wall and floor tiles
[ES_176]	Eurotomizado, S.A. (Planta 1)	Onda	Spain	Wall and floor tiles
[ES_180]	Gres De Andorra	Andorra	Spain	Wall and floor tiles
[ES_181]	Gres Aragon Planta 1	Alcaniz	Spain	Wall and floor tiles
[ES_182]	Gres Aragon Planta 2	Alcaniz	Spain	Wall and floor tiles
[ES_183]	Grespania planta Castellon	Castellón de la Plana	Spain	Wall and floor tiles
[ES_185]	Grespania planta Moncófar	Moncófar	Spain	Wall and floor tiles
[ES_190]	Hijos de Francisco Gaya Forés, S.L.	Onda	Spain	Wall and floor tiles
[ES_191]	Keraben Grupo	Nules	Spain	Wall and floor tiles
[ES_193]	Keros Ceramica S.L.	Nules	Spain	Wall and floor tiles
[ES_197]	Mercury Ceramica, S.L.	Onda	Spain	Wall and floor tiles
[ES_198]	Euroatomizado, S.A. (Planta 2)	Villafames	Spain	Wall and floor tiles
[ES_200]	Peronda Group – Factory 1	Onda	Spain	Wall and floor tiles
[ES_203]	CV-160, Km. 16.8, 12192 Vilafamés, Castellón	Villafamés	Spain	Wall and floor tiles
[ES_207]	Sociedad Anonima Minera Catalanoaragonesa	Onda	Spain	Wall and floor tiles

Source: [35, TWG 2023]

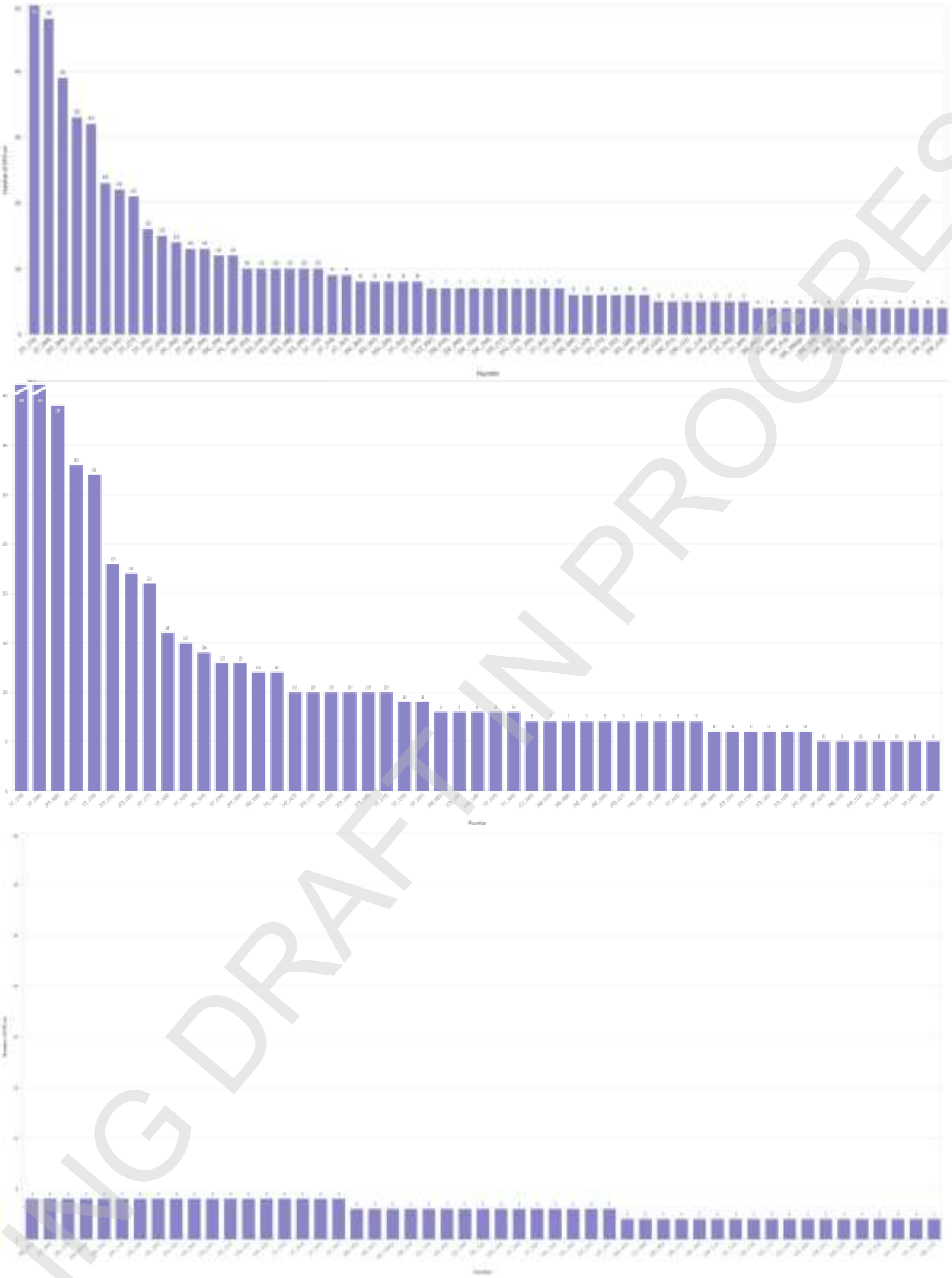
8.2 Number of emission points to air and water

Figure 8-1, Figure 8-2 and Figure 8-3 present the number of emission points to air (excluding emission points that only monitor dust emissions), emission points to dust and emission points to water by plant.



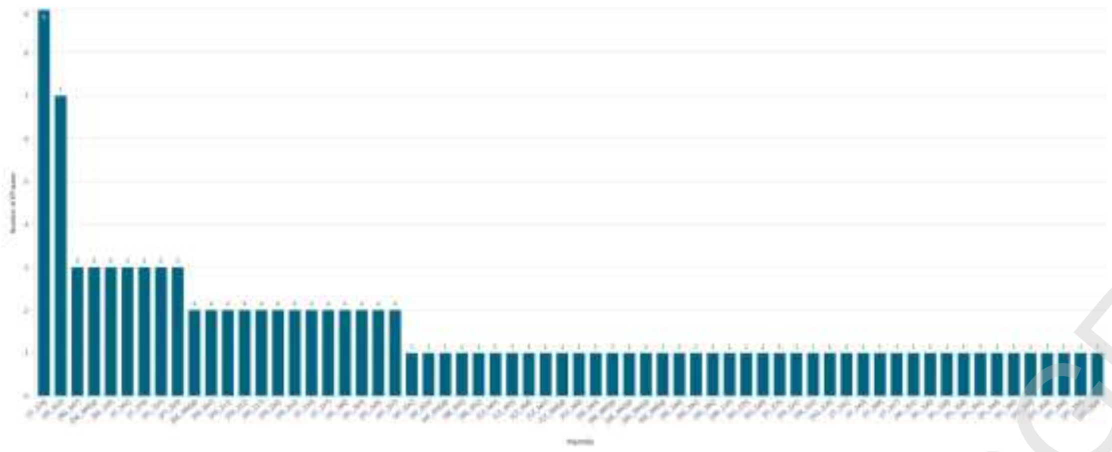
For better visualisation, the graph does not include plants that reported only one emission point.
Source: [35, TWG 2023]

Figure 8-1: Emission points to air that monitor other parameters besides dust (EPs Air)



For better visualisation, the graph does not include plants that reported only one emission point.
Source: [35, TWG 2023]

Figure 8-2: Emission points to air that only monitor dust (EPs Dust)



Source: [35, TWG 2023]

Figure 8-3: Emission points to water (EPs Water)

GLOSSARY

I. ISO country codes

ISO Code	Country
***Member States* (*)**	
AT	Austria
BE	Belgium
BG	Bulgaria
CZ	Czech Republic
DE	Germany
DK	Denmark
EL	Greece
ES	Spain
FI	Finland
FR	France
HU	Hungary
IT	Italy
NL	Netherlands
PL	Poland
PT	Portugal
SK	Slovakia
Non-member countries	
UK	United Kingdom
(*) The protocol of the Member States is based on the alphabetical order of their geographical names in the original language(s).	

II. 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 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

III. 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^2
bar	bar	Pressure (P)	1.013 bar = 100 kPa = 1 atm
°C	degree Celsius	Temperature (T) and temperature difference (ΔT)	
g	gram	Weight	
GJ	gigajoule	Energy	
h	hour	Time	
J	joule	Energy	
K	Kelvin	Temperature (T) and temperature difference (ΔT)	0 °C = 273.15 K
kg	kilogram	Weight	
kJ	kilojoule	Energy	
kPa	kilopascal	Pressure	
kWh	kilowatt-hour	Energy	1 kWh = 3 600 kJ
l	litre	Volume	
m	metre	Length	
m^2	square metre	Area	
m^3	cubic metre	Volume	
mg	milligram	Weight	1 mg = 10-3 g
mm	millimetre	Length	1 mm = 10-3 m
min	minute	Time	
Nm^3	normal cubic metre	Volume	at 101.325 kPa, 273.15 K
ouE	European odour unit	Odour	
Pa	pascal	Pressure	1 Pa = 1 N/m^2
ppm	parts per million	Composition of mixtures	1 ppm = 10-6
s	second	Time	
t	metric tonne	Weight	1 t = 1 000 kg or 106 g
t/d	tonnes per day	Mass flow and Materials consumption	
vol-%	percentage by volume	Composition of mixtures	
wt-%	percentage by weight	Composition of mixtures	
yr	year	Time	

IV. Chemical elements

Symbol	Name	Symbol	Name
Al	Aluminium	Mg	Magnesium
B	Boron	Pb	Lead
Ba	Barium	Pd	Palladium
Ca	Calcium	Pr	Praseodymium
Cd	Cadmium	Pt	Platium
Co	Cobalt	S	Sulphur
Cr	Chromium	Sb	Antimony
Cu	Copper	Si	Silicon

Symbol	Name	Symbol	Name
F	Fluor	Sn	Tin
Fe	Iron	Ti	Titanium
Mn	Manganese	V	Vanadium
Mo	Molybdenum	W	Tungsten
O	Oxygen	Zn	Zinc
N	Nitrogen	Zr	Zirconium
Ni	Nickel		

V. Chemical formula commonly used in this document

Chemical formula	Name (explanation)
Al_2O_3	Aluminium oxide
BN	Boron nitride
$Ca(OH)_2$	Calcium hydroxide
$CaCl_2$	Calcium chloride
$CaCO_3$	Calcium carbonate
CaF_2	Calcium fluoride
CaO	Calcium oxide
$CaSO_4$	Calcium sulphate
CO_2	Carbon dioxide
CO	Carbon monoxide
Fe_2O_3	Iron oxide
$Fe_2(SO_4)_3$	Iron sulphate
FeS	Iron sulphide
FeS_2	Ferrous disulphide (pyrite)
H_2O	Water
HCl	Hydrogen chloride
HF	Hydrogen fluoride
K_2O	Potassium oxide
$MgCO_3$	Magnesium carbonate (magnesite)
MgO	Magnesium oxide (magnesia)
Na_2CO_3	Sodium carbonate
Na_2O	Sodium oxide
Na_2SO_3	Sodium sulphite
NaCl	Sodium chloride
NaF	Sodium fluoride
$NaHCO_3$	Sodium hydrogen carbonate
NaOH	Sodium hydroxide
NH_3	Ammonia
NO_X	Nitrogen oxides
SiC	Silicon carbide
SO_2	Sulphur dioxide
SO_3	Sulphur trioxide
SO_X	Sulphur oxides
TiN	Titanium nitride

Chemical formula	Name (explanation)
TiO_2	Titanium dioxide
WB_2	Tungsten boride
ZrO_2	Zirconium dioxide

VI. Acronyms

Acronyms	Full phrase
AOX	Adsorbable organically bound halogens
BAT	Best Available Techniques
BAT-AEL	Best Available Techniques - associated emission level
BAT-AEPL	Best Available Techniques - associated performance emission level
BREF	BAT reference document
BTX	Benzene, toluene, xylene
CCS	Carbon capture and storage
CCU	Carbon capture and usage
CEN	Comité Européen de Normalisation (European Committee for standardisation)
CMS	Chemicals management system
COD	Chemical oxygen demand
DIN	Deutsches Institut für Normung (German national organisation for standardisation)
DN	Nominal width
Dust	Total particulate matter (in air)
EEA	European Environment Agency
EFTA	European Free Trade Association (established on 3 May 1960)
EIPPCB	European Pollution Prevention and Control Bureau
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)
EPs	Emission points
ESP	Electrostatic precipitator
HFO	Heavy fuel oil
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).
IED	Industrial Emissions Directive (2010/75/EU)
IPPC	Integrated pollution prevention and control
ISO	International Organisation for Standardisation
KEI	Key Environmental Issue
LCP	Large combustion plant
LNG	Liquefied natural gas
MS	(European Union) Member State
LWA	Lightweight expanded clay aggregate: a bloated clay aggregate made by the sudden heating of suitable clays either in a rotary kiln or in a sinter-hearth.
N	Normal – refers to volume of gases under normal operating conditions with a temperature of 273.15 K and pressure of 101.325 kPa
OMP	Odour management plan
OTNOC	Other than normal operating conditions

Acronyms	Full phrase
PAHs	Polycyclic aromatic hydrocarbons
PCDD/Fs	Polychlorinated dibenzodioxins/dibenzofurans
PTFE	Polytetrafluoroethylene
SS	Suspended solids
TEQ	Toxicity equivalents (iTEQ: international toxicity equivalents)
TOC	Total organic carbon
TSS	Total suspended solids
TVOC	Total volatile organic carbon
TWG	Technical Working Group
UBA	Umweltbundesamt – Federal Environment Agency, i.e. from Germany or Austria
VOC	Volatile organic compound
WFD	Waste Framework Directive (2008/98/EC)
WHO	World Health Organisation
WW	Waste water
WWT(P)	Waste water treatment (plant)

VII. Definitions

~~ENGLISH TERM~~ Term used	~~MEANING~~ Definition
~~a~~ Absorption	~~a~~ A volume process, in which one substance permeates another (soaking up).
~~a~~ Acid	~~p~~ Proton donor. A substance that, more or less readily, gives off hydrogen ions in a water solution.
~~a~~ Acidification	~~a~~ Adding acid to a substance to achieve acidic properties.
~~acute effect~~	~~an adverse effect on any living organism in which severe symptoms develop rapidly and often subside after the exposure stops.~~
~~acute toxicity~~	~~adverse effects that result from a single dose or single exposure of a chemical; any poisonous effect produced within a short period of time, usually less than 96 hours. This term is normally used to describe effects in experimental animals.~~
~~a~~ Adsorption	~~a~~ A surface process; the accumulation of molecules of a gas or liquid to form a thin film on the surface of a solid (surface assimilation).
~~aeration~~	~~the act of mixing a liquid with air (oxygen).~~
~~a~~ Aerobic	~~a~~ A biological process that occurs in the presence of oxygen
~~a~~ Alkali	~~p~~ Proton acceptor. A substance that, more or less readily, takes up hydrogen ions in a water solution.
~~anaerobic~~	~~a biological process which occurs in the absence of oxygen.~~
~~AOCl~~	~~adsorbable organic chlorine compounds.~~
~~AOX~~	~~adsorbable organic halogen compounds. The total concentration in milligrams per litre, expressed as chlorine, of all halogen compounds (except fluorine) present in a sample of water that are capable of being adsorbed on activated carbon.~~
~~atm~~	~~normal atmosphere (1 atm = 101325 N/m^2).~~
~~bar~~	~~bar (1.013 bar = 1 atm).~~
~~BAT~~	~~best available techniques~~
~~BAT AEL~~	~~BAT associated emission level~~
~~BF~~	~~batch wise flocculation.~~
~~BFW~~	~~boiler feed-water to produce steam.~~
~~biochemicals~~	~~Chemicals that are either naturally occurring or identical to naturally occurring substances. Examples include hormones, pheromones and enzymes. Biochemicals function as pesticides through non-toxic, non-lethal modes of action, such as disrupting the mating pattern of insects, regulating growth or acting as repellents.~~

~~ENGLISH TERM~~ **Term used**	~~MEANING~~ **Definition**
~~b~~ Biodegradable	Substance that can be broken down physically and/or chemically by micro-organisms. For example, many chemicals, food scraps, cotton, wool and paper are biodegradable.
~~biodiversity~~	~~the number and variety of different organisms in the ecological complexes in which they naturally occur. Organisms are organised at many levels, ranging from complete ecosystems to the biochemical structures that are the molecular basis of heredity. Thus, the term encompasses different ecosystems, species and genes that must be present for a healthy environment. A large number of species must characterise the food chain, representing multiple predator-prey relationships.~~
~~b~~ Biscuit	(1) ~~p~~Pottery that has been fired but not yet glazed. (2) ~~t~~This word, meaning ‘unglazed’, is used in compound terms such as ‘biscuit firing’.
~~BOD~~	~~biochemical oxygen demand: the quantity of dissolved oxygen required by micro-organisms in order to decompose organic matter. The unit of measurement is mg O_2/l. In Europe, BOD is usually measured after 3 (BOD_3), 5 (BOD_5) or 7 (BOD_7) days.~~
~~b~~ Body	(1) ~~a~~A blend of raw materials awaiting shaping into ceramic products. (2) ~~t~~The interior part of pottery, as distinct from the glaze.
~~BREF~~	~~BAT reference document.~~
~~BTEX~~	~~benzene, toluene, ethylbenzene, xylene~~
~~BTX~~	~~benzene, toluene, xylene~~
~~c~~ Calcite	~~c~~ Crystalline form of calcium carbonate
c Cassette	~~s~~ Special shaped kiln furniture to support~~, e.g.~~ roof tiles etc. during firing.
~~CEN~~	~~European Committee for Standardization~~
Ceramics	~~G~~ Generally the term ‘ceramics’ (ceramic products) is used for inorganic materials (~~with~~ possibly with some organic content), made up of non-metallic compounds and hardened by a firing process
~~c~~ Chalk	~~a~~ Amorphous type of calcium carbonate
Channelled emissions	Emissions of pollutants into the environment through any kind of duct, pipe, stack, etc.
~~c~~ Clay	~~a~~ A natural material characterised by its plasticity, as taken from the clay pit or after it has been ground and mixed with water.
~~COD~~	~~chemical oxygen demand: the amount of potassium dichromate, expressed as oxygen, required to chemically oxidise at approx. 150 °C substances contained in waste water.~~
~~cross-media effects~~	~~the calculation of the environmental impacts of water/air/soil emissions, energy use, consumption of raw materials, noise and water extraction (i.e. everything required by the IPPC Directive).~~
~~dH~~	~~grade of water hardness~~
~~D~~ Diffuse emissions	Non-channelled emissions to air. Diffuse emissions include fugitive and non-fugitive emissions. Fugitive emissions are non-channelled emissions to air caused by loss of tightness of equipment which is designed or assembled to be tight. Non-fugitive emissions may arise from atmospheric vents, bulk storage, and loading/unloading systems for example. ~~emissions arising from direct contact of volatile or light dusty substances with the environment (atmosphere, under normal operating circumstances). These can result from:~~ ~~- inherent design of the equipment (e.g. filters, dryers, etc.)~~ ~~- operating conditions (e.g. during transfer of material between containers)~~ ~~- type of operation (e.g. maintenance activities)~~ ~~- or from a gradual release to other media (e.g. to cooling water or waste water).~~ ~~Fugitive emissions are a subset of diffuse emissions.~~

~~ENGLISH TERM~~ **Term used**	~~MEANING~~ **Definition**
~~diffuse sources~~	~~sources of similar diffuse or direct emissions which are multiple and distributed inside a defined area.~~
Direct discharge	Discharge to a receiving water body without further downstream waste water treatment.
~~DN~~	~~nominal width.~~
~~d~~ Dolomite	~~t~~ Type of limestone the carbonate fraction of which is dominated by the mineral dolomite, calcium magnesium carbonate, $CaMg(CO_3)$.
Drying of ware	Thermal treatment at moderate temperatures (around 100 °C) to reduce the moisture content in the shaped ware in order to avoid cracks during the subsequent firing step. Dryers are generally separate from the kiln.
Drying-firing of expanded clay	This refers to the manufacturing of expanded clay, where the drying and firing processes occur consecutively in rotary kilns. The drying part of the kiln is directly connected to the firing part of the kiln. All hot gases from the firing process are used in the drying process.
~~DS~~	~~dry solids (content). The mass of a material remaining after drying by the standard method of test.~~
~~EC50~~	~~effect concentration 50. The concentration at which effects are observed in 50 % of the test population after administering a single dose. Effects include the immobilisation of daphnia, inhibition of growth, cell division or biomass production, or the production of chlorophyll by algae.~~
~~e~~ Effluent	~~p~~Physical fluid (air or water together with contaminants) forming an emission.
~~EIPPCB~~	~~European IPPC Bureau.~~
~~e~~ Emission	~~t~~ The direct or indirect release of substances, vibrations, heat or noise from individual or diffuse sources in the installation into the air, water or land.
~~e~~ Emission limit value~~s~~	~~t~~ The mass, expressed in terms of certain specific parameters, concentration and/or level of an emission, which may not be exceeded during one or more periods of time.
~~e~~ End-of-pipe technique	~~a~~ A technique that reduces final emissions or consumption~~s~~ by some additional process but does not change the fundamental operation of the core process. Synonyms: ‘secondary technique’, ‘abatement technique’. Antonyms: ‘process-integrated technique’, ‘primary technique’ (a technique that in some way changes the way in which the core process operates thereby reducing raw emissions or consumption~~s~~).
~~e~~ Engobe	~~a~~ A coating of slip, white or coloured, applied to a porous ceramic body to improve its appearance.
EPs Air	Emission points to air that monitor other parameters besides dust, generally associated with combustion processes, e.g. firing of ware, drying-firing of expanded clay, drying of ware
EPs Dust	Emission points that only monitor dust, generally associated with mechanical processes, surface treatment/decoration, transfer and handling of materials/products
EPs Water	Emission points to water
~~ESP~~	~~electrostatic precipitator.~~
~~e~~ Eutrophication	~~t~~ The pollution of a body of water by sewage, fertilisers washed from the land, and industrial wastes (inorganic nitrates and phosphates). These compounds stimulate the growth of algae, reducing the oxygen content in the water, and so killing animals with a high oxygen requirement.
~~existing installation~~	~~an installation in operation or, in accordance with legislation existing before the date on which this Directive is brought into effect, an installation authorised or in the view of the competent authority the subject of a full request for authorisation, provided that that installation is put into operation no later than one year after the date on which this Directive is brought into effect.~~

~~ENGLISH TERM~~ Term used	~~MEANING~~ Definition
~~f~~ Firing of ware	~~the process of h~~ Heat treatment of ~~ceramic~~ ware in a kiln to develop a ~~vitreous or~~ crystalline bond, thus giving the ware properties associated with a ceramic material.
Fired broken ware	Kiln-fired ware that is damaged (e.g. cracks, surface damage, broken) and does not fulfil the quality requirements.
Firing of ware	Heat treatment of ware in a kiln to develop a crystalline bond, thus giving the ware properties associated with a ceramic material.
~~f~~ Flue-gas	~~off-gas from firing/combustion processes~~. The exhaust gas exiting a combustion unit.
~~f~~ Flux	~~a~~ A substance that, even in small quantities, lowers the fusion point of material in which it is naturally present (e.g. alkalis in clay) or of material to which it has been added (e.g. borax added to glazes).
~~f~~ Frit	~~a~~ A ceramic composition that has been fused, quenched to form a glass and usually granulated.
~~f~~ Fuel oil EL	~~fuel oil e~~ Extra light fuel oil
f Fugitive emissions	Non-channelled emissions to air caused by loss of tightness of equipment which is designed or assembled to be tight. Non-fugitive emissions may arise from atmospheric vents, bulk storage, and loading/unloading systems for example. ~~emission caused by non-tight equipment/leak: emission into the environment resulting from a gradual loss of tightness from a piece of equipment designed to contain an enclosed fluid (gaseous or liquid), basically caused by a difference of pressure and a resulting leak. Examples of fugitive emissions: leak from a flange, a pump, a sealed or tightened equipment, etc.~~
Hazardous substances	Hazardous substances as defined in point 18 of Article 3 of Directive 2010/75/EU.
~~GDP~~	~~gross domestic product.~~
~~GJ~~	~~gigajoule.~~
~~g~~ Glass	~~a~~ A solid with no long range order in the arrangement of its atoms.
~~g~~ Glaze	~~a~~ A thin glassy layer formed on the surface of a ceramic product by firing-on an applied coating.
~~g~~ Glost	Glazed. ~~this word, meaning 'glazed', is used in compound terms such as 'glost ware' and 'glost firing'.~~
~~g~~ Green ware	~~ceramic products,~~ Pieces shaped, but not dried or fired
~~HFO~~	~~heavy fuel oil.~~
~~hPa~~	~~hectopascal.~~
~~IEF~~	~~Information Exchange Forum (informal consultation body in the framework of the IPPC Directive).~~
~~i~~ Immission	~~o~~ Occurrence and level of polluting substance, odour or noise in the environment.
Indirect discharge	A discharge that is not a direct discharge.
~~installation~~	~~a stationary technical unit where one or more activities listed in Annex I of the IPPC Directive are carried out, and any other directly associated activities which have a technical connection with the activities carried out on that site and which could have an effect on emissions and pollution.~~
~~IPPC~~	~~integrated pollution prevention and control.~~
~~I-TEQ~~	~~dioxin/furan toxicity equivalent.~~
~~K~~	~~Kelvin (0 °C = 273.15 K).~~
~~k~~ Kaolin	~~name derived from Chinese Kao-Lin, a high ridge where this w~~ White firing clay ~~was~~ ~~first discovered~~ (also named China Clay).
~~kcal~~	~~kilocalorie (1 kcal = 4.19 kJ).~~
~~k~~ Kiln	~~a~~ A high-temperature installation used for firing ceramic ware.
~~k~~ Kiln capacity	~~f~~ Fired volume of the kiln.
~~k~~ Kiln furniture	~~g~~ General term for pieces of refractory material used for the support of ceramic products during kiln firing ('firing auxiliaries').

~~ENGLISH TERM~~ Term used	~~MEANING~~ Definition
~~f~~ Facing brick	~~a~~ A type of building brick, which may be either of engineering-brick or facing-brick quality with low water absorption and high crushing strength.
~~kWh~~	~~kilowatt-hour (1 kWh = 3600 kJ = 3.6 MJ).~~
~~LAS~~	~~linear alkylbenzene sulphonate.~~
~~LC50~~	~~lethal concentration 50. The lowest concentration of a substance in water or ambient air in milligrams per litre sufficient to cause death in 50 % of the test population within a defined period (e.g. 96 hours for fish, 48 hours for daphnia).~~
~~LD50~~	~~lethal dose 50. The lowest dose of a substance administered to species such as mice and rats sufficient to cause death in 50 % of the test population within a defined period (no more than 14 days), expressed in milligrams of test substance per kilogram of bodyweight.~~
~~l~~ Limestone	~~m~~ Mineral rock consisting merely of CaCO$_3$; used as such or as raw material to produce ~~by decarbonisation~~ quicklime (calcium oxide) by decarbonisation, and ~~by hydration of quicklime,~~ hydrated lime (calcium hydroxide) by hydration of quicklime.
~~LNG~~	~~liquefied natural gas.~~
~~LOEC~~	~~lowest observed effect concentration. The lowest experimentally determined concentration of a test substance at which adverse effects can be observed.~~
~~LPG~~	~~liquefied petroleum gas.~~
~~LWA~~	~~lightweight expanded clay aggregate: a bloated clay aggregate made by the sudden heating of suitable clays either in a rotary kiln or on a sinter-hearth.~~
~~m^3/h~~	~~volume flow: if not otherwise mentioned in this document, the volume flows refer to 18 vol-% oxygen and standard state.~~
~~magnesia~~	~~magnesium oxide (MgO).~~
~~magnesite~~	~~magnesium carbonate (MgCO$_3$).~~
~~mg/m^3~~	~~concentration: if not otherwise mentioned in this document, the concentrations of gaseous substances or mixtures of substances refer to dry flue-gas at 18 vol-% oxygen and standard state, and benzene concentrations refer to 15 vol-% oxygen and standard state.~~
~~MJ~~	~~megajoule (1 MJ = 1000 kJ = 10^6 J).~~
~~M~~ Monitoring	~~p~~ Process intended to assess or to determine the actual value and the variations of an emission or another parameter, based on procedures of systematic, periodic or spot surveillance, inspection, sampling and measurement or another assessment method~~s~~ intended to provide information about emitted quantities and/or trends for emitted pollutants.
Mass flow	The mass of a given substance or parameter which is emitted over a defined period of time.
Mechanical processes	Process steps where mechanical techniques are applied to transform the size, shape or surface of the materials involved. This includes the following: – raw material preparation (e.g. crushing, milling); – mixing and shaping (e.g. pressing, moulding); – product finishing (e.g. grinding, polishing, rectifying).
~~MPa~~	~~megapascal.~~
~~multi-media effects~~	~~see cross-media effects.~~
~~n/a~~	~~not applicable.~~
~~n.a.~~	~~not available.~~
~~naphthenes~~	~~hydrocarbons containing one or more saturated rings of 5 or 6 carbon atoms in their molecules, to which paraffinic-type branches are attached (adjective: napthenic).~~
~~n/d~~	~~no data.~~
~~N-Kj~~	~~nitrogen analysed by Kjeldahl method.~~
~~Nm^3~~	~~normal cubic metre (273 K, 1013 hPa).~~
~~NOAC~~	~~no observed acute effect concentration.~~
~~NOEC~~	~~no observed effect concentration.~~

~~ENGLISH TERM~~ Term used	~~MEANING~~ Definition
~~o~~ Off-gas	The gas leaving a process which is further treated for recovery and/or abatement. This includes flue-gases from combustion processes. ~~general term for gas/air released during combustion processes or extraction processes at ambient temperatures.~~
~~o~~ Operator	~~a~~ Any natural or legal person who operates or controls the installation or, where this is provided for in national legislation, to whom decisive economic power over the technical functioning of the installation has been delegated.
~~p~~ Particulate matter	~~d~~ Dust.
pH	~~s~~ Symbol for the acidity or alkalinity of a solution. It is a number equivalent to the logarithm, to the base of 10, of the reciprocal of the concentration of hydrogen ions in an aqueous solution.
Plant	All parts of an installation that carry out the activities covered by the scope of this document and any other directly associated activities which have an effect on consumption and/or emissions. Plants may be new plants or existing plants. Different production lines may be part of the same plant.
~~p~~ Pollutant	~~i~~ Individual substance or group of substances which can harm or affect the environment.
Pore-forming agents	Materials used to form pores in clay blocks, e.g. foamed polystyrene, paper sludge, sawdust.
~~P~~ Pottery	~~this term is generally understood to mean d~~ Domestic ceramic ware.
~~ppm~~	~~parts per million.~~
~~p~~ Primary measure/technique	~~a~~ A technique that in some way changes the way in which the core process operates thereby reducing raw emissions or consumption~~s~~ (see end-of-pipe technique).
Process chemicals	Substances and/or mixtures as defined in Article 3 of Regulation EC/1907/2006 and used in the process(es). Process chemicals may contain hazardous substances and/or substances of very high concern.
~~PTFE~~	~~Polytetrafluoroethylene (Teflon).~~
~~rpm~~	~~revolutions per minute.~~
~~s~~ Secondary measure/technique	~~s~~ See end-of-pipe technique.
Residue	Substance or object generated by the activities covered by the scope of this document as waste or by-product.
Sensitive receptor	Areas which need special protection, such as: – residential areas; – areas where human activities are carried out (e.g. neighbouring workplaces, schools, day-care centres, recreational areas, hospitals or nursing homes).
~~s~~ Setting density	~~m~~ Mass of the ware to be fired without firing auxiliaries in the fired volume of the kiln in reference to the overall fired volume of the kiln.
~~s~~ Sintering	~~g~~ General term for the densification by heat of a powder compact to produce a polycrystalline body.
~~s~~ Slip	~~a~~ A suspension of clay and/or other ceramic materials in water.
~~s~~ Sludge	~~a~~ A suspension with a relatively high solids content.
~~SME~~	~~small and medium enterprise(s).~~
~~s~~ Sorption	~~t~~ The process~~,~~ in which one substance takes up or holds another by either absorption or adsorption.
~~s~~ Specific emission	~~e~~ Emission related to a reference basis, such as production capacity, or actual production (e.g. mass per tonne or per unit produced).
Spray drying	Spraying an aqueous suspension of raw material under pressure to produce fine droplets which enter into contact with a stream of hot air. This is followed by drying of the droplets to produce highly uniform, more or less spherical hollow granules, called spray-dried powder.

~~ENGLISH TERM~~ **Term used**	~~MEANING~~ **Definition**
Substances of very high concern	Substances meeting the criteria mentioned in Article 57 and included on the Candidate List of Substances of Very High Concern, according to the REACH Regulation ((EC) No. 1907/2006[4]).
Surface run-off water	Water from precipitation that flows over land or impervious surfaces, such as paved streets, storage areas and rooftops, and does not soak into the ground.
Unfired broken ware	Unfired ware that is damaged (e.g. broken or presents cracks, surface damage, or size defects) and does not fulfil the requirements to be fired.
~~SS~~	~~suspended solids (content) (in water) (See also TSS).~~
~~standard state~~	~~refers to a temperature of 273 K and a pressure of 1013 hPa.~~
~~TJ~~	~~terajoule.~~
~~TOC~~	~~total organic carbon.~~
~~TS~~	~~total solids (content). Solid content before drying of the material.~~
~~TSS~~	~~total suspended solids (content) (in water) (See also SS).~~
~~TWG~~	~~technical working group.~~
~~v~~ Vitreous	~~t~~ This term meaning ‘glassy’~~,~~ is applied to ceramic ware, ~~that~~ which as a result of a high degree of vitrification (as distinct from sintering) has an extremely low porosity.
~~V~~ Vitrification	~~t~~ The progressive partial fusion of a clay, or of a body, as a result of a firing process.
~~VOC~~	~~volatile organic compounds.~~
~~vol-%~~	~~percentage by volume.~~
~~W/(mK)~~	~~thermal conductivity.~~
~~wt-%~~	~~percentage by weight.~~
~~µg~~	~~microgram.~~
~~µS~~	~~microsiemens.~~

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[4] 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).

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